United States
Department of
Agriculture

Forest Service

Pacific Southwest
Forest and Range
Experiment Station

General Technical
Report PSW-100

Proceedings of the Symposium on

Multiple–Use Management of California's Hardwood Resources

November 12-14, 1986, San Luis Obispo, California

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Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

November 1987

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Timothy R. Plumb

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PREFACE

The Symposium on the Ecology, Management, and Utilization of California Oaks held in June 1979 at Claremont, California, was the first to take a comprehensive look at California's native oak resource. At that time, interest in several species of California oaks was rapidly growing with particular concern about their regeneration, preservation, and wildlife relationships. Urbanization and loss of oak woodlands was beginning to focus a new facet of concern on hardwoods, and regulations to monitor their use were established or seriously considered by a number of county governments. Until that time, hardwood research was extremely limited, mostly in a few specialized areas, and probably more time and effort had been spent to control hardwoods than to grow and manage them.

What has happened with hardwoods in the 7-1/2 years after the first oak symposium? A comparison of the numbers of papers and participants between the two meetings indicates the interest that has developed in hardwoods during this time. In 1979, about 200 people heard 52 reports. In 1986, there were 73 technical reports plus 2 keynote addresses and 12 poster presentations and over 500 participants. In addition to this large increase in symposium participation, a number of other hardwood-related developments have occurred including these:

1. A workshop on "Hardwood Inventory and Utilization" was held February 12-13, 1982, at California Polytechnic State University, San Luis Obispo. The conference featured 18 invited speakers and a field trip to central coast hardwood stands by 100 persons.

2. Two hardwood task forces were established by the California State Board of Forestry to study the growing concern about hardwood utilization, regeneration, and regulation of hardwoods, and hardwood rangelands in particular. In fact, the last of a series of public input meetings on oak hardwood regulation was held in conjunction with this Symposium.

3. Research on California hardwoods has increased greatly. A recent survey by researchers at University of California, Berkeley, indicates that there has been "an almost logarithmic increase in research studies" since the 1979 Oak Symposium. More than 85 research studies have been started and the University of California and California Department of Forestry and Fire Protection budgeted in excess of $600,000 for 1986-87 for an "Integrated Hardwood Range Management Program."

4. The Forest Inventory and Analysis Unit at the Forest Service's Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, recently completed a statewide hardwood inventory to obtain information necessary for policy decisions. Increment was measured on thousands of trees in existing plots and used to calculate growth and cubic volume by species. In addition, several hundred new plots were established in hardwood forests that were formally classified as "non-commercial."

5. Five new University of California Extension positions were established at the end of 1986 with responsibility for hardwood-range and related wildlife research and educational input.

All in all, interest and concern about hardwoods has increased dramatically in the last 7-1/2 years. Potential use and value of the hardwood resource for all types of forest products—energy to wildlife—will continue to grow as the population increases, the resource diminishes, and new uses for hardwoods develop.

The 1986 Symposium was hosted at Cal Poly, San Luis Obispo, by the Natural Resources Management Department and Forestry Club (Student Chapter of the Society of American Foresters). Major sponsorship for the Symposium was provided by the California Department of Forestry and Fire Protection; and the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; with additional support by the California State Board of Forestry; Society of American Foresters; University of California Cooperative Extension; Pacific Southwest Region, Forest Service, U.S. Department of Agriculture; and Bureau of Land Management, U.S. Department of the Interior.

The tenor for the Symposium was set by the two keynote speakers, Zane G. Smith, Regional Forester, Forest Service Pacific Southwest Region, San Francisco; and Harold R. Walt, Chairman of the California State Board of Forestry, Sacramento. Walt's presentation specifically identified the policy aspects of hardwood resources in California, a facet not identified or obvious in 1979.

We are grateful to the Technical Chairpersons who provided encouragement, admirably managed the eight technical sessions, and who provided first-line review of the Symposium manuscripts:

Ecology-Silviculture:	Susan Conard, *Pacific Southwest Forest and Range Experiment Station, Riverside.* James Griffin, *University of California, Natural History Reserve, Carmel Valley.*
Protection and Damage Factors:	Robert Martin, *University of California, Berkeley.*
Urban Forestry-Recreation:	Bailey Hudson, *California Urban Forests Council, Santa Maria.*

Wildlife:	Jared Verner, *Pacific Southwest Forest and Range Experiment Station, Fresno.*
Wood Products-Utilization:	Pete Passof, *University of California, Ukiah.*
Range:	John Menke, *University of California, Davis.*
Inventory-Measurements:	Charles Bolsinger, *Pacific Northwest Forest and Range Experiment Station, Forest Service, Portland*
Policy and Regulation:	Robert Ewing, *California Department of Forestry and Fire Protection, Sacramento.*

We also thank the many individuals at Cal Poly who made the Symposium go, especially Tim O'Keefe and other members of the Natural Resources Management Department, our many students, other University officials who provided the various physical requirements for the Symposium, and finally Julie Oxford (Conference Coordinator) who had the onerous task of day-to-day Symposium planning and supervision.

Timothy R. Plumb
Norman H. Pillsbury
Symposium Co-chairmen and Professors, Natural Resources Management Department, California Polytechnic State University

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

California Hardwoods: A Professional Challenge to the Resource Community[1]

Zane G. Smith, Jr.[2]

There are four reasons why I'm especially pleased that Norm Pillsbury asked me to speak at this Symposium.

First, many of you are researchers in the field of natural resources and this is my opportunity to thank you for the help you provide the Forest Service in doing its job. Resource managers have a lot of questions, and you are the people we turn to for answers.

Second, this Symposium is about a resource that calls for a lot more attention from all of us--managers, researchers, and policymakers alike.

Consider a few facts about hardwoods in California. They grow on about 10 percent of the land area and make up 25 percent of the forest and woodland in the State. About one fourth of the hardwoods are on public land, including the National Forests. The rest are on private lands.

A resource that is so widespread makes hardwood management a matter of interest to both private and public landowners. Yet in spite of the extent and volume of hardwood resources, we know as little about managing them as we did about managing chaparral brushland 20 years ago. I think it is fair to say that hardwoods are now the most important unmanaged renewable resource in California.

The third reason is that this Symposium represents what I call resource entrepreneurship.

We hear a lot about private sector initiative in developing new products and new sources of economic growth. I think that initiative in exploring a "lagging" natural resource, which has just begun to reveal its potential contribution to the California environment and society, compares favorably with similar efforts in the private sector.

And finally, this Symposium represents a partnership among researchers, managers, and policymakers that is essential to achieving EXCELLENCE in resource management in the decades ahead.

I believe that Hal Walt, Chairman of the State Board of Forestry, will agree that this kind of partnership is necessary for sound policy making. I know it is necessary for sound management on the ground.

With these thoughts in mind I'd like to review the potential for multiple-use management of hardwood resources for economic and environmental benefits and then discuss three challenges I believe California hardwoods present to us as resource professionals.

ECONOMIC POTENTIAL OF CALIFORNIA HARDWOODS

California has more than 30 species of hardwoods. The most common are black oak, canyon live oak, tanoak, Pacific madrone, blue oak, and coast live oak.

Individual trees grow to considerable size. For example, the largest Pacific madrone in California has a diameter of 122 inches and is 79 feet high. Trees more than 3 feet in diameter are not unusual in older hardwood stands.

Of the 9.5 million acres of hardwoods in California, about 2.2 million acres are in northern parts of the State and commonly interspersed with softwood timberland. The rest is mostly in foothill woodlands throughout central and southern California.

Currently the State has an estimated 25 billion board feet of hardwood sawtimber inventory, as compared with 236 billion board feet of softwood sawtimber inventory. Hardwood timber production remains largely undeveloped. About 25 million board feet of hardwoods are harvested in California each year, compared with more than 3.5 billion board feet of softwoods.

One reason hardwoods have been neglected as a resource is the "softwood mentality" common throughout the Western States. Abundant

[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

[2] Formerly Regional Forester, Pacific Southwest Region; now Special Assistant to the Chief, Forest Service, U.S. Department of Agriculture.

commercial grade softwoods and a strong market for them make hardwoods much less economically attractive.

Under current milling and marketing conditions this preference for softwoods is economically justified. California hardwoods have characteristics that make them difficult to mill for sawtimber or furniture grade lumber. In the timberlands of northern California, it is more economical to clear hardwoods and plant conifers.

Many attempts to utilize hardwoods have failed because we tried to work hardwoods with softwood methods. Hardwoods vary more than softwoods and processing must be adapted to that variability. Hardwoods require a cottage industry approach--smaller production and more selective processing and use of the log material. However, the added costs of production can be distributed over a wide range of products--from firewood to pallets to furniture.

For example, Cal Oak located in Oroville, the only volume manufacturer of products from California hardwoods currently in operation, produces paneling, flooring, quality doors, and furniture wood as well as pallets, firewood, and chip.

We now use most of our California hardwoods for firewood. Apart from use as biomass for fuel, improved utilization of California hardwoods will depend on developing appropriate milling techniques that can produce a reliable supply of quality material that meets the requirements of the wood products industry.

For example, California's furniture industry is second in the nation, yet it buys most of its hardwood from eastern States and from abroad. High quality eastern hardwoods are available, but they are getting scarce and expensive. Utilization of lower grade hardwoods looks increasingly attractive.

Over the last decade the Forest Service Forestry Sciences Laboratory in West Virginia worked with furniture manufacturers to find away to utilize lower grade eastern hardwoods. They developed a process called SYSTEM-6 that manufactures furniture blanks from hardwood logs 7 to 16 inches in diameter and 6 to 8 feet long. Boards milled from short logs are glued into furniture blanks of standard dimensions.

These furniture blanks have markets in the furniture industry, and SYSTEM-6 makes it possible to utilize small logs that otherwise would be burned as firewood.

California hardwoods commonly yield short sawlogs. Developing a similar processing system to provide a reliable supply of quality California hardwood for our furniture industry may be worth investigating.

I don't claim to know how to organize an expanded hardwood products industry in California. I am suggesting that we need not only scientific and technical research to develop silvicultural practices and wood processing technology, but also economic research in partnership with the woods products industry to develop markets and adapt the methods for economic production as well.

ENVIRONMENTAL VALUE OF HARDWOODS

Apart from economic considerations, hardwoods occupy a critical niche in the natural environment of California. Since European settlement, three prime wildlife habitats have been drastically reduced: wetlands, riparian areas, and hardwood forests.

Early settlers described dense oak forests extending as much as 5 miles from either bank along streams throughout the Central Valley. Songbirds used the extensive hardwood woodlands as flyways during migration, and deer, bear and other wildlife thrived on the acorns and browse provided by hardwood habitat. These riparian forests decreased from an estimated 700,000 acres to 19,000 acres in 1986.

Dense stands of hardwoods also grew throughout the foothills of California, but were gradually removed for structural timber, firewood, and to clear land for crops and cattle.

Traditionally, farmers, ranchers, and timber producers considered hardwoods as a pest vegetation to be reduced or eliminated. In recent times the acreage of hardwood woodland, especially in parts of the Sierra Nevada foothills and the Sacramento Valley, has declined as much as 20 percent due mainly to urban development.

In many areas of Central and Southern California, only isolated stands remain as habitat for Acorn woodpeckers and other birds and wildlife that use hardwoods for nesting and feeding. The rate of loss of hardwood stands makes research on the dependency of wildlife on hardwood habitat an especially urgent concern for resource managers if they are to meet the wildlife management objectives of State and Federal law. For this reason, National Forest plans call for retaining areas of hardwoods in parts of the forest managed for softwood timber production.

The first Symposium on California Oaks was held in 1979 to review the condition of oak woodlands and how to manage them. In 1983, the Hardwood Task Force of the State Board of Forestry launched a program to protect oak woodlands used for grazing, firewood, and wildlife habitats. This Symposium is the latest effort to review the condition and prospects for multiple-use management of hardwoods throughout the State and mobilize the resource community in a concerted effort to manage them.

CHALLENGES TO THE RESOURCE COMMUNITY

It is clear from these few indications that hardwoods have considerable importance for multiple use resource management, yet we are just beginning to conduct research and develop methods for managing them. With this background in mind I would like to mention three key challenges I think California hardwoods present to the natural resource community: achieving holistic management, working with the private sector, and balancing public demand and limited resources.

Holistic Management

First, given the extent and volume of hardwoods in California, resource professionals have an obligation to manage them.

This obligation reflects one of the most important changes in resource management since 1960--the move to holistic management. The term refers to considering the whole environment and ecological system when making resource management decisions.

A familiar example of the change to holistic management is the practices in chaparral brushland. Early attempts to suppress or eliminate wildfire in chaparral were socially sanctioned but environmentally unsound. We left the ecology of brushlands out of the equation and consequently created an impossible goal. In fact, suppressing wildfire tended to allow fuel to build up to even more hazardous levels--an example of how failure to apply holistic management can lead to greater environmental risks.

Through research in chaparral management and the role and effects of wildfire in the chaparral environment we have moved from fire suppression to chaparral resource management. We learned to use prescribed burning and other chaparral management methods to achieve social and environmental objectives within an environment where fire occurs naturally.

Research is essential if managers are to meet the challenge of holistic management. We need to know about the entire ecosystem if we are to enjoy the full benefits and calculate the full range of likely effects of our management decisions. That certainly includes hardwoods.

Partnership with the Private Sector

Another challenge to resource professionals in the public sector is to help people in the private sector manage hardwood resources and develop commercial uses that benefit the public at large.

Research on hardwood management and on processing and marketing hardwoods may eventually provide the climate of information and practice in which a hardwood industry can grow. The work done in West Virginia to develop a method for utilizing hardwood short logs is an example.

This is a logical extension of the "resource entrepreneur" role I mentioned earlier. We are in a position to obtain and distribute the information needed to develop a hardwood industry and to insure responsible management of hardwoods for wildlife, scenic quality, and other purposes.

Working closely with private landowners is especially important because hardwoods grow predominantly on private lands. The State program begun in 1983 offers a constructive framework for protecting hardwood resources through cooperation with and assistance to private landowners.

Narrowing Decision Space

The third challenge that particularly concerns me as a resource manager is the narrowing "decision space" between available resources and public demand for them. As use and management of resources intensifies, the shrinking decision space reduces both the range of choices available for meeting public demands and the margin of safety in resource decisions.

Past generations could transfer the consequences of their decisions to the future. The extent and abundance of resources meant they could leave their mistakes behind and simply move to new ground. But the margin of safety provided by abundant space and resources is gone.

The most dramatic example of this trend is threatened and endangered species of plants and wildlife. Managers are expected to accommodate concern for these species within the ongoing use and management of forest and range resources. To do so, managers preserve as a minimum what are called viable population levels determined by wildlife biologists and other experts.

We allow for a margin of safety. But demands for other goods and services require us to keep that margin at "reasonable" levels. In such cases managers need to be sure that the "viable" population levels do indeed assure survival and recovery of such species. Miscalculation could lead to an irreversible slide below the point of recovery.

I mention this extreme case to illustrate the kind of situations and the dilemmas that are likely to multiply in regard to many resource tradeoffs as the State's population increases from 27 million in 1986 to to more than 32 million by the year 2000.

Developing methods for managing hardwoods for wildlife, scenic quality, wood production, and watershed values will provide managers one more tool for balancing competing claims on forest and range resources.

This raises the question of what role land management and regulatory agencies should play in the preservation, management, and utilization of hardwoods in California. This question needs to be addressed so that the "margin of safety" remains.

CONCLUSIONS—COMMITMENT TO THE LAND ETHIC

Initiative in studying hardwoods, whether or not the subject presently receives emphasis in our management and budgets, will contribute to a better understanding of our environment and improve the quality of resource management.

I think your initiative reflects the ethical commitment that underlies the work of researchers, managers, and policymakers in the field of natural resources.

Dedication to the land ethic is an aspect of the resource professions that needs to be more widely emphasized in the years ahead. In the public mind in recent years, we have become too much associated with the purely scientific and technical side of managing resources. To reach the public we serve, we need to speak to the commitment to the land that all of us share.

This Symposium is a step in that direction.

Thank you very much.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Policy Paradigms and California's Hardwoods[1]

Harold R. Walt[2]

I am pleased to be here to welcome you to this symposium. The organizers and sponsors, Professors Pillsbury and Plumb in particular, are congratulated for bringing together such an impressive array of scientists, managers, landowners, citizens and policymakers to evaluate what is currently known about one of California's most valuable resource systems.

As many of you know, the Board of Forestry has taken a keen interest in hardwoods over the past 6 years. Our concern stems from a recognition that hardwoods, while largely outside the scope of our Forest Practice Act, grow on lands where we have fire and watershed protection, resource assessment, and other responsibilities. In addition, beginning in the late 1970's, county governments, environmental groups, citizens, and the State Department and Commission of Fish and Game have asked us to consider the need to place some restrictions on hardwood harvesting and conversion as these activities occur throughout California's timbered and nontimbered regions.

Our considerations of these requests will have a formal hearing during this symposium, when the Board meets to adopt an interim policy on hardwoods. Each of you is invited to attend this meeting and to testify if you so please. We expect to hear from many people with strong emotional ties to this natural resource. After all, since childhood most of us have heard hardwoods described as the standard of quality in many fields. For example, who can forget the stirring words from "Death of Nelson" by the poet Samuel James Arnold..."Our ships were British oak. And hearts of oak our men."

Today, not wanting to prejudge the outcome of the Board's hearing, I want to talk in more general terms about alternatives for developing a California hardwood policy. In this regard, I will discuss the role that scientific information and technology, and landowner, professional, and agency action can play in the development and implementation of such a policy.

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[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

[2] Chairman, State Board of Forestry, Sacramento, California.

As I observed the planning of this symposium, I was curious to see the title go through something of an evolution. I believe the proposed first title was: "Symposium on California Hardwoods." This became, of course: "Symposium on Multiple-Use Management of California's Hardwood Resources." What are we to make of this change?

On the surface, the change would appear to be a pragmatic improvement. The broader scope of the current title seems apropos in light of the various forces acting on the state's hardwood lands. Clearly, as policy makers, landowners, and scientists, we have an obligation to view hardwoods in terms of the various uses to which they are now put and to seek to design management and institutional approaches to sustain their productivity for the future. While biological and botanical information of individual hardwood species is a key, such information alone provides too narrow a focus. Thus, I think, the broadened concern for multiple-use management and hardwood resources is good.

On the other hand, the application of the term multiple-use to current discussions on California hardwoods makes me a little nervous. This nervousness results from a recognition that "multiple-use," a term popularized by the Forest Service, U.S. Department of Agriculture, can be a value-laden term derivative of a well-developed and comprehensive philosophy of resource management. The philosophy is the so-called progressive conservationist approach, which became part of the American mainstream through the work of Gifford Pinchot and others during the Teddy Roosevelt administration.

Pinchot's genius was to take Jeremy Bentham's tenet of "the greatest good for the greatest number over the longest time" and to apply it to forestry and resource management. As a vision or an overarching goal, the greatest good approach is superb. However, as a guide to action and in practice, the perspective is not without fault.

As a noted economist (Zivnuska, 1979) has argued, the conservation period has been "an era of happy platitudes filled with ethically loaded ambiguities." This also has been a time when certain practical strategies have been relied on, often without question to their efficacy or appropriateness in particular settings.

More specifically, progressive conservationism has had at its core three principles to guide the development of any resource program:

1. Government, not the market place, is the preferred institution for management implementation;

2. Professionals acting alone are best positioned to make resource use and allocation decisions; and

3. Science and technology can extend resource supplies and are the basis for a better future.

Let me assure you that I consider myself a conservationist, and that I believe there is an important role for government, professionals, and science in resource decisionmaking. But enough for the early 1900's. We are now living in an entirely different environment. The mission of this conference is to look at tomorrow. I simply want to make the point today that any solution to California's hardwood problems must be more broadly based, free of ideology, and much more appropriate to the issues at hand.

To make these points more clearly, let me turn to the excellent discussion of current hardwood concerns recently prepared by Board and Department of Forestry staff (California State Board of Forestry, 1986). They define, I think correctly, the current status of our hardwood resources as a function of several broad trends generated by the evolution of California as an economic, social, and political entity. The paper begins:

> "In a general sense, the problem faced by the Board of Forestry [and indeed the problem faced by all of us in this room] is that over time the state's hardwood forests have been modified to accommodate other uses, with very few people asking what is the effect of this conversion. Removal of hardwoods has been an accepted way of life. They often have been unwanted vegetation in the path of agricultural crops, range improvement, and construction of freeways, dams, and houses.
>
> "Almost ironically, no significant hardwood sawtimber or furniture grade lumber industries have emerged. California species are hard to mill for these uses. On timberlands of northern California, it is more profitable to clear hardwoods and plant conifers. Traditionally, California's furniture industry, the nation's second largest, has relied on imports from eastern states or abroad for lumber.
>
> "At the same time, the state's population continues to grow and its values change. Demands not related to timber or livestock production expand. There is pressure to remove more hardwoods for residential development. People want more recreation space and firewood. They also come to appreciate the aesthetic qualities of oaks and, especially in urban areas, pass laws to protect these trees. And, as with any resource, hardwoods can only tolerate so much use and conversion before some effects are noticed. Thus, it is not surprising to find questions being raised about the loss of wildlife habitat, degradation of soil and water quality, and even if hardwoods are regenerating."

To this discussion, I submit, we need to add the problems that have befallen the people with the highest responsibility for our hardwood lands--California's private livestock and landowner community. These private owners hold over 80 percent of the state's so-called hardwood rangelands, and recent problems in the nation's livestock markets have left many of these individuals and firms with limited economic options. I would argue that any state policy on hardwoods _must_ address the economic condition of this important landowner group.

Based on this problem review, we can see that our solution must be cast in terms that transcend disciplinary boundaries and go beyond the landscapes of rural California. In many ways, we face a problem similar to the one faced by the state's agricultural community. David Pierpont Gardner, President of the University of California, noted recently in announcing the appointment of the respected agricultural economist Kenneth Farrell to be the new University of California Vice President for Agriculture and Natural Resources:

> "The future of California agriculture will be increasingly influenced by national politics, international trade agreements and other economic and political occurrences well beyond the boundaries of traditional agriculture."

Like our agricultural friends, we foresters must learn to deal with the many new pressures that affect California's rural areas. Under such conditions, can we afford to look only to the set patterns that have guided the roles of government, science, and professionals in the past?

The answer to this question, I think, is: _no_, not entirely. Rather, we need to adopt an approach that takes the strength of our traditional experience, but mixes in new elements appropriate to today's California.

In this light, the goals of any state policy on hardwoods should not depend _just_ on the work of professionals and scientists, but must include a broader political-type process. In essence, the Board of Forestry has taken the lead in such a process over the past several years and I think we have identified an effective set of goals to guide future activity. Of course, these goals remain open to public comment, but as laid out they set a reasonable vision for the future (California State Board of Forestry, 1986).

This vision, which has been developed from discussion with a variety of groups and from a reading of existing state laws and policies, is as follows:

1. The hardwood resource, whether on conifer or hardwood rangelands, should be protected and enhanced. This means that all hardwood species are regenerating, soil and water quality are preserved, and sufficient habitat diversity is achieved statewide to protect the viability of critical wildlife species;

2. Range and timber stand improvement can continue--but such activities should take into account sensitive environmental areas and serious wildlife damage. Additional sources of income to landowners need to be available through improved utilization, new markets for products from species that are regenerating well, and programs to compensate landowners for leaving hardwoods;

3. Land can still be converted to intensive agriculture and residential/commercial development--but it should be directed away from environmentally sensitive areas, avoid serious damage to wildlife, and not interfere with the ability of landowners to manage their land economically;

4. Government involvement in land management decisions of private landowners should be minimal and, insofar as is possible, supportive of their needs. Public agencies, federal through local, should understand and coordinate with each other and with private landowners their management goals and practices.

This last goal offers a particularly important perspective because it defines a partnership between government and the private sector. The problems of maintaining hardwood resources in California are not well suited to control by a single government. A reasonable answer is not having the state purchase properties for public ownership, nor an autocratic enactment of restrictive, land use controls save the day. Rather, we need to employ a set of programs that allow the state to ensure long-term environmental health while allowing the landowner as full use as possible of his or her property. No one would be served if we create the conditions the biologist Garrett Hardin so aptly described as "the tragedy of the commons." We do not want to constrain private initiative to the point that the motivation and wherewithal for productive management is absent. Hardwoods won't be saved if landowners are driven from their property.

This said, I do see a role for government in hardwoods. The exact specification of this role will be worked out by the Board of Forestry and other authorities over time. But the policies adopted need to employ a variety of means. Likely to be required are research, monitoring and assessment programs, strategies to relieve pressures for hardwood removal, improved management information, and perhaps even some form of regulation. While not a preferred choice, I feel personally that some limited form of regulation may be required to protect sensitive and threatened areas if landowners fail to heed voluntary controls.

Whatever means are involved, we must work closely with the professional and scientific communities represented at this symposium. As the conservationists understood, science and technology have an important function in natural resource programs. California hardwoods are no exception. But the partnership between the people, government, and the scientific and professional community on hardwoods has to be an open process. On the one hand, researchers need to try to be socially responsible and to design studies and perform research that helps solve the hardwood management problems of today and tomorrow. On the other hand, the broader hardwood community needs to appreciate the time and support required to produce scientifically verifiable results and to stand willing to experiment with new ideas as they become available.

In this regard, I am impressed with the cooperative spirit that has emerged in the new University of California-Department of Forestry "Integrated Hardwood Management Program." It is now sponsoring over 15 studies in the first year of a 10-year basic and applied research program, and may be just what we need to bridge the traditional gap among researchers, landowners, and the public on hardwoods.

This symposium can also help to bridge this gap: all nine members of the Board of Forestry, two members from the Fish and Game Commission, and several other state, federal, and county officials are attending. The willingness of these policymakers to familiarize themselves with the full array of information which the state's scientific community has to offer may be unprecedented. I know I am impressed and proud that my colleagues on the Board of Forestry have agreed to attend this symposium. While their actions at the policy hearing and in succeeding months must be based on a wide number of factors, it is important that we take advantage of all the technical papers presented here.

So as we begin this 3 day conference on hardwoods, let me wish each of us full attention, an open mind, a pragmatic bent, and an eye toward the future. Let us take advantage of the things that connect us and put aside our differences. We are not here for ourselves; we are here to consider means to protect and extend one of California's most distinctive and important resources--the natural, human and social complex that constitutes California's hardwood heritage. Thank you.

REFERENCES

California State Board of Forestry. Policy Options for California's Hardwoods. Sacramento, CA. September 1986. 25 p.

Zivnuska, John. The Case for Dominant Use. In: proceedings of the Society of American Foresters, 1979: 49-53.

Ecology-Sivilculture

Hardwood Ecology and Silviculture—Some Perspectives[1]

Susan G. Conard and James R. Griffin[2]

Understanding the way hardwood species and communities function is critical for effective management of the approximately 15 percent of California's area which they dominate. Basic knowledge of ecology and silvicultural responses of these vegetation types is important whether management interest focuses on wood products, wildlife, recreation, range, or hardwood control (e.g., where hardwoods compete with commercial conifers). Yet—surprisingly little has been published on the ecology and management of most California hardwood species.

This session was structured to meet two objectives: first, to review available information on general topics, and second, to provide new information on current research in hardwood ecology and silviculture. To introduce the topic, four invited speakers reviewed available knowledge on the evolution and adaptations of California's hardwood flora (particularly as influenced by drought and nutrient stresses), described the structure and distribution of the five major hardwood vegetation types in the state, reviewed what is known about the current status of natural regeneration in California's major oak species, and provided an overview of mixed hardwood-conifer silviculture.

Contributed papers added to our knowledge in several key areas:

- Stand structure and dynamics—This topic was addressed in papers on the mixed-evergreen forest, northern oak woodlands, valley oak riparian forests, and Engelmann oak savannas and woodlands.
- Seed and seedling regeneration—In a series of five papers, germination timing and factors affecting germination and seedling establishment were discussed for all major tree-form oak species in the state.
- Silviculture—Two papers presented recommendations for management (one for northern oak woodlands, the other for tanoak), and one reported on establishment of a thinning study in coast live oak.
- Nutrient cycling—Information was presented comparing the amount of available nitrogen in soil under evergreen and deciduous oak species.

Clearly much more research information is needed in all four areas. Still, little is known about the vegetation dynamics or stand age structure of some of our major hardwood types. Studies of response to silvicultural treatments (e.g., thinning, fire) are generally lacking for all except the dominant hardwood competitors of northern California conifer forests (tanoak, California black oak, madrone, red alder). We are learning a great deal about the germination and reproduction requirements of the major oak species; this research is driven largely by concern over inadequate natural reproduction to maintain current stands. However, little information is available on seed reproduction of other hardwood species, or on vegetative reproduction of most oak species. Only one paper addressed physiological ecology of hardwood species. Better understanding of responses to water and nutrient stresses will increase in importance as artificial regeneration of hardwoods becomes more widespread. Additional nutrient cycling information would enhance our understanding of dynamics and productivity of hardwood stands and hardwood ranges.

Most hardwood research in California continues to focus on oaks (or the closely related tanoak), with little ecological or silvicultural research on other widespread species such as madrone, big-leaf maple, and the various alder and poplar species. The dominant focus in oak research appears to be on the range hardwoods, although increasing emphasis is being placed on oak woodland and forest types throughout the state.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Origins and Adaptations of California Hardwoods[1]

Philip W. Rundel[2]

Abstract: California's flora of hardwood trees has evolved from a mixture of Arctotertiary and Madro-tertiary progenitors under selective pressures of drought and low nutrient availability. Plant growth form and evergreen vs. deciduous leaf duration are important aspects of morphological adaptation to Mediterranean-climate conditions. Architecture and phenology of below-ground tissues may be at least as important as that of above-ground tissues. Physiological responses at both the whole plant and tissue levels are important aspects of adaptation in hardwoods, and these can be seen in comparative drought tolerance and xeromorphy of wood anatomy. In comparison to hardwoods, the conifer species which dominate most California forests exhibit a much more conservative mode of adaptive variation in canopy architecture, leaf retention, and drought response.

Interpretations of the origins and adaptations of California's hardwoods are inherently founded on knowledge of the comparative physiological response of these apecies to environmental stress. What do we know then about the environmental factors and selective pressures which have led to the evolutionary diversification of hardwood species within the state? The answer is that we know precious little. While there have been extensive studies of the physiological ecology of conifer species because of their economic importance, and of chaparral and desert shrubs because of interests in adaptations to stressful environments, there has been very little study of hardwood tree species in the west. The limited data on the physiological ecology of California oaks, the predominate group of hardwood species in the state, were discussed in an earlier review paper in 1981 (Rundel 1981), and since that time there has been little new information published.

Despite the relative absence of good sets of comparative data, there is no question that California hardwoods exhibit a remarkable range of ecological tolerance. In comparison to the conifers which dominate most California forests, hardwoods possess a far broader range of morphological, physiological and phenological adaptations to their environments. These adaptations can be seen in their canopy architecture, root architecture, photosynthetic capacity, tissue water relations, adaptation to low nutrient soils, leaf phenology, and hydraulic architecture of the xylem.

ORIGINS OF CALIFORNIA HARDWOODS AND HARDWOOD COMMUNITIES

The majority of our California hardwoods evolved from subtropical antecedants which were members of the Madro-Tertiary geoflora in the Tertiary (Axelrod 1975). As climatic conditions became drier and more seasonal through the Tertiary and Pleistocene, elements of the Madro-Tertiary geoflora migrated into what is now California and began to form differentiated hardwood communities

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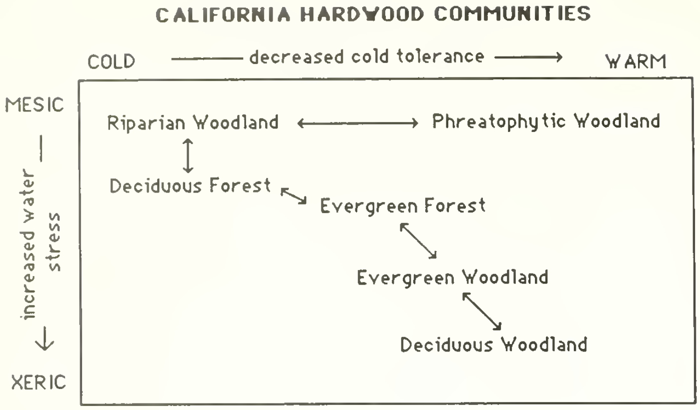


Figure 1--Environmental distribution of California hardwood communities

similar to what we see today. Another floristic group of California hardwood species evolved from cold-temperate ancestors termed the Arcto-Tertiary geoflora. These are remnants of a once larger conifer and deciduous forest flora which came across the Bering Straits from East Asia. Hardwood trees from this floristic element are largely winter-deciduous with photoperiodic cues for leaf fall. From the fossil record, it appears that the majority of our modern hardwood species from both elements had evolved by the mid- to late-tertiary (Axelrod 1975).

The environmental conditions leading to the differentiation of hardwood communities in California through the Tertiary were largely of two types (fig. 1). One of these was higher mean temperatures producing mild winters and warm summers. The other was increased influence of Mediterranean-climate conditions with lower total precipitation and increasing levels of summer drought.

The coolest and most mesic communities of California hardwoods are the riparian woodland and deciduous forests of the northwestern areas of the state and in montane and subalpine mountain communities (fig. 1). Such deciduous dominants as big-leaf maple (*Acer macrophyllum*), red alder (*Alnus rubra*), California black oak (*Quercus kelloggii*) and quaking aspen (*Populus tremuloides*) are Arcto-Tertiary in origin.

Dominant species in evergreen hardwood forests and woodlands [madrone (*Arbutus menziesii*), interior live oak (*Quercus wislizenii*), coast live oak (*Q. agrifolia*)] and deciduous woodland [blue oak (*Quercus douglasii*), valley oak (*Q. lobata*), Oregon oak (*Q. garryana*)] are evolved from subtropical Madro-Tertiary elements. A few Arcto-Tertiary elements, most notably California buckeye (*Aesculus californica*) and tanbark oak (*Lithocarpus densiflorus*), have also become part of these communities today. At the driest and warmest end of environments in California in the Sonoran and Mojave Desert, hardwood trees are still able to maintain local community dominance in phreatophytic woodlands where they tap ground water supplies at depth. Examples of these include mesquite (*Prosopis glandulosa*) woodlands (Sharifi et al. 1982, Nilsen et al. 1983) and California fan-palm (*Washingtonia filifera*) oases.

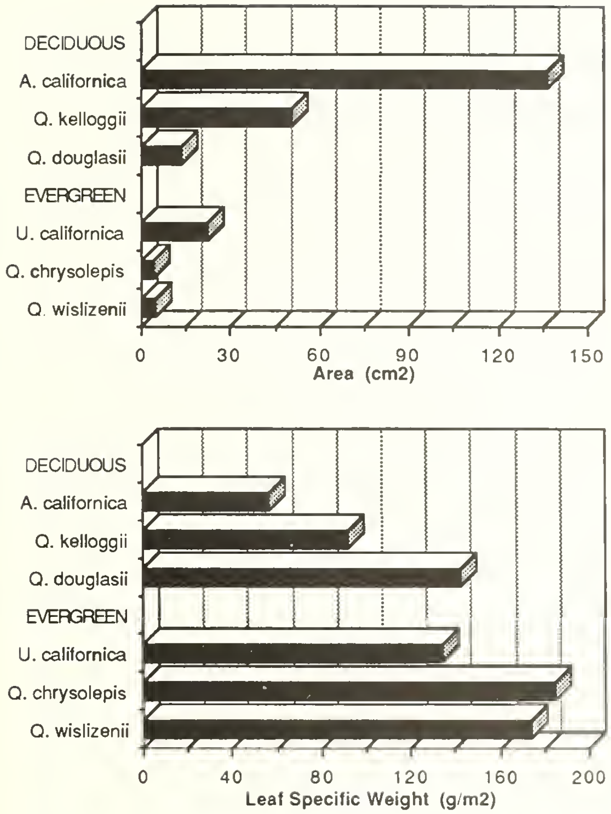
PHYSIOLOGICAL AND MORPHOLOGICAL ADAPTATIONS

Leaf Characteristics

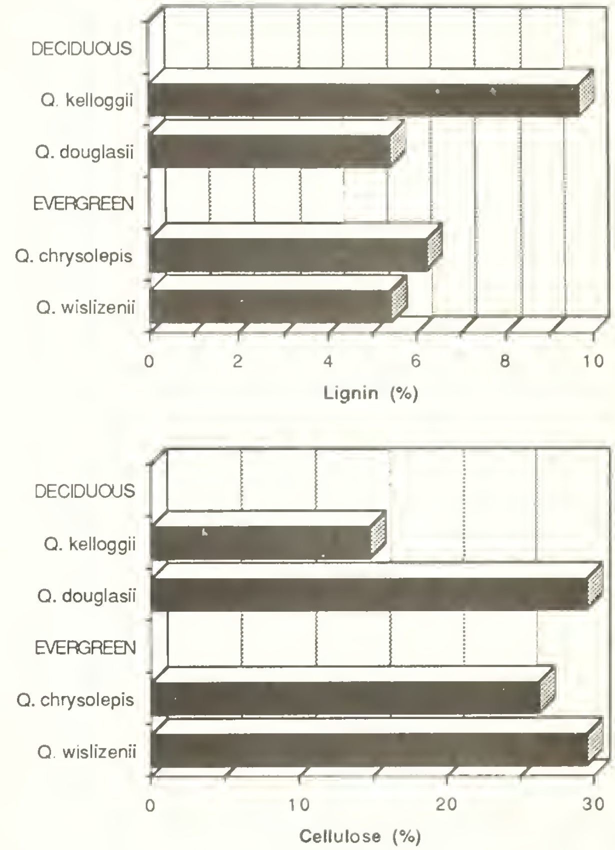
An obvious component of differentiation among California hardwoods is the presence of either evergreen or deciduous leaves. Each of these phenological patterns characteristically correlates with a number of physiological traits. Evergreen leaves in temperate latitudes are sclerophyllous in texture with a course or leathery feel. In the typical evergreen hardwood, these leaves are thinner in texture and are much less resistant to environmental streams. Leaves are present on trees only during favorable seasons for growth and are lost during periods of environmental stress. This stress period is generally winter in virtually all of California's hardwoods, even in desert phreatophytes, but summer drought may also be a factor. Drought-deciduousness is characteristic of subshrubs in many Mediterranean-type ecosystem and in desert shrubs and subshrubs.

Comparative data on leaf characteristics of evergreen and deciduous hardwood trees are available from ecological studies carried out over the past decade by my laboratory group at Sequoia National Park. These data derive from ecological studies of hardwood trees in foothill woodlands, mixed evergreen woodlands, black oak woodlands and riparian woodlands. Mean projected surface areas for individual leaves of six species studied ranged from 137 cm^2 in the deciduous *Aesculus california* to 2.4 cm^2 in the evergreen *Quercus chrysolepis*. While deciduous leaves are commonly larger than those of evergreen species (fig. 2), the deciduous *Q. douglasii* has small and relatively sclerophyllous leaves. This sclerophyllous nature can be seen in its leaf specific weight of 142 $g\ m^{-2}$ which is much more like that of the evergreen leaves (fig. 3). Similarly, in terms of fiber, the lignin and cellulose contents of *Q. douglasii* were comparable to those present in the two evergreen species (figs. 4 and 5). *Quercus kelloggii*, the least sclerophyllous of the oak species studied, surprisingly had the highest lignin content of the four at more than 9 percent, although its cellulose content was the lowest as expected. Calculated values of mean sclerophylly index (fiber to protein ratio x 100) were 208, 309, 485 and 417 for *Q. kelloggii*, *Q. douglasii*, *Q. chrysolepis* and *Q. wislizenii*.

Leaf nitrogen content, often a good correlate of photosynthetic capacity (Field and Mooney 1986) averaged about 1.8 percent in the two deciduous oaks and 1.4 percent in the evergreen species (fig. 6). This suggests higher rates of potential photosynthesis in the two deciduous species. On a seasonal basis, however, there may be very



Figures 2 and 3--Comparative values of leaf area and leaf specific weight for hardwood trees in the foothill woodlands of Sequoia National Park (Rundel, unpublished data)



Figures 4 and 5--Comparative values of leaf lignin and cellulose for hardwood trees in the foothill woodlands of Sequoia National Park (Rundel, unpublished data)

different capacities for growth in these two deciduous trees. While Q. kelloggii, in the upper foothill and lower montane zones, has leaves for about five months per year, Q. douglasii, in the lower margin of the foothills keeps its leaves for nine months or longer.

While comparative data on photosynthetic capacity are largely lacking for California hardwoods, it is possible to estimate relative differences between evergreen and deciduous species using field measurements of foliar conductance in sympatric congeners. Conductance rates in general are strongly correlated with the photosynthetic rates (Schulze and Hall 1982). Such comparative data on conductance is shown in figure 7 for individuals of Quercus douglasii and Q. wislizenii growing side-by-side in a mixed evergreen woodland commity at 430 m in Sequoia National Park. Under late summer conditions, maximum rates of conductance occurred in midmorning for both species, with a high of 0.85 cm sec^{-1} for Q. douglasii and 0.52 cm sec^{-1} for Q. wislizenii, suggesting higher rates of net photosynthesis. Both of these rates were higher than those of evergreen shrubs in adjacent chaparral communities.

Drought Tolerance and Avoidance

Tolerance of summer drought is an obvious factor in the separation of species within hardwood communities in California. Mesic deciduous forest habitats provide minimal problems of water stress, while drought tolerance or avoidance becomes increasingly critical in a gradiant from evergreen woodlands to deciduous woodlands to phreatophytic woodlands in desert washes.

Hardwood trees in California have evolved a variety of adaptive strategies to deal with problems of seasonal drought. The availability of soil moisture to plants is a function not of the absolute water content of the soil in the rooting

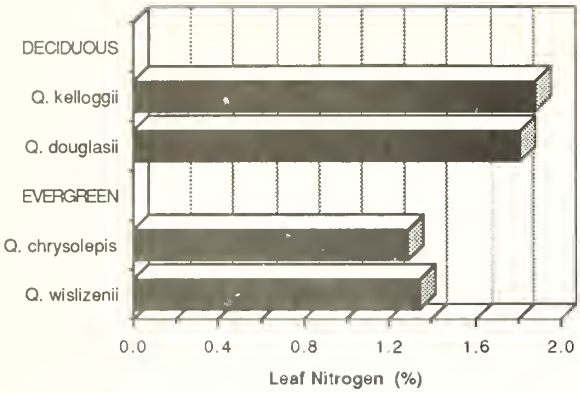


Figure 6--Comparative concentrations of leaf nitrogen for hardwood trees in the foothill woodlands of Sequoia National Park (Rundel, unpublished data)

zone, but rather to the soil water potential. Soil water potential is a function of the matric potential (i.e. capillary effects), the solute potential (i.e. the effect of osmotic solutes), and the gravitational potential. Since plants can only take up soil water along a passive potential gradient from high to low (water potentials are negative numbers), survival of drought conditions requires that hardwoods maintain positive rates of water uptake. One strategy for accomplishing this is to utilize deep roots to tap pools of groundwater which do not fluctuate seasonally. Many species of oaks are known to root very deeply (Lewis and Burghy 1964, Griffin 1973). Tree-form legumes such as Prosopis glandulosa in the Sonoran Desert of California are typically phreatophytes as well, tapping deep groundwater pools (Nilsen et al. 1983, 1984).

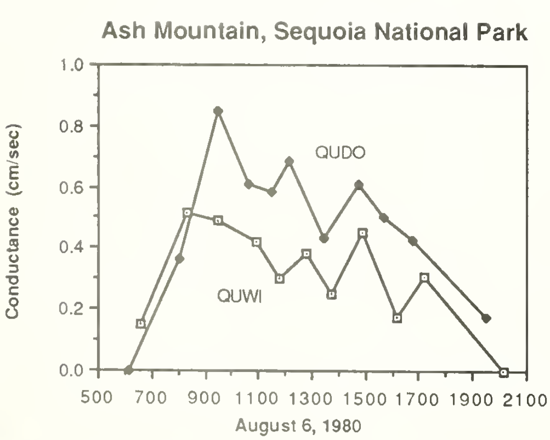
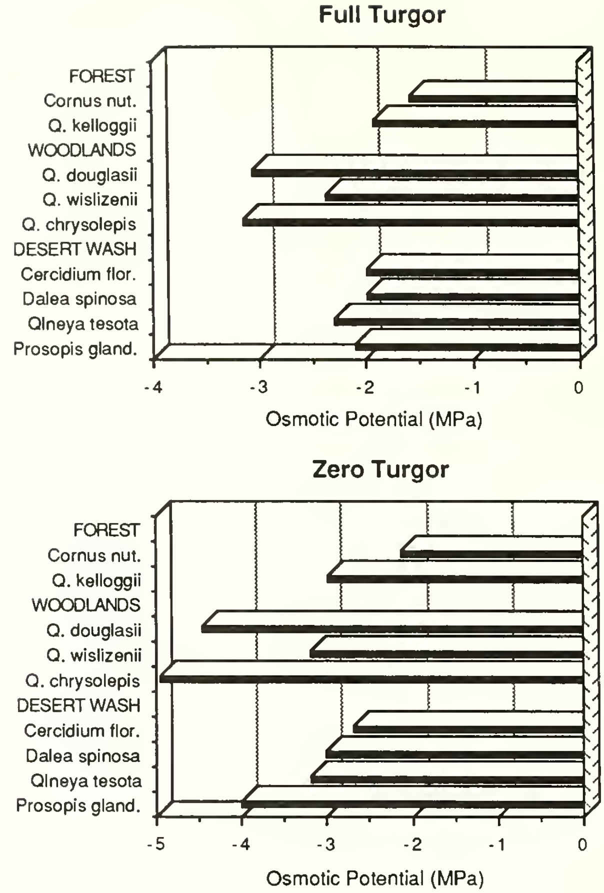


Figure 7--Diurnal cycle of leaf conductance for Quercus douglasii and Q. wislizenii at Ash Mountain, Sequoia National Park, on August 6, 1980 (Rundel, unpublished data)



Figures 8 and 9--Comparative values for osmotic potential at full and zero turgor for California hardwoods (Rundel, unpublished data)

A more physiological strategy to allow water uptake from dry soils is to maintain plant water potentials lower than those of the soil so that a favorable water potential gradient can be maintained from leaf tissues to soil. An important means to accomplish this is the utilization of osmotically active cellular components, both organic and inorganic. Increasing osmotic concentration of leaf tissue provides a steeper water potential gradient to facilitate water uptake from the soil to roots and up into the leaves.

Under full turgor conditions, the lowest osmotic potentials (most negative) occur not in desert wash species but in oak species of deciduous and evergreen woodlands (fig. 8). This reinforces the importance of phreatophytic root architecture in the desert species. The highest osmotic potentials at full turgor occur as expected, in deciduous forest species of mesic habitats.

At the point of zero turgor, no growth is possible and lower levels of water potential may lead to

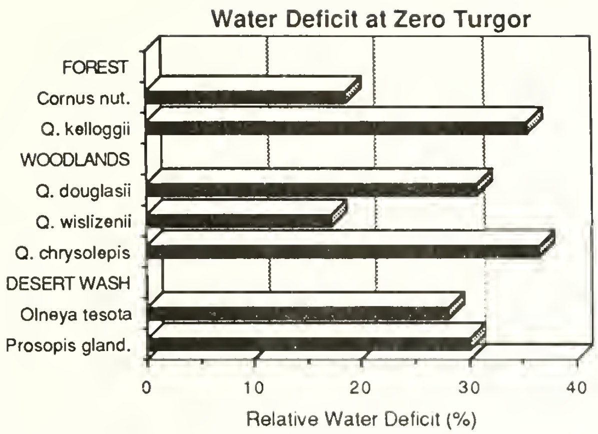


Figure 10-- Comparative values of water deficit at zero turgor for California hardwoods (Rundel, unpublished data)

permanent tissue damage. Thus, a relatively low osmotic potential at zero turgor would be expected to correlate with the ability of a species to maintain net growth at increasing levels of water stress. Cornus nuttallii, the most mesic of the hardwood species we have studied, has an osmotic potential at zero turgor of -2.2 MPa (fig. 9). At the other end of the spectrum, Quercus chrysolepis loses turgor at an osmotic potential of -4.8 MPa. This is as low or lower than that found in most desert shrubs, indicating the high degree of drought tolerance found in these trees.

Another measure of drought tolerance in hardwood species is the relative water deficit of mature leaves at the point of zero turgor. Three oak species, Q. kelloggii, Q. douglasii and Q. chrysolepis can lose more than 30 percent of their turgid water content before reaching zero turgor, while Q. wislizenii and Cornus nuttallii lose turgor at 16-18 percent relative water deficit (fig. 10).

Xeromorphy in Wood Anatomy

In recent years anatomists have developed an increasing interest in the adaptational significance of quantitative characteristics of wood structure. Many characteristics of vessel morphology and arrangement appear to have profound significance on the manner in which woody plants deal with problems in water availability. Indicators of xeromorphy in wood anatomy include large numbers of vessel elements per unit of cross-sectional area, narrow vessel diameter, short vessel elements, clustering of vessel elements, the presence of vascicentric tracheids, helical sculpturing inside vessels, and the presence of growth rings (see discussion in Carlquist 1985, Carlquist and Hoekman 1985).

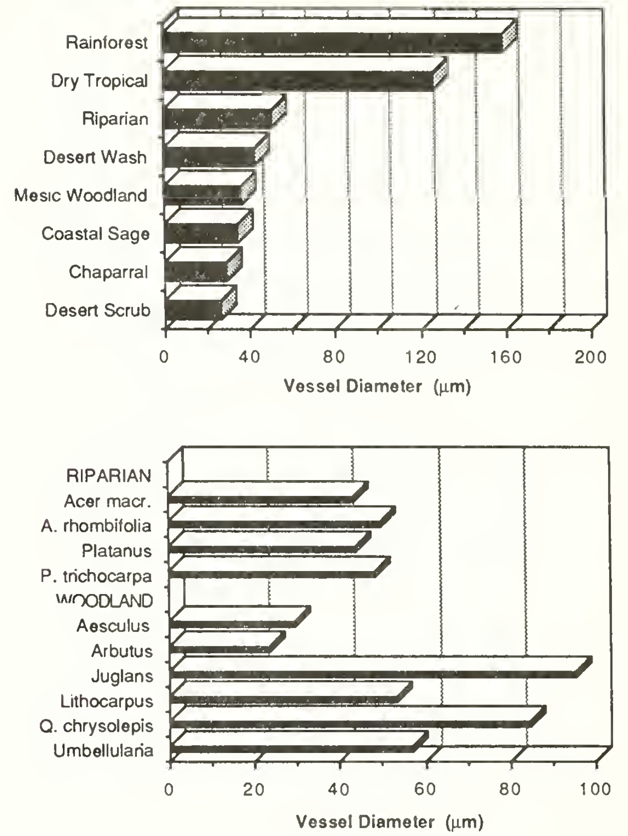
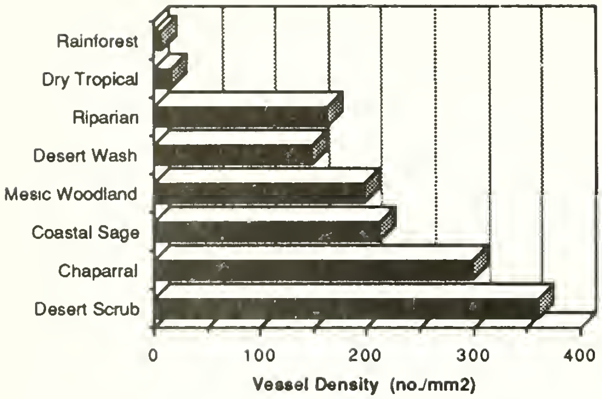


Figure 11--Comparative xylem vessel diameters for: a) California and tropical rainforest communities; b) California hardwood species. Data from Carlquist and Hoekman (1985) and Barajas-Morales (1985)

Mean vessel diameters in California hardwoods present in desert wash and mesic woodland communities are only slightly greater than those of coastal sage, chaparral and desert scrub species (fig. 11a). While riparian hardwoods are somewhat wider, they are still quite narrow in comparison to those of woody plants in dry and wet tropical forests. Mean community values for vessel diameter, however, may mask considerable variation among species, while riparian species are relatively similar to each other, forest and woodland species vary four-fold in vessel diameters (fig. 11b). Aesculus californica, a relatively xeric species has quite narrow vessels, while the much more mesic Quercus chrysolepis has wide vessels.

In a comparison of mean community values for vessel density, mesic woodlands are intermediate among California communities dominated by woody dicotyledons (fig. 12a). Riparian hardwoods are no more xeromorphic in this characteristic than



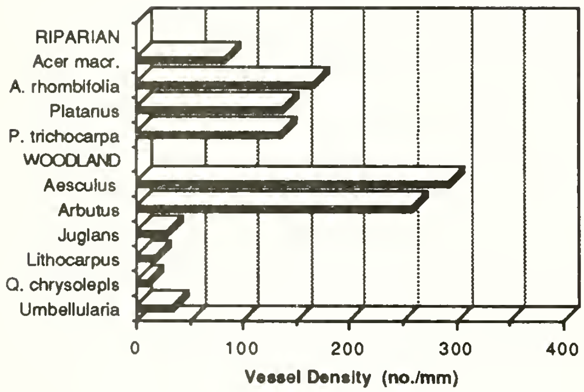


Figure 12--Comparative xylem vessel densities for: a) California and tropical rainforest communities; b) California hardwood species. Data from Carlquist and Hoekman (1985)

desert wash species. Tropical forest communities support species with very low vessel densities. At the individual species level, considerable interspecific variation is again present. Among woodland hardwoods, Aesculus californica and Arbutus menziesii have high vessel densities more like those typical of chaparral shrubs, while Umbellularia, Juglans california, Lithocarpus densiflorus, and Q. chrysolepis all have very low densities (fig. 12b).

There is little question that wood anatomy has played an important role in the adaptation of California hardwoods to drought stress. More study is clearly needed, however, to link anatomical data with physiological data on drought tolerance. Studies of hydraulic architecture will be particularly important in forging this linkage.

CONCLUSIONS

All of the available data, sparse as it may be, strongly suggests that California hardwoods have evolved a broad range of both form and functional adaptations to the gradients of environmental conditions which occur within the state. Summer drought associated with a Mediterranean-type climate has been a primary selective pressure, with soil nutrient availability as a secondary factor in influencing leaf duration. As we continue to learn more about ecosystem processes within our California landscape, we will be better able to interpret adaptive modes of both water and nutrient use efficiency.

ACKNOWLEDGMENTS

Research described in this paper was made possible by a research contract from the National Park Service, Sequoia National Park and by additional support from the Ecological Research Division of the Office of Health and Environmental Research, U.S. Department of Energy. Many individuals helped in this project. I would particularly like to thank David Parsons, Thomas Stohlgren, Peter Rabenold and Gail Baker for their assistance.

REFERENCES

Axelrod, D. I. Evolution and biogeography of Madrean-Tethyan sclerophyll vegetation. Annal. Missouri Bot. Gard. 62:280-334; 1975.

Barajas-Morales, J. Wood structural differences between trees of two tropical forests in Mexico. IAWA Bull. 6:355-364; 1985.

Carlquist, S. Vasicentric tracheids as a drought survival mechanism in the woody flora of Southern California and similar regions: review of vasicentric tracheids. Aliso 11:37-68; 1985.

Carlquist, S. and Hoekman, D. A. Ecological wood anatomy of the woody Southern California flora. IAWA Bull. 6:319-347; 1985.

Field, C. F. and Mooney, H. A. The photosynthesis nitrogen relationship in wild plants. In: Givnish, T. J., ed. On the Economy of Plant Form and Function. Cambridge: Cambridge Univ. Press; 1986:25-56.

Griffin, J. R. Xylem sap tension in three woodland oaks of Central California. Ecology 54:152-159.

Lewis, D. C.; Burghy, R. H. The relationship between oak tree roots and ground water in fractured rock as determined by tritium tracing. J. Geophys. Res. Wash. 69:2579-2588; 1964.

Nilsen, E. T.; Sharifi, M. R.; Rundel, P. W. Diurnal and seasonal water relations of the desert phreatophyte Prosopis glandulosa (honey mesquite) in the Sonoran Desert of California. Ecology 64:1381-1393; 1983.

Nilsen, E. T.; Sharifi, M. R.; Rundel, P. W. Comparative water relations of phreatophytes in the Sonoran Desert of California. Ecology 65: 767-778; 1984.

Rundel, P. W. Adaptations of Mediterranean-climate oaks to environmental stress. In: Symposium on the Ecology, Management and Utilization of California Oaks. Gen. Tech. Rep. PSW-44. Berkeley: CA: Pacific Southwest Forest and Range Experiment Station, Forest Service. U.S. Department of Agriculture; 1981:43-54.

Sharifi, M. R.; Nilsen, E. T.; Rundel, P. W. Biomass and net primary production of Prosopis glandulosa (Fabaceae) in the Sonoran Desert of California. Amer. J. Bot. 69:760-767; 1982.

Schulze, E.-D.; Hall, A. E.. Stomatal responses, water loss and CO_2 assimilation rates of plants in contrasting environments. In: Lange, O. L.; Nobel, P.; Osmond, C. B.; Ziegler, H., eds. Encyclopedia of Plant Physiology. Volume 12B. Water Relations and Photosynthetic Productivity. Berlin: Springer Verlag; 1982:181-230.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Community Ecology and Distribution of California Hardwood Forests and Woodlands[1]

Michael G. Barbour[2]

Abstract: Hardwood forests and woodlands, characterized by relative cover of hardwoods being >50 percent, dominate about 16 percent of the State's area. There are five major hardwood types: riparian forest, blue oak woodland, southern oak woodland, mixed evergreen forest, and montane aspen parkland. Some of these types have regional phases. Species characteristic for these types are: Populus fremontii, Quercus douglasii, Q. agrifolia, Q. chrysolepis, and Populus tremuloides var. aurea, respectively. Community structure, dynamics, and distribution are related to macroclimate, soil, and disturbance. Few autecological details, based on experimentation, are known for the dominant hardwoods; consequently, management techniques are largely intuitive. Some types or phases are even synecologically poorly known.

Hardwood trees dominate about 16 percent of California's 100,000,000 acres (40,500,000 ha) of terrestrial vegetation (Barbour and Major, 1977). Except for aspen parkland at high elevations, hardwood forests and woodlands occur below 1400 m elevation in areas characterized by a mediterranean climate, with mean annual temperature >13°C and mean annual precipitation <900 mm. For the purposes of this review, hardwood woodlands, parklands, and forests are defined as having an overstory tree canopy >5 m tall of >40 percent cover, and with hardwoods contributing >50 percent relative cover.

Five taxa serve as threads to define most hardwood vegetation or community types in the state: Fremont cottonwood (Populus fremontii) for the riparian forest, blue oak (Quercus douglasii) for the blue oak woodland, coast live oak (Q. agrifolia) for the southern oak woodland and a coastal phase of the blue oak woodland, canyon live oak (Q. chrysolepis) for the mixed evergreen forest, and quaking aspen (Populus tremuloides var. aurea) for aspen parkland and high elevation riparian forest. Several other taxa may be locally dominant, but none has the regional importance of these five species.

Ecologically, all five may be characterized as occupying sites episodically disturbed by natural phenomena (fire or flood) and (more recently) by human-directed phenomena (logging and grazing). Stand age structures reflect disturbance history, most often by exhibiting a pattern of episodic regeneration. Despite their association with disturbance, the general autecology of the five taxa is so poorly known that the nature of their tolerances of, adaptations to, or even requirements for, such disturbance phenomena remain largely undocumented at an experimental level.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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RIPARIAN FORESTS

These are the only extensive forests in California dominated by broadleaved, mesophytic, winter-deciduous taxa. The geological and floristic connections between these taxa and those of the eastern United States deciduous forest have been well described by Holstein (1984) and Robichaux (1977). Human activities have severely modified the extent and structure of riparian forests; <10 percent of the statewide acreage present in 1800 still remains (Sands 1977, Warner and Hendrix 1984), and little of this remnant has protected status.

The most detailed description of the best remaining stands comes from the Sacramento Valley (Conard et al. 1977, R. Holland unpublished data). An elevational sequence of communities extend back from the river, progressing through a willow thicket, a cottonwood forest, and a valley oak forest.

Cottonwood forest has a 25 m tall overstory dominated by Fremont cottonwood, associated with valley oak (Quercus lobata), white alder (Alnus rhombifolia), arroyo willow (Salix lasiolepis), and ash (Fraxinus latifolia/velutina complex). Subcanopy tree, shrub, vine, and herb canopies, each of 10-50 percent cover, are also present. Tree density averages 250 ha^{-1}, with 39 $m^2 ha^{-1}$ basal area (BA). Relative canopy cover by cottonwood is >40 percent. Plant and animal species diversity is possibly greater here than for any other California plant community.

Valley oak forest canopy reaches to 35 m and it is closer to being monospecific than cottonwood forest canopy (75 percent relative cover by valley oak). Associated species include those listed above, and in addition California sycamore (Platanus racemosa). Both sycamore and valley oak are large trees; consequently, this forest is less dense than the cottonwood forest, only 125 trees per hectare with 18 $m^2 ha^{-1}$ BA. California black walnut (Juglans hindsii) may be a part of the overstory, but its distribution today has been greatly expanded by man over its pristine limits (Thomsen 1963). Subdominant tree, shrub, vine, and herb canopies are also present, with herb canopies more continuous than in the cottonwood phase, approaching 100 percent cover.

All riparian trees are phreatophytes, but cottonwood and alder seem favored by shallower water tables than oak and sycamore. Valley oak exhibits maximum growth when the water table is about 10 m below the surface. Even so, valley oak exhibits remarkably little variation in xylem pressure over the course of a year or between wet and dry years (Griffin 1973, R. MacDonald unpublished data).

Anecdotal, historical accounts (Thompson 1961) describe the pristine, low elevation riparian forest as "jungle-like," with "impenetrable walls of vegetation" facing the water. Sycamores were reported to be 23-30 m tall, valley oaks 2-2.5 m diameter breast height (dbh) and reaching 18 m to the first limb. The willow, cottonwood, and oak phases apparently extended 1-8 km on each side of major rivers, occupying natural, coarse-textured levees 1.5-6 m above water level.

More upland, narrower tributaries of major rivers are often dominated by big leaf maple (Acer macrophyllum), black cottonwood (Populus trichocarpa), and quaking aspen. Coastal tributaries are dominated by red alder (Alnus rubra) and black cottonwood. Valley oak is absent from southern California (Griffin and Critchfield 1972); consequently, I have taken Fremont cottonwood to be the indentifying thread for most low elevation riparian forest.

Very little has been published on vegetation dynamics, productivity, and mineral cycling of California riparian forests. Strahan (1984), Bahre and Whitlow (1982), and Whitlow and Bahre (1984) have examined short-term succession on a variety of substrates and sites in the central valley, but I have found no data on productivity, biomass or nutrient accumulation, or rates of species turnover during succession.

BLUE OAK WOODLAND

This community forms a nearly continuous ring around the central valley of California, generally between 100 and 1200 m elevation. Common synonyms include: digger pine-oak forest or woodland, pine-oak woodland, and foothill woodland. Probably this type covers 8 percent of the state.

This is essentially a two-layered community. An overstory canopy, 5-15 m tall, is 30-80 percent closed, and blue oak, with an importance value above 67 percent (Brooks 1971, Vankat and Major 1978), is dominant. Associated trees include coast and interior live oaks (Q. agrifolia towards the coast, Q. wislizenii towards the interior), digger pine (Pinus sabiniana) and two deciduous oaks, valley oak at lower elevations with shallow water tables, and black oak (Q. kelloggii) at higher elevations or on mesic slopes. Sapling and tree density combined is usually less than 200 ha^{-1}, but dense stands can reach 1000 ha^{-1} (Griffin 1977). California buckeye (Aesculus californica) occurs as scattered individuals or in small clumps. Tree life span (except for valley oak) is <300 yr and tree girth is modest, averaging 20-30 cm dbh.

Shrubs 1-2 m tall are regularly present, but cover is insignificant, usually 5 percent. The herbaceous ground stratum, now composed mainly of introduced annual grasses and of native annual and perennial forbs, averages >80 percent.

Oak woodland occurs on moderately rich, loamy, well-drained soils with neutral or slightly basic pH, in inceptisol, alfisol, and mollisol orders. Topography is often gently rolling to steep (10-30 percent slope). Oak woodland often occurs in a mosaic with grassland, savanna (<25 percent tree cover), and chaparral--a mosaic which reflects differences in slope, aspect, soil depth, and frequency of fire more than differences in climate. Mean annual temperature is 16°C, and mean annual precipitation is 530 mm.

Phases

The Coast Range phase of blue oak woodland is dominated by coast live oak. Other phases may also be adjacent to each other, as shown by recent studies in the Sierra Nevada (Brooks 1971; Vankat and Major 1978; Baker et al. 1981). An interior live oak phase may occur both below blue oak woodland, in somewhat riparian habitats, and above it, on steeper slopes. Tree canopy tends to be more closed, tall shrubs may increase, and herbaceous ground cover may decrease. Increasing elevation may add canyon live oak, black oak, and conifers (Pinus ponderosa, Pseudotsuga menziesii) to form a transition to mixed evergreen forest. On other slopes or on exposed ridges, a black oak phase of blue oak woodland may occur at 1000-1500 m elevation; in this phase, tree and shrub canopy cover are not greatly changed, but herb cover declines to 30-65 percent. Formally, I include canyon live oak and black oak phases within the mixed evergreen forest (next section).

With elevational rise in the Coast Range, blue oak woodland is replaced by a xeric mixed evergreen forest, dominated by Coulter pine (Pinus coulteri), coast live oak, canyon live oak, and black oak (Griffin 1977, Sawyer et al.

1977). Well within the blue oak woodland zone, but in riparian-like habitats, is a live oak-buckeye phase, dominated by coast or interior live oaks and buckeye, and with blue oak regularly present (Bowerman 1944).

Axelrod (1965), Major (1977), Myatt (1980), and Vankat (1982) all documented gradients in precipitation, mean annual temperature, and annual amplitude of temperature with elevation which correspond with the upper limit of blue oak woodland. There is also some evidence (Dunn 1980, Baker et al. 1981) that soil C:N ratio and content in N, P, Ca, ad organic matter rise as one moves upslope out of blue oak woodland. Within blue oak woodland, there is conflicting evidence for a positive or negative impact of blue oaks on the growth and nutritional content of associated understory species (Holland 1980, Holland and Morton 1980, Kay and Leonard 1980).

Stand Dynamics

White (1966) made a detailed study of 38 ha of blue oak woodland in the Central Coast Range, Monterey County. Two blue oak age groups were evident: 60-100 yr old and 150-260 yr old. Successful establishment had been declining for the past 90 yr, and essentially no establishment had taken place in the last 30 yr. Establishment, then, appeared to be episodic, with the most recent flush occurring in the late 1870's. Vankat and Major (1978), working from historical records and photographs in the Sequoia-Kings Canyon area, also concluded that there had been a flush of blue oak establishment in the 1870's.

In a series of papers, Griffin (1971, 1976, 1977, 1980a) concluded that major causes of deciduous oak seedling mortality were: inability of the root to penetrate compact soils; summer drught away from tree canopies on southern exposures; and browsing by pocket gophers, above-ground rodents, deer, and cattle. Thousands of seedlings were marked, and only those on north-facing slopes, in partial shade, and protected from all grazing animals survived for 6 yr, at a density of 9 m^{-2}. Mortality was 100 percent in all other cases. The flush of establishment in the 1870's could have coincided with low herbivore population numbers and optimal fall germination conditions, followed by mild summers. Rodent, deer, and livestock populations currently are all too high to permit significant establishment. Deciduous oaks (blue oak and valley oak) show less successful establishment than evergreen oaks (coast live oak).

Stand structure may, of course, reflect episodic disturbance in the form of ground or crown fires. There has been surprisingly little research on assessing the role of natural fire frequency in oak woodlands. It is known that all oak tree species are capable of sprouting in California, though valley oak and blue oak lose the ability once they reach a certain mass or age (Plumb 1980, Griffin 1980b). Trees in the blue oak woodland are also subject to local defoliation by western tent caterpillar, on 8-10 yr cycles, but I have seen no reports in the literature on the impact this herbivory has on oak growth and survival.

Blue oak is much more xerophytic than valley oak or coast live oak. In Coast Range woodlands, Griffin (1973) showed that average summer pre-dawn water potential for blue oak was -11 bars, while nearby valley oak and coast live oak trees averaged only -4 bars. In a Sierran woodland, Rundel (1980) and Baker et al. (1981) showed that peak late-summer pre-dawn potentials for blue oak, interior live oak, and canyon live oak all averaged -20 bars.

It is clear from Rundel's (1980) review of oak ecology that we have insufficient data to define or compare photosynthetic rates, productivity, or patterns of biomass allocation of California oak trees. We cannot yet assume that the generally held tenets about photosynthetic differences between evergreen and deciduous species (eg, Mooney 1972, Larcher 1980) apply to California oaks. These oaks provide an excellent test for such hypotheses, and they even offer hybrids between evergreen and deciduous species (eg, *Q.* x *morehus*, a common hybrid of *Q. kelloggii* and *Q. wislizenii*; see Tucker 1980).

SOUTHERN OAK WOODLAND

This community occurs in the outer portion of the Central Coast Range, beginning near the northern border of San Luis Obispo County (35°45'N) and extending south into the Transverse Ranges, where it occupies north-facing and coast-facing slopes and ravines below 1200 m elevation. It also occurs in interior valleys and on gentle foothill slopes of the Peninsular Ranges, mainly at 150-1400 m elevation, continuing south to the Sierra San Pedro Martir, 30°N, on western slopes below 2000 m.

Southern oak woodland has a physiognomy and stand architecture similar to that of blue oak woodland. The overstory is 9-22 m tall and incompletely closed, and the understory herbaceous layer approaches 80 percent cover. In the Coast Range, coast live oak is the major dominant, but in the Transverse, Peninsular, and Baja California Ranges, it is associated with (and sometimes subordinated to) two deciduous species: California walnut (*Juglans californica*, especially from Orange to Santa Barbara Counties) and mesa or Engelmann oak (*Quercus engelmannii*, especially in an 80 km-wide belt running north-south about 30 km from the coast, from Los Angeles to San Diego Counties; Pavlik 1976). Synonyms for these phases within southern oak woodland include: coast live oak woodland, walnut-oak woodland, and Engelmann oak woodland.

Axelrod's (1977) analysis of climatic relationships among California oak woodlands suggests that the southern California types differ from each other, and from blue oak woodland, in terms of warmth and equability. Equability declines (that is, amplitude of annual temperature increases) in the series: coast live oak--walnut woodlands--Engelmann oak--blue oak. Mean annual temperature is still 16°C, but annual fluctuations are reduced in the south, due to a maritime influence and summer fog (USDC, 1964). Mean annual precipitation remains about 530 mm, as in blue oak woodland.

According to Griffin's (1977) review, very little descriptive stand data for the southern oak woodland exists. Walnut woodlands have been largely disturbed, modified, or supplanted due to human activity. The best description of the interior phase comes from work in the Santa Ana mountains and from vegetation type map (VTM) surveys by Wieslander in Riverside and San Diego Counties in the 1930's (summarized by Griffin 1977). Only 10 percent of VTM plots located in oak woodland contained mesa oak; the rest were dominated by coast live oak. Some mesa oak stands were savanna-like, with 27 trees ha^{-1}, but others were denser, with 50-150 trees ha^{-1}, and these were either with equal densities of mesa and coast live oak or with a mix of mesa, coast, and black oaks. Mesa oak diameter distribution is much like that of blue oak, most trees being in the 20-30 cm dbh class. In general, coast live oak is more abundant on steeper or moister slopes and mesa oak on gentler, more arid slopes. Mesa oak and coast live oak resprout following fire or cutting, mesa oak doing so more vigorously (Snow 1980).

The Nature Conservancy, in cooperation with the State of California, has put both mesa oak and walnut woodlands in their highest priority class for acquisition of vegetation/habitat data and for inclusion in protected natural areas (Holstein 1981). They are viewed as two of the State's 32 most endangered plant communities.

MIXED EVERGREEN FOREST

This community is between oak woodland below and mid-montane conifer forests above; consequently, the list of characteristic species can be long, taking in species which range considerably above and below the mixed evergreen forest. The floristic composition of the type and the distributional limits of its various phases are well known, but quantitative descriptions are few. The lack of stand data is surprising, given the forest's wide distribution, covering 3-4 percent of California's area (Barbour and Major 1977). Cooper (1922) included it in his "broad sclerophyll forest formation," and synonyms for some of its phases include canyon oak woodland, Coulter pine forest, big-cone spruce forest, mixed hardwood forest, Douglas fir-hardwood forest, tanoak-madrone forest, and Santa Lucia fir forest.

Sawyer et al. (1977) identified three trees as common throughout the forest's range--big leaf maple, canyon live oak, and bay (Umbellularia californica)--but I would emphasize the oak as the most common thread, as maple and bay are more restricted to mesic canyons and are not as widespread. A conifer overstory, when present, is scattered and 30-60 m tall. Beneath is a more completely closed canopy, 15-30 m tall, of broad-leaved evergreen trees with scattered deciduous trees. Both canopies together may contribute 40-100 percent cover. Shrub, moss, and perennial herb cover usually average 5-25 percent. In some hardwood phases, however, the community is essentially one-layered, the ground covered with a thick mat of undecomposed leaf litter, and with shrubs and herbs largely absent.

As defined here, mixed evergreen forest extends in a broken ring around the central valley, facing the valley on Sierran slopes at 600-1200 m elevation, but away from the valley in the Coast Ranges and there expanding its zone to 300-1500 m, depending on proximity to the ocean. In the Transverse, Peninsular, and Baja Ranges, the forest exists between 900 and 1400 m elevation (Wright 1968, Minnich 1976, Vogl 1976, Thorne 1977, Wiggins 1980).

Climatic data for eleven mixed evergreen forest stations (Major 1967 and 1977, McDonald 1980, Talley 1974; USDC 1964, Wainwright and Barbour 1984) show mean annual temperature to be 14°C, significantly cooler than blue oak woodland, and mean annual precipitation to be 870 mm, nearly 40 percent above that for oak woodland. In Axelrod's (1977) thermal scheme, tanoak-madrone does not seem to differ significantly from oak woodland. Myatt (1980), however, found that the various Sierran phases of mixed evergreen forest fell out rather well between oak woodland and mixed conifer on an elevational/moisture gradient.

Douglas Fir Hardwood Phase

This phase occurs at relatively low elevations in Marin and Sonoma Counties and at higher elevations in the Sierra Nevada. One detailed study was done at Annadel State Park, 300 m elevation, in the Sonoma Mountains of Sonoma County (Wainwright and Barbour 1984). Douglas-fir and bay shared dominance in terms of stems per hectare. Douglas-firs in some stands were large, 30-170 cm dbh. Low woody vegetation (excluding juveniles of overstory species), ferns and mosses, and (largely perennial) herbs contributed 15 percent cover. A recent study by Karl Gudmunds (later in this volume), of stands at about 1000 m elevation in the Coast Range and the Sierra Nevada at about 39°N latitude, showed that this phase does exist in the Sierra Nevada, even though previously unreported. A similar comparative study by Gray (1978) leads one to the same conclusion, even though Gray himself did not express that conclusion.

Coulter Pine-Hardwood Phase

Pinus coulteri is scattered from Mount Diablo (38°N) south through the Coast Ranges, then as large patches into the Transverse Ranges and down the Peninsular Ranges into Baja California. Within this area it becomes an important, sometimes dominant, element in the mixed evergreen forest.

In the Santa Lucia Range, it is a regular but minor part of forests on steep slopes at 1200-1600 m elevation (Talley and Griffin 1980). Extending down to lower elevations, 250-1500 m, Abies bracteata can become an added element, but other associated species do not change (Sawyer et al. 1977). Tree cover is 40-65 percent, and herb and shrub cover are each 5 percent. These steep, rocky sites are relatively more fire free (Griffin 1978). Santa Lucia fir has a very limited range of 1800 km^2 in the Central Coast Range (Griffin and Critchfield 1972), so it is today a minor element of mixed evergreen forest as a whole.

In the Transverse and Peninsular Ranges, the Coulter pine phase is best developed between 1200 and 1800 m elevation (Minnich 1976; Thorne 1977), and it is associated with ponderosa pine (Pinus ponderosa), canyon live oak, black oak, and a shrub stratum of 10 percent cover. Vogl (1976) and Borchert (1985) have pointed out its spatial association with chaparral, and described it as a semi-closed-cone conifer which may require fire for maintenance of its range. Vogl concluded that there is an absence of any ecological studies of the species.

On steep north-facing slopes and in ravines, big-cone spruce (Pseudotsuga macrocarpa) can be a common element. At lowest elevations of 1100 m (Minnich 1976, 1980), big-cone spruce trees are scattered individuals 15-30 m tall above a closed canopy of canyon live oak. At about 1500 m elevation, the oaks thin and big-cone spruce becomes increasingly abundant (80-190 trees ha^{-1}). Tree canopy cover may total 85 percent (about equally divided between oak and big-cone spruce) and shrub cover is 5-13 percent. As with Santa Lucia fir stands, these stands appear to be more fire free than surrounding mixed evergreen phases, such as canyon live oak and Coulter pine (Minnich 1980). Coulter pine and canyon live oak occur on more xeric, frequently disturbed sites adjacent to chaparral, and big-cone spruce and canyon live oak occur on more mesic, protected, fire-free sites.

Non-Coniferous Phases

Within the mixed evergreen forest belt, the forest may be dominated exclusively by broad-leaved trees: buckeye, madrone (Arbutus menziesii), tanoak (Lithocarpus densiflora), coast live oak, canyon live oak, black oak, interior live oak, and bay. In some cases, this phase is seral following fire or logging which removed a conifer element once present. The hardwood species typically recover by stump sprouting, resulting in a dense stand of pole-size trees (2500 ha^{-1}) with little commerical value.

Other hardwood phases are edaphic or topographic climaxes, on steep slopes, in canyons, or on poor soils; these are nearly pure stands of canyon live oak or black oak. The USDA Forest Service map by Matyas and Parker (1980) shows that considerable areas of the west flank of the Sierra Nevada are in these two oak phases. Both may extend well into the montane conifer zone (Myatt 1980). Canyon live oak forest, as mentioned earlier, is also common at all elevations within the mixed evergreen forest in southern California.

ASPEN PARKLAND PHASE

Quaking aspen is the most widely distributed tree species in North America (Fowells 1965). It may be mainly represented in montane California by the variety aurea, which has been monographed by Barry (1971). In the Sierra Nevada, quaking aspen occurs from elevations as low as 1500 m in the north (40°N) to near timberline above 3000 m in the south (36°N). It is nearly absent from suothern California, occurring in a stand at 2200 m in the San Gorgonio Wilderness Area of the San Bernardino Mountains (Minnich 1976; Thorne 1977) and in a stand west of Lake Arrowhead in the San Bernardino Mountains (Axelrod, per. comm.). It reappears in the Sierra San Pedro Martir above 2100 m (Goldman 1916; Wiggins 1980).

I have found no published, quantitative studies of Sierran aspen stands. A 50-yr record of publications from the Pacific Southwest Forest and Range Experiment Station (Aitro 1977) fails to include even one publication on aspen. It appears that mature overstory trees may commonly attain 65 cm dbh and 20 m height; canopy cover may reach 100 percent. White fir (Abies concolor var. lowiana) and red fir (A. magnifica) saplings can be common in the herbaceous understory (Barry 1971 reported densities of 2500 ha^{-1}), implying that some stands are seral. Aspen stands are not resistant to fire (Fowells 1965), but the roots remain alive after fire and these are capable of sending up new shoots.

AREAS FOR FUTURE RESEARCH

Significant contributions to our ecological understanding of Californian hardwood vegetation can be made at all levels, from basic stand descriptions, to autecological studies of key species, to demographic studies of stand dynamics, and to the construction of management models. Several hardwood communities have been so severely affected by human-mediated activity that they are in danger of becoming extinct.

Comparative data on productivity, photosynthetic rate, carbon allocation patterns, and water relations of California oak species are few. Closely related deciduous and evergreen species and their hybrids could be compared to test published general hypotheses about their putative ecological/adaptive value. There is very little quantified information on stand data for southern oak woodland phases, especially coast live oak woodland and walnut woodland. There is little information on natural fire frequency and stand response to fire in the various oak woodlands of California. Stand data on all the phases of mixed evergreen forest are few. Autecological studies of such important, wide-ranging dominants in mixed evergreen forest as Pinus coulteri, Quercus chrysolepis, and Pseudotsuga macrocarpa have not been conducted. There seems to have been no research attention paid to Sierran quaking aspen by the US Forest Service in the past 50 yr. Our lack of hardwood ecological studies indicates an imbalance in public research priorities that should be corrected.

REFERENCES

Aitro, V.P., compiler. Fifty years of forestry research, 1926-1975. Gen. Tech. Rep. PSW-23. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Serv., U.S. Department of Agriculture; 1977.

Axelrod, D.I. A method for determining the altitudes of Tertiary floras. Paleobotanist 14:144-171; 1965.

Axelrod, D.I. Outline history of California vegetation. In: Barbour, M.G.; Major, J., editors. Terrestrial vegetation of California. New York: Wiley-Interscience; 1977; 139-192.

Bahre, C. J.; Whitlow, T. J. Floristic and vegetational patterns in a California dredge field. J. Biogeogr. 9:79-90; 1982.

Baker, G. A.; Rundel, P. W.; Parsons, D. J. Ecological relationships of Quercus douglasii (Fagaceae) in the foothill zone of Sequoia National Park, California. Madrono 28:1-12; 1981.

Barbour, M. G.; Major, H., editors. Terrestrial vegetation of California. New York: Wiley-Interscience; 1977. 1002 p.

Barry, W. J. The ecology of Populus tremuloides, a monographic approach. Davis, CA: University of California; 1971. 730 p. Dissertation.

Borchert, M. Serotiny and cone-habit variation in populations of Pinus coulteri (Pinaceae) in the Southern Coast Ranges of California. Madrono 32:29-48; 1985.

Brooks, W. H. A quantitative ecological study of the vegetation in selected stands of the grass-oak woodland in Sequoia National Park, California. Unpublished progress report submitted to Superintendent, Sequoia-Kings Canyon National Park, Three Rivers, CA; 1971.

Conard, S. G.; MacDonald, R. L.; Holland, R. F. Riparian vegetation and flora of the Sacramento Valley. In: Sands, A., editor. Riparian forests of California: their ecology and conservation. Institute of Ecology, Publication 15, Univ. of California, Davis; 1977. 47-55.

Cooper, W. S. The broad-sclerophyll vegetation of California. Washington, DC: Carnegie Institution of Washington, Publication 319; 1922. 124 p.

Dunn, P. H. Nutrient-microbial considerations in oak management. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 148-160.

Fowells, H. A., compiler. Silvics of forest trees of the United States. Agricultural Handbook 271. Washington, DC: U.S. Department of Agriculture; 1965. 762 p.

Goldman, E. A. Plant records of an expedition to Lower California. Contrib. U.S. Nat. Herb. 16:309-371; 1916.

Gray, J. T. The vegetation of two California mountain slopes. Madrono 25:177-185; 1978.

Griffin, J. R. Oak regeneration in the upper Carmel Valley, California. Ecology 52:862-868; 1971.

Griffin, J. R. Xylem sap tension in three woodland oaks of central California. Ecology 54:152-159; 1973.

Griffin, J. R. Regeneration in Quercus lobata savannas, Santa Lucia Mountains, California. Amer. Midl. Natur. 95:422-435; 1976.

Griffin, J. R. Oak woodland. In: Barbour, M. G.; Major, J., editors. Terrestrial vegetation of California. New York: Wiley-Interscience; 1977; 383-425.

Griffin, J. R. The Marble-Cone fire ten months later. Fremontia 6(2):8-14; 1978.

Griffin, J. R. Animal damage to valley oak acorns and seedlings, Carmel Valley, California. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980a. 242-245.

Griffin, J.R.. Sprouting in fire-damaged valley oaks, Chews Ridge, California. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980b. 216-219.

Griffin, J. R.; Critchfield, W. B. The distribution of forest trees in California. Res. Paper PSW-82. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1972. 114 p.

Holland, V. L. Effect of blue oak on rangeland forage production in central California. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 314-318.

Holland, V. L.; Morton, J. Effect of blue oak on nutritional quality of rangeland forage in central California. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 319-322.

Holstein, G. Special plant communities of California--working lists. San Francisco: The Nature Conservancy; 1981. 26 p.

Holstein, G. California riparian forests: deciduous islands in an evergreen sea. In: Warner, R. E.; Hendrix, K. M., editors. California riparian systems. Berkeley, CA: Univ. California Press; 1984. 2-22.

Kay, B. L.; Leonard, O. A. Effect of blue oak removal on herbaceous forage production in the north Sierra foothills. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 323-328.

Larcher, W. Physiological plant ecology, 2nd edition. New York: Springer-Verlag; 1980. 303 p.

Major, J. Potential evapotranspiration and plant distribution in western states with emphasis on California. In: Shaw, R. H., editor. Ground level climatology. Washington, D.C.: AAAS; 1967. 93-126.

Major, J. California climate in relation to vegetation. In: Barbour, M. G.; Major, J., editors. Terrestrial vegetation of California. New York: Wiley-Interscience; 1977. 11-74.

Matyas, W. J.; Parker, I. CALVEG, mosaic of existing vegetation of California. San Francisco, CA: Regional Ecology Group, Forest Service, U.S. Department of Agriculture; 1980. 28 p + map.

McDonald, P. M. Growth of thinned and unthinned hardwood stands in the northern Sierra Nevada, preliminary findings. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 119-127.

Minnich, R. A. Wildfire and the geographic relationships between canyon live oak, Coulter pine, and bigcone Douglas-fir forests. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 55-61.

Mooney, H. A. The carbon balance of plants. Ann. Rev. Ecol. Syst. 3:315-346; 1972.

Myatt, R. G. Canyon live oak vegetation in the Sierra Nevada. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 86-91.

Pavlik, B. M. A natural history of southern California oaks. An unpublished report to the West Los Angeles County Resource Conservation District, Van Nuys, CA; 1976. 73 p.

Plumb, T. R. Response of oaks to fire. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 202-215.

Robichaux, R. Geologic history of the riparian forests of California. In: Sands, A., editor. Riparian forests of California: their ecology and conservation. Davis, CA: Institute of Ecology, publication 15, Univ. of California; 1977. 21-34.

Rundel, P. W. Adaptations of mediterranean-climate oaks to environmental stress. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 43-54.

Sands, A., editor. Riparian forests of California: their ecology and conservation. Davis, CA: Institute of Ecology, publication 15, Univ. of California; 1977. 122 p.

Sawyer, J. O.; Thornburg, D. A.; Griffin, J. R. Mixed evergreen forest. In: Barbour, M. G.; Major, J., editors. Terrestrial vegetation of California. New York: Wiley-Interscience; 1977. 359-415.

Strahan, J. Regeneration of riparian forests of the central valley. In: Warner, R. E.; Hendrix, K. M., editors. California riparian systems. Berkeley, CA: Univ. California Press; 1984. 58-67.

Talley, S. N. The ecology of Santa Lucia fir (Abies bracteata), a narrow endemic of California. Durham, NC: Duke Univ.; 1979. 209 p. Dissertation.

Thompson, K. Riparian forests of the Sacramento Valley, California. Ann. Assoc. Amer. Geogr. 51:294-315; 1961.

Thomsen, H. H. Juglans hindsii, the central California black walnut, native or introduced? Madrono 17:1-10; 1963.

Thorne, R. F. Montane and subalpine forests of the Transverse and Peninsular Ranges. In: Barbour, M. G.; Major, J., editors. Terrestrial vegetation of California. New York: Wiley-Interscience; 1977. 537-557.

Tucker, J. M. Taxonomy of California oaks. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 19-29.

USDC (U.S. Department of Commerce). Climatic summary of the United States, supplement for 1951 through 1960, California. Washington DC: U.S. Government Printing Office; 1964. 216 p.

Vankat, J. L. A gradient perspective on the vegetation of Sequoia National Park, California. Madrono 29:200-214; 1984.

Vankat, J. L.; Major, J. Vegetation changes in Sequoia National Park, California. J. Biogeogr. 5:377-402; 1978.

Vasey, M. C. Natural hybridization between two evergreen black oaks in the North Coast Ranges of California. In: Plumb, T. R., editor. Ecology, management and utilization of California oaks. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 30-35.

Vogl, R. J. An introduction to the plant communities of the Santa Ana and San Jacinto Mountains. In: Latting, J., editor. Plant communities of southern California. Berkeley, CA: California Native Plant Society, Special Publication 2; 1976. 77-98.

Wainwright, T. C.; Barbour, M. G. Characteristics of mixed evergreen forest in the Sonoma Mountains of California. Madrono 31:219-230; 1984.

Warner, R. E.; Hendrix, K. M., editors. California riparian systems. Berkeley, CA: Univ. California Press; 1984. 1035 p.

White, K. L. Structure and composition of foothill woodland in central coastal California. Ecology 47:229-237; 1966.

Whitlow, T. H.; Bahre, C. J. Plant succession on Merced River dredge spoils. In: Warner, R. E.; Hendrix, K. M., editors. California riparian systems. Berkeley, CA: Univ. California Press; 1984. 28-74.

Wiggins, I. L. Flora of Baja California. Stanford, CA: Stanford Univ. Press; 1980. 1025 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Natural Regeneration of Californian Hardwoods[1]

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Abstract: Concerns over insufficient regeneration to perpetuate hardwood species, largely based on inference from oak size distributions, have been expressed for over 75 years. During this period little progress has been made towards identifying factors which will prevent future regeneration, although favorite culprits enjoy repeated mention in the literature. Lack of information about past distribution and structure of hardwood stands limits interpretation of regeneration. Current stand structure may reflect excessive recruitment in the last century. Recent surveys have shown that patterns of past regeneration were highly species and site-specific, and probably not related to any single factor or repeated combination of factors. Regardless of the specific causes, current establishment appears insufficient to maintain current stand structure for some sites, although all major species are reproducing. Live oak species will increasingly dominate the State's woodlands under current land use if patterns persist.

Sudworth (1908) identified "the regeneration problem" for California hardwoods and pointed to several causes, including livestock grazing. Jepson (1910) repeatedly refers to a concern over the lack of regeneration for several important species. For 75 years those concerns have been repeated and added to based on observation, regional surveys, local surveys, and some experimental investigations. A common thread of these reports has been overgeneralization of the actual status of regeneration and its causes for the different species in various locations. An understanding of regeneration requires detailed information about past changes in stand structure, past successful establishment, current and future mortality in established trees, and prospects for future regeneration. Identification of causes requires an understanding of individual factors which may prevent regeneration and the complex of conditions which allows for successful regeneration.

Most studies have inappropriately focused on reproduction, not regeneration. Regeneration is a term defined in botany and zoology as the renewal or replacement of any hurt or lost organ or part. As applied to vegetation or stand, that renewal is through establishment of new individuals or resprouting of destroyed aboveground plant parts. Foresters define regeneration as either the renewal of the tree crop or the young crop itself (Arvola 1978). Reproduction, on the other hand, refers only to the process, sexual or asexual, by which animals and plants produce new individuals, and implies no tie to prior structure.

Because regeneration represents replacement of trees that have died or been harvested, assessment depends equally on information about stand structure, mortality, and reproduction. The published information on California oaks infers regeneration from the structure of existing stands, either characterizing past patterns from living older trees, or projecting future recruitment from presence of small trees. Structure of former stands, which must be known to assess regeneration, cannot necessarily be determined from present trees. It is important to note that successful reproduction, defined as the production of seedlings or seed, is not the limiting factor in establishment of new individuals for most hardwood species (Griffin 1971, Bolsinger In Press, Muick and Bartolome 1986).

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[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, California Polytechnic State University, San Luis Obispo, CA.

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Because the available literature has been recently assembled and will soon be available (Griffin, MacDonald, and Muick In Press), an exhaustive catalog of published work is not needed. Instead we analyze the regeneration problem, and suggest an approach for further investigation. This review will concentrate on Quercus regeneration under natural conditions, with few examples from other taxa.

SPATIAL AND TEMPORAL CHANGES IN VEGETATION

Spatial variability in hardwood types, from large to small scale, begins with range of the species and extends to distribution of individual trees. The descriptions of species extent (Sudworth 1908) were quite complete from the start and are currently well-documented (Griffin and Critchfield 1972). Descriptions of the vegetation types containing hardwoods have been common (e.g. Munz and Keck 1949), and have included classification, description, and mapping (e.g. Küchler 1977). Because the vegetation typing involves broad definitions of characteristics, the extent of these types is little affected by regeneration in the short-run.

Historically, the structure of hardwood stands in California has undoubtedly changed, but changes have not been well-documented. We do not know, for example, if hardwood stands are presently of higher or lower density than historically, because the available sources of information, current stand structure, only consist of survivors. Obviously, where cutting was present, stumps indicate higher prior density (White 1966) unless they have been overgrown by sprouts. The probable widespread clearing for agricultural purposes which centered on the Valley Oak (Quercus lobata Nee) (Griffin 1976) leaves no direct evidence once the stumps are removed.

The extent of presettlement oak types remains subject to speculation and criteria for interpretation. Although blue oak (Quercus douglasii H&A) occupied the Sierran foothills by 5 million years ago (Axelrod 1977), its post-glacial and pre-settlement distribution is unknown. Widespread clearing of oaks beginning in the mid-19th century undoubtedly altered the extent of the woodlands. The lack of good information on historical distribution limits the evaluation of regeneration status. If current coast live oak (Quercus agrifolia Nee) woodlands, for example, have few saplings in southern California (Muick and Bartolome 1986), does this lack of small trees reflect a long-term change in stand structure, or is it related to current stand density? Without better information about the historical changes in oak types, little use can be put to information about natural regeneration in relation to maintenance of natural stand structure.

Recent changes in extent of hardwood types have been described by Bolsinger (In Press). By comparing his data from 1981-1984 to previous inventories he determined that area occupied by hardwoods on rangeland (savannas and woodlands) decreased by over 1 million acres since 1945. He claims that most of this decrease was due to clearing for rangeland improvement. During that same period, hardwoods in commercial forest lands increased by 400,000 acres due to increases following logging, and primarily in tanoak (Lithocarpus densiflora (H&A) Rehd.) and madrone (Arbutus menzesii Pursh.). More recently-- in the approximately 10 years prior to 1981-- over 100,000 acres of blue oak, and lesser amounts of other types were converted to "non-forest" (Bolsinger In Press). Because these conversions rarely remove all oaks, these acreage changes probably do not reflect changes in overall geographic range of oak distributions.

Historical changes in stand density were poorly documented prior to European settlement, but several studies have used stand age or stand size structures to infer past changes. Usually workers have assumed that apparently low regeneration was resulting in decreasing stand densities (Baker, et al 1981). This assumption was a major factor motivating the Hardwood Task Force (Mayer, et al 1986) and led to detailed investigations of the status of regeneration of oak species and other hardwoods (Muick and Bartolome 1986, Bolsinger, In Press).

A major source of misinformation on hardwood regeneration has been overextension of the limited information available from stand size distributions (McClaran 1986). Stand age information, although limited in utility because it provides data only on a single point in time, does contribute to the framework which allows identification of causes. Because of the difficulties in obtaining cores to age oaks, most of our information about stand structure has been based on inferences from size distributions. However, size-based information is even less valuable, because age-size relationships for oak species are only moderately correlated (McClaran 1986). At best, size structure information can only point to possible avenues for investigation, although it can be a starting point.

Current stand size structure varies considerably by species. Statewide, Valley and blue oaks have apparently established infrequently during the last 50 years, based on present size and age structure. The widespread presence of sapling sized Interior

(Quercus wislizenii A. DC) and Canyon (Q. chrysolepis Liebm.) live oaks indicate apparent recent establishment. Coast live oak stands in the north contain more small trees than stands in the southern portion of the species' range (Muick and Bartolome 1986). Black oak (Quercus kelloggii Newb.), tanoak, madrone, and bay (Umbellularia californica (H&A) Nutt.) show signs of recent establishment through presence of small trees (Bolsinger In Press), and Tanoak and madrone have expanded in range. Bay shows evidence of recent establishment, and in the San Francisco Bay Area is replacing coast live oak (McBride 1974). Bolsinger lists all other important hardwood trees as regenerating well, based on the presence of saplings in his survey plots, with the exception of Fremont Cottonwood (Populus fremontii Wats.).

The statements above are tentative with respect to regeneration, because the current stand structure only represents presently live trees and does not address mortality. Present size distribution of individuals, whether it be size or age based, does not tell us of previous stands. All we know is that live trees established at some time in the past. Where the majority of individuals are from sprouts, we cannot determine when initial establishment occurred. Thus, for example, the widely postulated lack of blue oak regeneration in the past 60-100 years (White 1966) is probably an accurate generalization but whether or not such episodes occurred previously is unknown because of the few survivors from those older stands. The regeneration episode may have created excessively stocked stands which subsequently have provided little opportunity for recruitment.

Mortality rates for hardwood species, even under present conditions, are not known, although Bolsinger (In Press) suggests that for blue oak, mortality is about 0.3 percent per year. This suggests that in a stand of 600 trees per hectare establishment of an average of 1.8 trees per year would be adequate to replace mortality. If this establishment were episodic, say every decade, only 18 trees would need to establish in a hectare in that favorable period. Oaks are generally long-lived, with individuals living to several hundred years. Snow (1973) counted 345 rings in an Engleman oak (Quercus englemannii Greene) and 245 rings in a coast live oak. McClaran (1986) reported counting over 400 rings in a blue oak cut in the central Sierra Nevada. One of us (Muick) has counted over 400 rings in a Valley oak stump. Based on size structures, most stands contain many individuals which are between 100 and 200 years old, but few very old trees. This suggests either that many trees died without a trace or that stands have become markedly more dense in the last few centuries. Knowledge of the longevity and mortality rates of individual oak species is obviously critical to determining the long-term replacement rates necessary to maintain current densities.

FACTORS ASSOCIATED WITH SUCCESSFUL REGENERATION

Muick and Bartolome (1986) looked at the identifiable factors associated with presence of small trees in oak stands and found regional variations in regeneration. Blue oak stands contain more small trees at higher elevations. Coast live oak stands in the north are more likely to have small trees than those in the south. These observations are consistent with those of Griffin (1976), who noted that Valley oaks in the Santa Lucia Mountains were regenerating some at higher elevations, but not in savannas. Stand structure in mixed live and deciduous oak stands suggest that live oaks will increasingly dominate. Because this information is based on size-structure and because the amount of regeneration necessary to perpetuate stands is unknown, these data can at best indicate only potential regeneration status.

McClaran (1986) found differences in age distribution between two blue oak stands in the northern Sierra which probably related to different human impacts from fuelwood cutting and from altered fire frequencies. The area nearer a mining settlement contained no old trees. Most of the regeneration was sprouts associated with natural and recent human-caused fires although trees originating from acorns were also common.

Small-scale variations in site are associated with successful establishment. Snow (1973) found that rock outcrops were associated with apparent regeneration of coast live oak in the Santa Rosa Plateau, but that live oak appeared not to be influenced by outcrops in a grazed savanna. Muick and Bartolome (1986) found that valley and blue oak saplings were more common at canopy edges than under canopy or in open grassland. This association ties in with the observations of Griffin (1971) that seedling survival of blue and valley oak was higher in shade. This pattern of sapling distribution has significant implications for identification of factors associated with regeneration and also for management. The influence of mature parent tree cover on regeneration should help managers determine the impacts of individual tree removal. Other small-scale site characteristics have been poorly investigated in relation to regeneration. Although, for example if the proposed interference with establishment by European annuals (Griffin 1980) turns out to be important, then small-scale site differences should be important.

CONCLUSIONS AND RECOMMENDATIONS FOR RESEARCH

Determination of causes for regeneration failure and for successful establishment should not necessarily require the same approach. Once regeneration status is determined we can look for historical coincidences if stand age information is specific enough to allow this approach. However, it is unlikely that such coincidences will be apparent. First, the stand age information is either lacking or not very accuratly tied to specific years of establishment. Second, if trees die after initial establishment, they will not be detectable in the stand, thus dates and causes for mortality are not likely to be found.

Because the causes of lack of establishment can be a single event, these factors are not likely to be regionally uniform. For example, browsing by livestock and wildlife is frequently described as an important factor related to regeneration (Griffin 1980, Bolsinger In Press, Muick and Bartolome 1986). But patterns of livestock and wildlife browsing pressure are likely to vary considerably from place to place, even within stands (McClaran 1986). Some sites without livestock grazing for decades have shown no new establishment (Duncan and Clawson 1980). Grazing can prevent regeneration but removal of grazing does not always produce recruitment. Small mammals have been proposed as the most important herbivores preventing regeneration (Griffin 1980).

Other factors associated with lack of regeneration also likely will vary almost with the site of each individual. Conditions which have allowed past regeneration are more likely to show regional patterns associated with current stand age structures, at least for recent, post European settlement events. Favorable weather patterns have been proposed as a prerequisite for successful regeneration (Griffin 1971). Species like blue oak and coast live oak are regenerating more successfully in moister climates (Muick and Bartolome 1986) and in shadier, presumably more mesic sites (Griffin 1976). Other likely candidates are changes in livestock numbers (McClaran 1986), lowered deer populations due to market hunting (Griffin 1971), and fuelwood cutting which favors sprouting (McClaran 1986). Little investigated, but important for oak regeneration in the foothills is fire frequency. McClaran (1986) found most blue oak regeneration within one year of fires over the past 300 years at two sites along the Yuba River.

Detailed information about temporal changes associated with regeneration consist of a few stand age studies from a few sites. These studies suggest little recent establishment for blue oak and, from one site, some recent establishment of coast live oak but little recent establishment of Engleman oak. However, because these and size-based studies cannot reveal past mortality or past stand structures, the regeneration status is not fully apparent. We do not know how much establishment is needed for regeneration of present stand structure, nor whether past patterns included periods without establishment prior to most recent establishment. Perhaps present patterns of stand age represent excessive regeneration following disturbances since settlement.

If size structure is included, information for more sites and for more species is added. However, size structures are not adequate to accurately predict ages. Although correlation between size and age in oaks is statistically significant, this correlation is inadequate to determine most of the details of stand age necessary to assess regeneration. The lack of small trees can be used as an indicator suggesting a lack of recent establishment. Seedlings of the species suspected of a lack of regeneration are generally ephemeral, and thus their presence is not indicative of successful recruitment.

Cycles in regeneration will remain a persistent problem in assessment. If past regeneration was cyclic, then we only have information about the most recent episode, which is associated with disruption of many factors which could influence establishment. For some sites, stands may be overstocked from this recent episode, and lack of recent recruitment is the expected outcome, but new individuals are presently unnecessary for regeneration.

Spatial changes in hardwood stands under natural conditions remain speculative. Even changes in present stands are largely based on conjecture. Although clearing and cutting of hardwoods obviously exists and land has continued to be affected since 1945, the nature and extent of hardwood types prior to that date are only sketchily understood, and extent and structure prior to 1850 are unknown. The suggestion (Griffin 1977) that the boundaries of the oak woodland have remained relatively stable is still unsupported.

Factors affecting regeneration, including historical and present land use status, likely will vary considerably by species and by site. It is unlikely that the same factors will affect establishment over wide areas and over several species. Regional differences, which suggest some general influences, include the better regeneration of blue oak in wetter areas and the better apparent regeneration of coast live oak in the north compared to the south. Even if environmental factors are investigated, generally work has suffered from a lack of proper temporal perspective on regeneration, particularly an explicit understanding of how past stand structure affects the need for recruitment. The factors presently limiting establishment seems to be grazing in many locations, although it is difficult to see how establishment was successfully accomplished under natural conditions.

Better regeneration information requires a redirection of research in hardwood ecology and management. Detailed information about the current status of regeneration for the several key species in different locations is required. The information about stand age essential for assessing regeneration status needs work. Answering the other half of the regeneration question, the loss of individuals which crate the need for replacement, will be more difficult. First is the need for better information on general distribution of the types, especially prior to human influence. Next, information is required about stand structure and changes in density both under natural conditions and since settlement. This information can perhaps come from assessment of historical accounts of stand structure, succession studies which may help to provide insight into past vegetation change, and the use of macro and micro fossils to asses prior stand extent. None of these techniques allow much room for optimism. Unless better information is available on natural stand dynamics, more information about current establishment and the factors controlling this process will not produce a solution to the still poorly defined regeneration problem.

Factorial experiments with several hardwood species under conditions reflecting several types of sites are badly needed. The factors which appear most likely to reward investigation are those associated with grazing and how present canopy structure and the local site potential affect understory environment for recruitment. The inconclusive results to date most often implicate grazing as an important impediment to regeneration. Since regeneration surveys have shown an association between canopy and apparent establishment, the environmental effects of the canopy on establishing seedlings need investigation. Unlikely to be important general factors are acorn production and predation, climatic change, and competition with herbaceous species. Pathogens remain unexplored.

Given the problems in assessing natural stand structure and factors influencing regeneration, the best approach to managing regeneration where it is a problem appears to consist of three steps. These steps have little relationship to the previous research into existing stand structures and factors which may have prevented past recruitment. First determine an appropriate range of desired stand structures. Next manipulate the environmental factors to create a favorable environment for any needed recruitment. This can be done, although for some sites and some species the degree of technical intervention will not be acceptable. Third, monitor changes in stand extent and structure and take further action as needed, placing emphasis on planning the future of hardwoods, not their past.

LITERATURE CITED

Arvola, T.F. 1978. California forestry handbook. State of Calif. Dept. For., Sacto. 233p.

Axelrod, D.I. 1977. Outline history of California vegetation. In: Barbour, M.G. and J. Major (eds.) Terrestrial vegetation of California. New York: Wiley Interscience pp.137-187.

Baker, G.A., P.W. Rundel, and D.J. Parsons. 1981. Ecological relationships of Quercus douglasii (Fagaceae) in the foothill zone of Sequoia National Park, California. Madrono 28: 1-12.

Bolsinger, C.L. (In Press) The hardwoods of California timberlands, woodlands, and savannahs. Portland, U.S.D.A., For. Ser. Res. Pap. PNW--

Duncan, D.A. and W. J. Clawson. 1980. livestock utilization of California's oak woodlands. In:T.R. Plumb (Tech. Coor.) Proceedings of the symposium on the ecology, management, and utilization of California oaks. Berkeley, U.S.D.A., For. Ser. Tech. Pap. PSW-44. pp306-313.

Griffin, J.R. 1971. Oak regeneration in the upper Carmel Valley, California. Ecology 52:862-868.

Griffin, J.R. 1976. Regeneration in Quercus lobata savannas, Santa Lucia Mountains, California. Am. Midl. Nat. 95:422-435.

Griffin, J.R. 1980. Animal damage to valley oak acorns and seedlings, Carmel Valley, California. In: T.R. Plumb (Tech. Coor.) Proceedings of the symposium on the ecology, management, and utilization of California oaks. Berkeley, U.S.D.A., For. Serv. Gen. Tech. Rep. PSW-44. pp:242-245.

Griffin, J.R. and W.B. Critchfield. 1972. The distribution of forest trees in California. Berkeley, U.S.D.A., For. Ser. Res. Pap. PSW-82.

Griffin, J.R., P.M. McDonald, and P.C. Muick. (In Press). California oaks--a bibliography. Berkeley, CA: U.S.D.A. For. Serv., Gen. Tech. Rep. PSW-96.

Jepson, W.L. 1910. The Silva of California. University of Calif. Memoirs 2: 1-480.

Kuchler, A.W. 1977. The map of the natural vegetation of California. In:M.G. Barbour and J. Major (eds.) Terrestrial vegetation of California. NY: Wiley Interscience pp909-938.

Mayer, K.E., P.C. Passof, C. Bolsinger, W.E. Grenfell, Jr., and H. Slack. 1986. Status of the hardwood resource of California: a report to the Board of Forestry. Calif. Dept. For., Sacto. 126p.

McBride, J.R. 1974. Plant succession in the Berkeley Hills, California. Madrono 22:317-329.

McClaran, M.P. 1986. Age structure of Quercus douglasii in relation to livestock grazing and fire. Ph. D. Diss. Univ. Calif., Berkeley. 119p.

Muick, P.C. and J.W. Bartolome. 1986. Statewide oak regeneration survey. Report to Calif. Div. For., Sacto, CA. 100p.

Munz, P.A. and D.D. Keck. 1949. California plant communities. El Aliso 2:87-105, 199-202.

Snow, G.E. 1972. Some factors controlling the establishment and distribution of Quercus agrifolia Nee and Q. engelmannii Greene in certain southern California oak woodlands. Ph. D. Diss. Oregon State Univ., Corvallis, OR. 150p.

Sudworth, G.B. 1908. Forest trees of the Pacific slope. U.S. For. Serv., Wash. DC 441p.

White, K.L. 1966. Structure and composition of foothill woodland in central coastal California. Ecology 47:229-237.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Mixed Evergreen Forest Stands in the Northern Sierra Nevada[1]

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ABSTRACT: Forest stands similar to the Coast Ranges' mixed evergreen forest occur in the northern Sierra Nevada. Declines in evergreen hardwood importance in both areas are related to increasing total stand basal area, which may reflect a gradient of site moisture availability. Deciduous hardwoods do not follow this pattern, but their total stand importance is generally low. The hardwood to conifer transition in dominance occurs at greater total stand basal areas in coastal stands, probably reflecting the more moderate coastal climate favorable for evergreen hardwood growth.

Many of California's hardwoods occur on sites which support several species of both hardwoods and conifers. If we are to understand the ecology of hardwoods and manage them wisely, we cannot ignore the ecological relationships between hardwoods and conifers. California's mixed evergreen forest provides an array of associations where one can study these relationships and the contribution of conifers, evergreen hardwoods and deciduous hardwoods to vegetation patterns.

Sawyer et al.(1977) and Whittaker (1960) describe the composition of mixed evergreen forest of California's Coast Ranges. Principal conifer species are Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco.) and ponderosa pine (*Pinus ponderosa* Lawson), with sugar pine (*Pinus lambertiana* Dougl.) and white fir (*Abies concolor* (Gord. & Glend.) Lindl.) of less importance. Coast redwood (*Sequoia sempervirens* (D. Don) Endl.) is regionally important in North Coast stands. Principal hardwood species are canyon live oak (*Quercus chrysolepis* Liebm.), California black oak (*Quercus kellogii* Newb.), Pacific madrone (*Arbutus menziesii* Pursh.) and tanoak (*Lithocarpus densiflorus* (H. & A.) Rehd.). California bay (*Umbellularia californica* (H. & A.) Nutt.) can be locally important, and coast live oak (*Quercus agrifolia* Nee.) is regionally important in South Coast stands.

Tree species common to the mixed evergreen forest of California's Coast Ranges are also found in the Sierra Nevada (Griffin and Critchfield 1976). Gray (1978) studied the conifer-hardwood vegetation of south facing slopes in the northern Sierra Nevada along an elevation gradient, and compared this to the vegetation of a Coast Range site. Recent studies have addressed the stand development (Tappeiner and McDonald 1983) and competitive importance (Stone 1984) of hardwoods within the Sierran mixed conifer zone (Rundel et al. 1977). However, little quantitative stand data has been published for most mixed evergreen forest associations. Little is known of the composition and structure of hardwood dominated stands in the northern Sierra Nevada or how these stand characters change with increasing conifer dominance. These stands may be important for wildlife, watershed protection, and as fuelwood resources (Plumb 1979). Also, because of the hardwoods' association with commercial conifers and the increasing urbanization pressures in these areas, it is important to understand the ecological importance of hardwood and conifer-hardwood stands before they are heavily disturbed. Some studies have addressed these points for coastal mixed evergreen forest stands (see Sawyer et al. 1977, Plumb 1979), but the recognition of similarity between coastal and Sierran conifer-hardwood stands has been slight (e.g. Sawyer et al. 1977 p.371 & Griffin and Critchfield 1976 p.9).

This paper aims to fill some of the lack of quantitative stand data for California's conifer-hardwood mixtures, and relate vegetation parameters of these stands to environmental variables. We describe tree species composition and abundance of some low elevation, north facing mixed evergreen forest stands in the northern Sierra Nevada, along a transition from hardwood to conifer dominance. This information is compared to results from a study of coastal mixed evergreen forest (Wainwright and Barbour 1984).

METHODS

Study Site

Nine forest stands in the Yuba River drainage of the northern Sierra Nevada mountains (N39° 25′, W121° 07′) were subjectively chosen to encompass a wide range of hardwood importance. Three stands each were chosen by the South Yuba River, the Middle Yuba River, and the New Bullard's Bar Reservoir (North Yuba River), all of similar age (90-105 yr.) and showing little recent disturbance. All stands are on north facing slopes; these sites are richest in tree species and are comparable to coastal sites in their closed canopies and tree compositions. Surface

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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fires and broken topography are common in this region (Rundel et al. 1977), but stands were selected which were relatively homogeneous for >1 hectare (ha). These are thought to be representative of mesic conifer-hardwood stands in this area.

Climatic data for Nevada City (8 to 20 km south of the stands) show 30 yr mean annual precipitation of about 140 cm and total mean annual snowfall of 46 cm (National Oceanic and Atmospheric Administration 1985). January mean daily minimum temperatures are -1 to -3°C and July mean daily maximum temperatures are 30-32°C. Soils are generally well drained loams to cobbly clay loams formed over metasedimentary or metabasic rock (South and Middle Yuba stands; Brittan 1975) or over granitic rock (Bullard's Bar stands; Herbert and Begg 1969). Coastal stands of similar latitude (Wainwright and Barbour 1984) have a drier and more moderate climate: mean annual precipitation is 71-77 cm, snowfall is rare, January mean daily minimum temperatures are 2-3 °C and July mean daily maximum temperatures are 28-29 °C. Soils of Wainwright and Barbour's (1984) study were mostly loams to clay loams formed over volcanics.

Field Methods

The rangefinder/prism method (Lindsey et al. 1958) provided data on basal area and density for tree species. Each stand was sampled at ten points arranged in two parallel 100m line transects, with five equally spaced points each. Transect lines were 25m apart and perpindicular to slope contours. Each transect began at a random point >25m within stands.

At each of the ten sampling points in a stand, trees taller than 0.5m but less than 5cm diameter at breast height (dbh) were counted on a $10m^2$ circular plot; trees >5cm dbh were counted by 20cm dbh size classes on a $100m^2$ circular plot at each point. A prism (English BAF 10) was used for basal area tallies by species at each sampling point. These tallies were done at breast height. Crown closure estimates were made with a modified "moosehorn" (Garrison 1949), which projects one's view vertically through a grid of points. The number of points which intercept the forest canopy is proportional to the degree of canopy closure. No significant differences in average canopy closure were found between stands. Data on cover of herbs, shrubs and trees <0.5m tall are not described here.

RESULTS

Tree composition and stand structure of the Northern Sierran stands is similar to that described by others (Whittaker 1960; Sawyer et al. 1977; Wainwright and Barbour 1984) for coastal mixed evergreen forest. A summary of site features and tree composition for each Sierran stand is provided in table 1. Stands are listed in order of increasing total stand basal area (BA).

TABLE 1. STAND SUMMARY. For site features, S refers to South Yuba River, M to Middle Yuba River, and B to Bullard's Bar stands. Density (# ha^{-1}) is of stems >5cm dbh. Basal area (m^2 ha^{-1}) is stand total. For tree composition, upper figure is basal area, middle figure is density of stems >0.5m tall and <5cm dbh, and lower figure is density of stems >5cm dbh.

Stand:	S1	S2	M1	S3	B1	B2	M2	M3	B3
Elevation (m):	500	410	550	460	670	640	490	550	690
Slope (pct.):	24	47	38	29	27	21	26	31	13
Aspect:	NNW	NE	N	NNW	N	NNE	NNE	NNW	N
Density:	770	720	670	860	1170	590	1150	730	1290
Basal Area:	26.2	27.3	27.5	33.9	35.1	36	37	38.6	39.6
HARDWOODS:									
Umbellularia	0.2								
californica	600								
	40								
Acer	0.7	0.5	2.3			1.3			
macrophyllum	0	0	300			0			
	80	30	60			10			
Quercus	4.6	8.5	5.5	5.7			1.8	6.7	
chrysolepis	900	1100	100	1600			300	200	
	200	310	200	240			90	120	
Arbutus	13.1	6.0	5.0	7.3	9.9	2.3	6.2	1.4	0.7
menziesii	0	0	100	600	0	0	0	100	0
	260	90	80	230	310	20	220	60	30
Quercus	4.4	8.0	7.6	6.4	4.1	2.0	6.7	1.8	8.3
kellogii	0	100	0	100	0	0	0	0	0
	180	140	120	90	70	10	180	20	110
Cornus			0.5		2.1	2.0	0.7	1.4	0.9
nuttallii			300		400	300	400	100	100
			10		130	120	80	30	110
Lithocarpus			1.1		2.5	7.9			1.1
densiflorus			100		2500	3500			1100
			40		220	220			130
Hardwood BA:	23.0	23.0	22.0	19.4	18.6	15.5	15.4	11.3	11.0
CONIFERS:									
Calocedrus	2.5	0.9	0.7	12.2	6.9	1.8	5.3	3.4	2.3
decurrens	0	300	200	0	300	300	0	0	100
	10	20	50	290	130	20	250	150	130
Pseudotsuga		3.4	4.6		8.0	16.6	13.3	21.8	24.3
menziesii		0	200		800	0	700	1100	300
		130	110		280	170	320	340	720
Pinus	0.7			2.3	1.6	0.3	3.0	2.1	0.9
ponderosa	0			0	0	0	0	0	0
	0			10	30	0	10	10	10
Abies			0.2			1.8			0.2
concolor			0			0			400
			0			20			50
Pinus									0.9
lambertiana									0
									0
Conifer BA:	3.2	4.3	5.5	14.5	16.5	20.5	21.6	27.3	28.6

Along this sequence of total BA, stand composition changes from an oak-madrone association, to Douglas fir-incense cedar, Douglas fir-tanoak, and Douglas fir-oak associations. These groups are similar to those described by Sawyer et al.(1977) and Wainwright and Barbour (1984) for north coast mixed evergreen forest types, except for the presence of incense cedar.

The Sierran stands are notably different in tree species composition from the coastal stands in the absence of coast redwood and coast live oak, the sparsity of California bay, and the widespread occurrence of incense cedar in the Sierran stands.

A Gradient

The order of increasing total stand BA is also the order of decreasing hardwood absolute and relative BA. Hardwood relative densities almost exactly match this sequence, and absolute densities less so. The sequence of hardwood importance is not strongly related to other single environmental or vegetation parameters, but total stand BA is related to a combination of increasing site elevation, declining slope steepness, increasing density, and aspect oriented toward NNE (multiple $r^2=0.47$; $p<0.05$). Conifers overwhelmingly account for the increase in total stand BA in both regions (Yuba $r^2=0.97$; Sonoma $r^2=0.94$), and Douglas fir accounts for most of this conifer trend (Yuba $r^2= 0.82$; Sonoma $r^2=0.91$).

Total stand BA is an integration of many environmental and biotic factors including moisture availability, disturbance history, age of stand, and growth characteristics of the trees. However, soil moisture is probably most influential here. There is a general increase in stand elevation and decrease in slope steepness along the Yuba stand sequence of increasing BA. Cores of several conifers and hardwoods revealed little difference in ages of large trees among stands (90-105 yrs). These ages are similar to those reported by Tunison (1973) for the Sonoma study area. Natural disturbance patterns are probably very similar for the stands, or vary mostly with site moisture availability. Therefore, the sequence of increasing stand BA likely reflects mostly a gradient of increasing soil moisture availability. Conifers and hardwoods are responding differently to this gradient, and are influencing each other in their responses.

In the Yuba River stands, hardwood relative BA shows a stronger relation to total BA than does hardwood relative density (fig. 1A,B). Data from 10 stands of mixed evergreen forest in Sonoma County (Wainwright and Barbour 1984) reveal similar trends over the same range of total BA, but show a continuation of hardwood importance at high total stand BA not shown by the Yuba data (fig. 1A,B). Conifers contribute the remaining BA and density in both regions (their complementary relative BA and relative density lines are not shown). The increase in relative density of hardwoods at high stand BA on the coast largely accounts for the continued importance of hardwoods in conifer dominated stands there. In both regions, BA and density patterns of individual tree species along this sequence are usually more sporadic than for ecological groups (see table 1), though sample sizes are small.

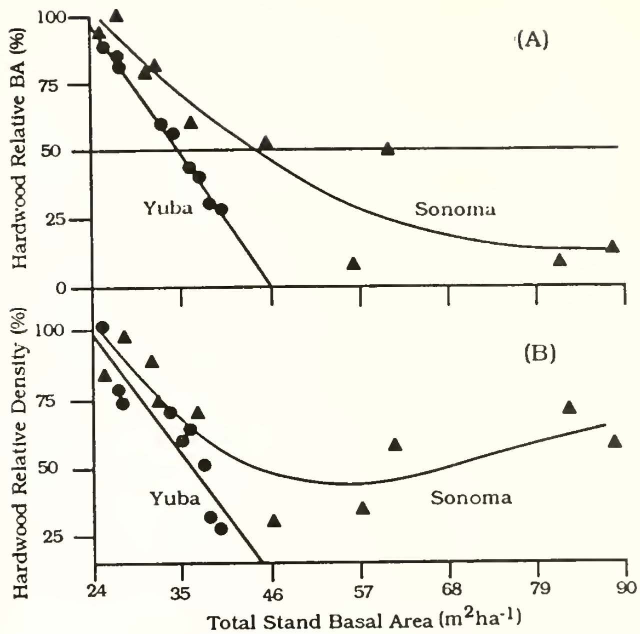

FIGURE 1. Hardwood relative basal area (A) and relative density (B) as they change with total basal area of the stand, in the Yuba and the Sonoma study areas. Yuba data points (circles) are means of ten samples per stand; Sonoma data points (triangles) are means of 1-3 transects per stand.

Hardwood Basal Areas

Hardwood basal area and relative basal area decline with increasing total stand basal area (Fig. 1A). The Yuba hardwood decline in basal area is steeper than the Sonoma decline and is a stronger relationship. The drop in hardwood relative BA with increasing stand BA is 2 to 5 fold less than the complementary increase in conifer relative BA.

Yuba hardwood absolute BA decline is highly negatively correlated with the gradient of increasing total stand BA ($r=-0.94$; $p<0.01$). The Sonoma hardwood BA relationship is linear only at lower stand BA. In the Yuba data set, an approximate increase in conifer BA of $1m^2$ ha^{-1} is accompanied by a hardwood decrease of 0.7 m^2. The Sonoma tradeoff is not as great when the entire sequence is considered: there is ~0.3 m^2 ha^{-1} drop in hardwood BA with each 1 m^2 conifer BA increase. Relative BA of conifers exceeds 50% at a greater total stand BA in the Sonoma than the Yuba stands (45 vs. 35 m^2 ha^{-1}), but drops to near zero at about the same total stand BA (25-26 m^2 ha^{-1}). Conifers apparently do not become important in stands of these areas unless the sites can support >25m^2 ha^{-1} by these stand ages. Also, hardwoods dominate coastal stands to higher total stand basal areas than in the Sierras.

Sierras

For the Yuba stands, evergreens account for much of the drop in hardwood absolute BA (evergreens vs. all hardwoods r^2=0.77; p<0.01). Pacific madrone has the highest correlation with the trend in stand BA (r=-0.62; p<0.10), followed by canyon live oak (r=-0.56; p<0.10). Pacific madrone accounts for 66% (r^2=0.66; p<0.01) of the variation in evergreen BA, possibly followed by canyon live oak (r^2=0.22; not statistically significant, ns).

Yuba deciduous hardwoods show no statistically significant trend in absolute BA along the sequence of increasing total stand BA. Their contribution to stand importance is generally low. However, trends in deciduous BA may be a response to a different gradient, possibly light associated with canopy gaps, or edaphic factors. The pattern in deciduous BA is accounted for by black oak (r^2=0.79; p<0.01); big leaf maple and Pacific dogwood show little pattern in basal area along a sequence of deciduous BA in this study.

Coast

For the Sonoma stands, trends were analyzed over the entire sequence of total stand BA. The hardwood trend along this sequence is nonlinear, but is similar to the Yuba trend at lower stand BA (fig. 1A). Evergreen hardwoods as a group account for 33% (r^2=0.33; p<0.10) of the hardwood decline and deciduous hardwoods show no trend along this sequence. Of the evergreens, Pacific madrone appears to be of highest importance in the total hardwood decline with increasing total stand BA, followed by coast live oak at low stand BA and bay at higher stand BA (r^2=0.14 for madrone (ns); less for others). Within the evergreens, coast live oak is responsible for the drop in evergreen BA (r^2=0.46; p<0.05), possibly followed in importance by madrone, then bay.

Hardwood Densities

Hardwood densities and relative densities also drop with increasing stand basal area in both regions (Fig. 1B). As with basal areas, the Yuba decline is steeper than the Sonoma decline. The Sonoma relationship is nonlinear, but is similar to the Yuba trend over the lower range of stand basal areas. Hardwood density values provided by Wainwright and Barbour (1984) include all trees >1m tall. The Yuba relationship is weakened when small trees (>0.5 m tall and <5cm dbh) are included in the Yuba data set. When this smaller size class is eliminated and only trees >5 cm dbh are evaluated, the Yuba hardwood relative density relationship becomes linear (r^2=0.79; fig. 1B).

Sierras

Evergreens account for 83% (r^2=0.83; p<0.01) of the trend of total hardwood decline in absolute density of trees >5cm dbh. Pacific madrone has the highest correlation to the evergreen contribution (r^2=0.73; p<0.01), possibly followed by canyon live oak (r^2=0.15; ns). Black oak comprises most of the deciduous trend (Black oak vs. deciduous hardwoods r^2=0.59; p<0.05), possibly followed by big leaf maple (r^2=0.16; ns).

Coast

Overall, Sonoma hardwood absolute density declines with increasing stand BA. The following results apply to trends over the entire sequence of stand BA, though the Sonoma hardwood trend is nonlinear. Evergreens contribute most of the response of declining hardwood density (evergreens vs. total stand BA r^2=0.32; p<0.10). Deciduous hardwoods, as a group, may contirbute half this amount to the trend (r^2=0.16; ns). California bay accounts for 48% of the evergreen density pattern, but madrone is more highly correlated to total stand density (r^2=0.44 for madrone vs. 0.15 for bay), and may comprise a large share of the evergreen pattern (r^2=0.29; ns). Again,, again black oak is responsible for the pattern of deciduous hardwoods, (r^2=0.88; p<0.01), but the trend was not found related to a gradient of stand BA and deciduous hardwood contibution to stand structure is often minor.

Size Class Distributions

Size hierarchies in a stand are important to species interactions, and provide clues to the course of stand development. Densities by size class for major Yuba hardwoods and conifers are presented in figure 2. Data are grouped from all

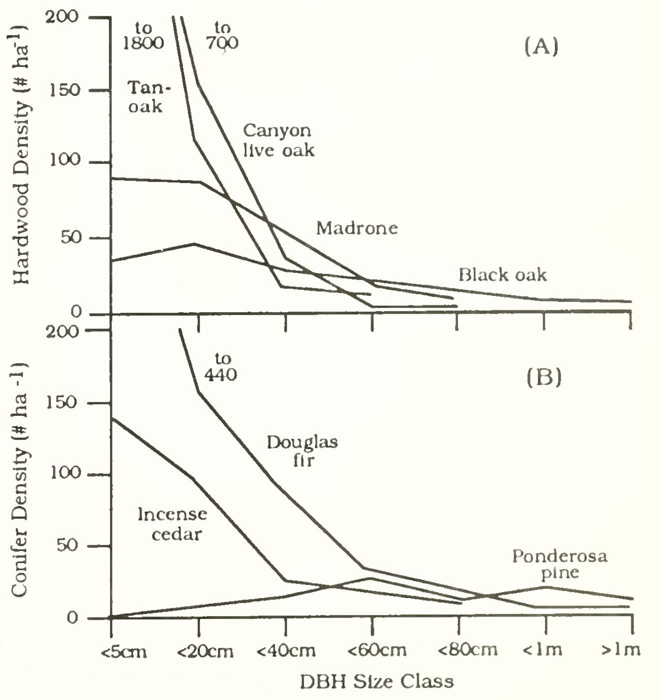

FIGURE 2. Size class distributions for hardwoods (A) and conifers (B) in the Yuba study area. Values are averages for all stands in which a species was sampled. Minor species are not shown.

stands, and so provide only a general pattern for stands in this area. Recruitment into larger size classes and canopy dominance change along the sequence of increasing conifer importance (table 1.).

Douglas fir dominates the larger size classes and shows high recruitment into larger size classes, though this is sporadic among stands (see table 1). Canyon live oak and tanoak recruitments are high, but also sporadic. Neither black oak, madrone, nor ponderosa pine recruitment appear adequate to sustain their numbers in larger size classes, and this may reflect early stand establishment and episodic regeneration. Incense cedar recruitment is low, but it is shade tolerant and the smaller trees may mostly represent advance regeneration.

DISCUSSION

In summary, tree species composition is similar for coastal mixed evergreen stands and stands of some low elevation northern Sierra Nevada conifer-hardwood sites. Changes in species composition with increasing stand BA is similar between the study areas, also.

As stand BA increases, conifers - primarily Douglas fir - in both the Yuba and Sonoma study areas constitute the majority of BA increase, and hardwood BA declines. Madrone and black oak are important in both areas; canyon live oak is important in the Sierran stands and coast live oak is important in the coastal stands. The hardwood trend of declining BA and density is stronger and steeper in the Sierras, and evergreens account for most of this. Deciduous hardwoods cannot be grouped for this trend on the coast; their total stand contribution is minor, but they may be responding to a different gradient than that reflected by increasing stand basal area, e.g. disturbance.

Site moisture availability is probably largely responsible for the trend of increasing stand BA. Hardwoods can attain large growth in hardwood stands of these ages and their drop in absolute basal areas and densities implies a suppression of growth by conifers. Conifers become important on sites in these two study areas when stands can produce a total stand basal area of >25 m^2 ha^{-1} by these ages (90-105 yrs), and conifers dominate stands over 35 m^2 ha^{-1} (Yuba) to 45 m^2 ha^{-1} (Sonoma) total BA. Further research is needed on the influence of conifers upon hardwood growth.

The differences between Coastal and Sierran study areas and species groups are likely a result of many factors. Human and natural disturbance influence both regions and cloud the picture; successional status is likely important, but not well known; stand ages between the areas may differ enough to contribute to the more gradual decline in hardwoods on the coast; and Douglas fir and coast redwood attain very large sizes on the coast, producing high stand BA at low densities. The more moderate coastal climate probably underlies the differences between regions, allowing evergreen hardwoods to persist in conifer dominated-high stand BA sites on the coast where they drop out in the Sierras, probably because of the cooler winter temperatures or heavier snowfall.

Despite these differences, tree composition and stand structure are similar between coastal and Sierran stands. Also, the importance of some species can be directly related to total stand BA in similar ways in the two study areas. For these reasons, we prefer to call these Sierran conifer- hardwood stands part of California's diverse mixed evergreen forest. Further research is needed on the response of individual species of this forest to environmental gradients and competition, and the importance of these stands to wildlife, watershed protection, and fuelwood use.

Acknowledgements: The senior author is grateful for the support of an Ecology Graduate Fellowship (1984-86) and Research Award (1984-85) by U.C. Davis during this study, and travel expenses by the Botany Department, U.C. Davis.

REFERENCES

Brittan, Lynn A. Soil survey of Nevada County area, California. Soil Conservation Service, Washington D.C. 1975 August. 105p +ill.

Garrison, G. A. Uses and modifications for the "moosehorn" crown closure estimator. J. Forestry 47: 733-735. 1949.

Gray, John T. The vegetation of two California mountain slopes. Madroño 25(4): 177-185. 1978 January.

Herbert, Fred W. jr.; Begg, Eugene L. Soils of the Yuba area, California. UC Cooperative Extension and County of Yuba.1969 June. 170p. ill.

Lindsey, Anton A.; John D. Barton jr.; S.R. Miles. Field efficiencies of forest sampling methods. Ecology 39(3): 428-444. 1955.

National Oceanic and Atomospheric Administration. Climates of the States. Volume 1. Book Tower, Detroit, Michigan. 1985.

Plumb, Timothy R. (Tech. Coord.). Proceedings of the Symposium on the Ecology, Management, and Utilization of California Oaks June 26-28, 1979, Claremont, California. Gen. Tech. Rep. PSW-44. Berkeley, CA ; Pacific Southwest Forest and Range Experiment Station, U.S. Department of Agriculture; 1979. 368p.

Rundel, Philip W.; Parsons, David J.; Gordon, Donald T. Montane and subalpine vegetation of the Sierra Nevada and Cascade Ranges. IN Barbour, M.G. and Major, J., eds., Terrestrial Vegetation of California. John Wiley and Sons, New York. 1977. p. 559-599.

Sawyer, John O.; Dale A. Thornburgh; James R. Griffin. Mixed evergreen forest. IN Barbour, M.G. and Major, J., eds, Terrestrial Vegetation of California. John Wiley and Sons, New York. 1977. p. 359-381.

Stone, Sandra A. Analysis of a U.S. Forest Service plantation release program in the Douglas fir-tanoak-madrone vegetation type. Berkeley, CA; University of California, Berkeley; 1984. 47p. Thesis.

Tappeiner, John C. II; McDonald, Philip M. Development of tanoak understories in conifer stands. Canadian J. Forestry Research. 14:271-277. 1984.

Tunison, John Timothy. A synecological study of the oak-dominated communities of Bennet Mountain, Sonoma County, California. Sonoma, CA; California State University, Sonoma; 1973. 127p. Thesis.

Wainwright, Thomas C.; Barbour, M.G. Characteristics of mixed evergreen forest in the Sonoma Mountains of California. Madroño 31(4): 219-230. 1984 November.

Whittaker, R.H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecol. Monogr. 30: 279-338.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Life History Aspects of *Quercus lobata* in a Riparian Community, Sacramento Valley, California[1]

Monty D. Knudsen[2]

Abstract: Valley oak acorn production, seedling and acorn survival and growth were examined in a riparian community of the Sacramento Valley. Population structure was determined and correlated to riparian habitat types. Although acorn and seedling mortalities were high in the grassland study plots, the population structure indicates that significant numbers of seedlings survive and become established in ecotonal habitats. Rodents were the most significant herbivores limiting seedling establishment in the grassland study plots. Visual mast estimates suggest that trees growing in open habitats are more productive than trees in dense woodland or riparian forest.

Quercus lobata Nee' occurs in a variety of physiographic positions within the oak woodland and savanna communities throughout much of California (Griffin and Critchfield 1976). It frequently grows on moist deep soils of the Central Valley and valleys of the Sierran foothills and Coast Ranges (Jepson 1910). Thompson (1961) noted that in the Sacramento Valley, Q. lobata was a conspicuous element of the riparian forests.

The few quantitative biological and ecological studies of the valley oak undertaken include Elliott (1958), Griffin (1967, 1971, 1973, 1976, 1980a and 1980b), and Matsuda and McBride (1986). Griffin (1971, 1976, 1980b) found valley oak regeneration virtually nonexistent in savanna and woodland habitats of the south coast noting high mortality of acorns and seedling trees from herbivory and soil moisture depletion. Comparable studies of Q. lobata in the Sacramento Valley region are not available in riparian habitats where considerable regeneration appears to be occurring (pers. obs., Dutzi 1979, and Strahan 1984). Therefore, this study investigated seedling survival, regeneration, demography, and habitat affinities of Quercus lobata in a Sacramento Valley riparian community.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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DESCRIPTION OF THE STUDY AREA

The study was conducted at the Bobelaine Audubon Sanctuary, located 3.2 kilometers north of the town of Nicolaus, Sutter Co. (38° 56'15" north latitude, 121° 35'45" west longitude) on the west bank of the Feather River directly opposite the confluence of the Bear and Feather Rivers. The site comprises 174 hectares with diverse high and low terrace riparian habitats and a large population of valley oaks of various ages.

Motroni (1984) described the bird fauna of the sanctuary and identified and mapped five vegetation associations (fig. 1). Knudsen (1984) briefly discussed the physiographic and hydrologic conditions, and mammal fauna of the sanctuary.

METHODS

Seedling Survival

Three study plots, similar to those of Griffin (1976), were established in the high terrace grassland on the east side of the Sanctuary. Each study plot consisted of three subplots comprising a 10 x 10 x 1.83 meter high deer exclosure and three 2 x 5 meter acorn placement plots placed beside and under the canopy of a large oak. Within each deer fence two 2 x 5 meter acorn placement plots were placed, one of which was protected from gophers by an exclosure of 1.3 centimeter galvanized hardware cloth buried 1 meter deep. The third 2 x 5 meter acorn plot, placed outside the deer exclosure acted as a control. No naturally established oak seedlings occurred in any of the plots.

During late October 1979, acorns and soil were collected from the area where the exclosures were placed. Acorns were

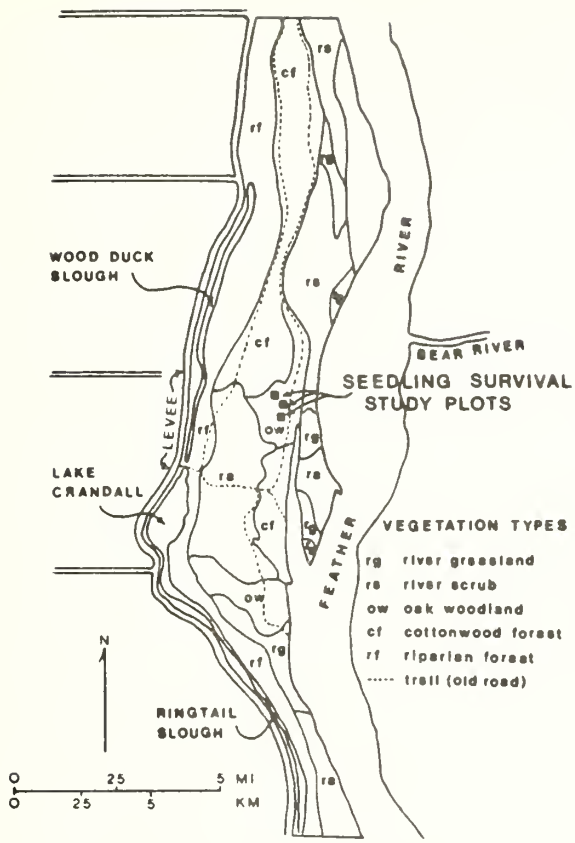


Figure 1--Vegetation map of Bobelaine Audubon Sanctuary and location of seedling survival studies.

carefully examined for evidence of insect damage. Those with noticeable damage were allowed to germinate for later examination. Visibly defective or abnormally small acorns were discarded. Only vigorous, germinated acorns were used in the exclosure experiment.

Acorns were planted on their sides on the soil surface in small peat pots, that were in turn placed in plastic bedding trays filled with additional soil. The trays were then placed in an unheated greenhouse, watered regularly, allowing the acorns to germinate and grow for 56 days. In December 1979, the germinated acorns and their peat pots were transplanted into the field plots, 33 in each of the three treatments. Each acorn and peat pot was placed 1 to 3 centimeters below the soil surface, covered with soil from the planting site and labeled with a small white numbered plastic tag.

Acorn Production and Availability

Although two techniques were undertaken to evaluate acorn production and availability, the first technique, wire cylinder acorn traps (Griffin 1971, 1976) was abandoned because of recurring damage from cattle. The second method, a visual estimate, followed the procedures of Graves (1980). The same 12 trees used in the trap studies were visually evaluated, 4 each within dense riparian, dense canopy woodland, and open grassland.

Population Structure and Habitat Affinities

A stratified random sampling technique was used to obtain quadrat data representing the range of vegetation and habitat types supporting *Q. lobata* and to provide for statistical analysis of population structure. A series of nine line transects was established running northwest at approximately right angles to the river. Transect lines were spaced every 200 meters from the southwestern boundary of the Sanctuary, proceeding northeasterly across the widest portion, including the majority of the open scrub/savanna habitat. Along each transect, 200 meter^2 (0.02 ha) circular quadrats were randomly located.

Vegetation Classification

Each quadrat was visually classified as one of the following cover-types (adapted from Motroni, 1984): Grassland/savanna; Riparian forest; Rose/elderberry scrub; Woodland-cottonwood, sycamore, and valley oak phases; and ecotone. In classifying each plot, consideration was given to the appearence of the vegetation immediately surrounding each quadrat (White 1966, Zuill 1967). Ecotones commonly occurred at riparian forest/shrubland or forest/grassland junctures and at channel and pond edges.

For each quadrat a list was made of all plant species present along with a visual estimate of the cover-abundance of each species using the Braun-Blanquet cover-abundance scale (Mueller-Dombois and Ellenberg 1974). For trees and shrubs the cover-abundance rating represented the estimated canopy coverage of that species within the plot.

In addition to the visual vegetation classification, quadrat data (e.g., species presence/absence and cover abundance) were sorted using an association-analysis program developed by Ceska and Roemer (1971) as modified by Drs. Randall and Taylor (unpubl., available from the University of California, Davis, Botany Dept.). Thus, the visual classification together with the computer program provided a means to compare the oak population structure within relatively objectively identified habitats or vegetation cover-types.

Age Determination

To determine tree ages and provide information on valley oak growth rate, increment cores were taken from 29 trees randomly selected from open grassland habitat, shaded riparian habitat or dense woodland. Cores were taken at breast height of 1.4 meters. In those instances where complete ring counts could not be made (e.g., trees greater than 80 centimeters d.b.h., trees with heart rot, or instances where the center was missed by the core) age was interpolated.

RESULTS

Condition of Acorns

Of the 752 collected acorns, 403 (58 percent) had clear evidence of insect damage at the time of collection; 33 more developed emergence holes while in the greenhouse (Table 1). Of the infested acorns 42 percent did not germinate. Surprisingly, insect larvae did not seem to inhibit or adversely affect germination and growth of 58 percent of the infested acorns as those that developed seedlings did not differ visually in vigor or growth from the uninfested acorns.

I found two species of insect larvae infesting the acorns: filbert worm larvae (Melissopus latiferreanus, Lepidoptera; Olethreutidae, 433 acorns) and coleopterous larvae (probably filbert weevil, Curculio occidentis: Curculionidae, 3 acorns).

Germination

During the collection of acorns from the study site several acorns had emerged radicles while still hanging in the tree and 9 percent of those collected from the ground had already germinated. Five days after collection 146 (21 percent) of the previously ungerminated insect free acorns had fully emerged radicles and another 22 showed splitting around the micropyle. By 15 days after collection all 272 insect free acorns had fully emerged radicles. The remaining 44 insect free acorns (14 percent) never germinated. Very poor acorn crops in subsequent years prevented additional analyses.

Although root growth was not directly measured, it was calculated as roughly 7 millimeters per day, similar, but lower than the rates obtained by Matsuda and McBride (1986).

Seedling Survival

Shoot emergence was highly variable (Table 2) and after one year (December 1979 to December 1980) nearly all the seedlings disappeared (fig. 2). Although high seedling mortality occurred in all the treatments, the depletion rate within the gopher exclosures was noticably lower than the control and deer exclosure plots. This probably was not the result of the gopher exclusion because losses from gophers outside the gopher exclosures were very low (6 percent). Rather, the above ground hardware cloth probably deterred rabbits and other small rodents from entering the gopher exclosures.

Although many acorns were dug up or taken from above ground before seedlings were observed, 17 percent of these still produced seedlings. Small mammal live-trapping conducted within the study area during June of 1983 produced three species of small rodents, white-footed deer mice (Peromyscus maniculatus, 1 capture), California vole (Microtus californicus, 21 captures), and house mice (Mus musculus, 25 captures). Trap success was 14 percent over 340 trap days. Based on these trapping results I concluded that house mice and California voles were the primary small-rodent acorn predators in the study area. A large population of rabbits (Sylvilagus sp.) also occurred in the exclosure study area as evidenced by

Table 1--Condition of collected acorns as a reflection of their probable viability, Bobelaine Audubon Sanctuary, October 1979 (N=752).

Germination	Acorns with insect damage, (pct)	Acorns apparently free of insect damage, (pct)	Total acorns (pct)
germinated	251 (33)	272 (36)	523 (70)
ungerminated	185 (25)	44 (06)	229 (30)
Total	436 (58)	316 (42)	752 (100)

Table 2--Progress of Quercus lobata seedling emergence within the study exclosures at Bobelaine Audubon Sanctuary.

Date	No. of new seedlings observed	Number left	Mortality	Acorns w/o seedlings	Cum. no. of seedlings observed, (pct)
Dec. 15	(+5)[1]	(+5)[1]	0	(290)[1]	(+5)[1]
Jan. 6	139	139	78	80	139 (47)
Jan. 12	22	161	118	18	161 (54)
Feb. 2	13	128	157	12	174 (59)
Mar. 2	7	126	168	3	181 (61)
Apr. 19	3	115	182	0	184 (62)

[1]Actual number of emerged seedlings not counted, but very few seedlings had emerged by December 15 when the acorns were planted in the study plots.

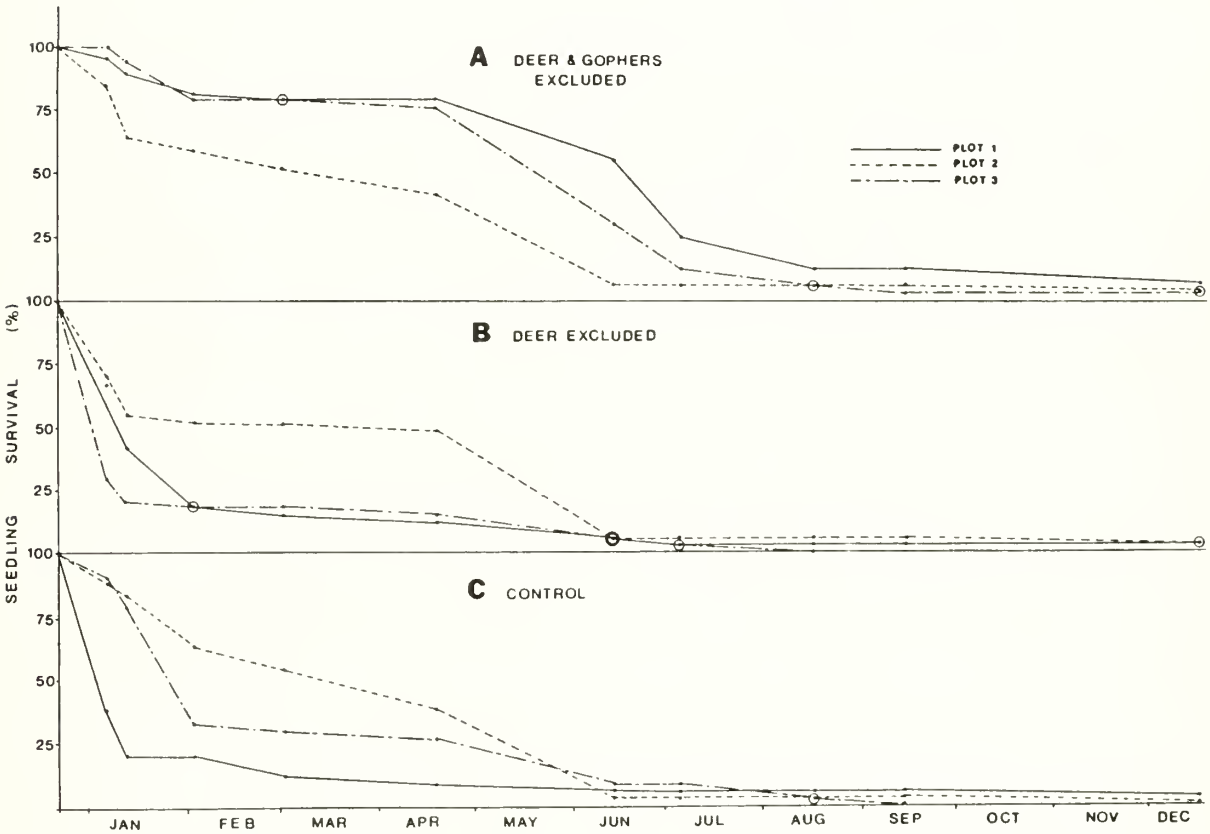


Figure 2--Survival curves for 297 germinated acorns according to treatment from plots 1, 2, and 3.

numerous droppings and frequent early morning sightings. Scrub jays also entered the exclosures and were observed pulling on the seedlings on two occasions.

Insect grazing damage to seedlings occurred mainly on newly emerged leaves. Small holes or grazing marks were observed on 17 (6 percent) of the seedlings. Large grazing marks (e.g., whole leaves or whole stems) were probably grazed by animals other than insects. Table 3, lists the apparent mortality causes.

Treatment Effects

Although deer and gophers were effectively excluded from their respective exclosures, the many other small mammals

Table 3--Apparent causes of mortality for acorns in high terrace study exclosures (December 1979-December 1980) Bobelaine Audubon Sanctuary.

Cause of mortality	Number of acorns	Percent of total (297)	Possible agent(s)
Acorns dug up	4	1.4	Scrub jays, cottontail rabbits, rodents (voles, house mice, deermice)
Acorn taken before seedling appeared	88	29.6	Same as above (deer in control plots)
Acorn and seedling taken	164	55.2	Same as above (deer in control plots)
Desiccation	12	4.0	Competition with grasses, herbs?, overexposure?
Seedling dug up	2	0.7	Scrub jays, cottontail rabbits, rodents, (voles, house mice, deermice)
Pocket gopher	18	6.0	Pocket gopher (*Thomomys bottae*)
Insects	2	0.7	?

and birds entering the exclosures produced high mortalities in all of the treatments. Even within treatments there was substantial variation in the depletion patterns.

Low survival in all plots precluded statistical analyses of the losses within within and among treatments. Regressions computed for the combined data for each of the three treatments revealed no obvious difference in mortality rates for the three treatments.

Acorn Production and Availability

Surprisingly, visual crop estimates were low for all areas during 1979 through 1983 (Table 4). Nonetheless the data generally suggest that acorn production is greater on oaks growing in full sun as compared to those in shade or partial shade. However, the relatively small sample size and short time period involved casts doubt on the reliability of these short term data.

Population Structure

Figure 3 presents the size class distribution of valley oaks at Bobelaine indicating a healthy reproducing population. Regression analyses of ring and diameter data revealed a weak linear relationship (fig. 4a). Although a slightly better fit was obtained using a log-log transformation (fig. 4b), the best fit was obtained by separating trees growing in the open from those growing in shade (fig. 4c).

Age ranges were assigned to each size class using the general regression equation from figure 4a (Table 5). Although there is an unknown time span between the germinated seed and the young tree stage (d.b.h. ~ 2.5 centimeters) not accounted for in the core, that time span was assumed to be between 5 and 9 years based on work from McClaran (1983).

Habitat Affinities

Numbers of seedling and sapling valley oaks increased dramatically within riparian and ecotonal cover types at Bobelaine (fig. 5). These sites had noticably reduced grass densities, greater plant species diversity and higher percentages of exposed soil. Seedling and sapling occurences also correlated to the number of plant species per plot (seedlings <2.5cm d.b.h, r_s = 0.555, P<

Table 4--Acorn mast classes for 1979-1983 at Bobelaine Audubon Sanctuary using the technique of Graves (1980).

	Riparian[1] Tree Number				Woodland Tree Number				Savanna Tree Number			
Year	1	2	3	4	1	2	3	4	1	2	3	4
1979	1[2]	1	1	1	1	1	1	1	2	1	2	1
1980	2	2	1	1	2	1	1	2	3	1	3	1
1981	1	1	1	1	2	1	1	1	2	1	2	1
1982	1	1	1	1	1	1	1	1	2	1	1	1
1983	1	1	1	1	1	1	1	1	1	1	1	1

[1] Comparisons of acorn mast classes between habitat types were conducted using the Tukey test (Zar 1984 pp. 200-201).

[2] Class 1 = no acorns observed; Class 2 = one or few acorns observed; Class 3 = acorns readily observed but not covering the tree; Class 4 = acorns readily observed and limbs sag from the weight.

Comparisons: riparian vs. savanna = n.s. (not significantly different); riparian vs. woodland = n.s.; woodland vs. savanna acorn = n.s.

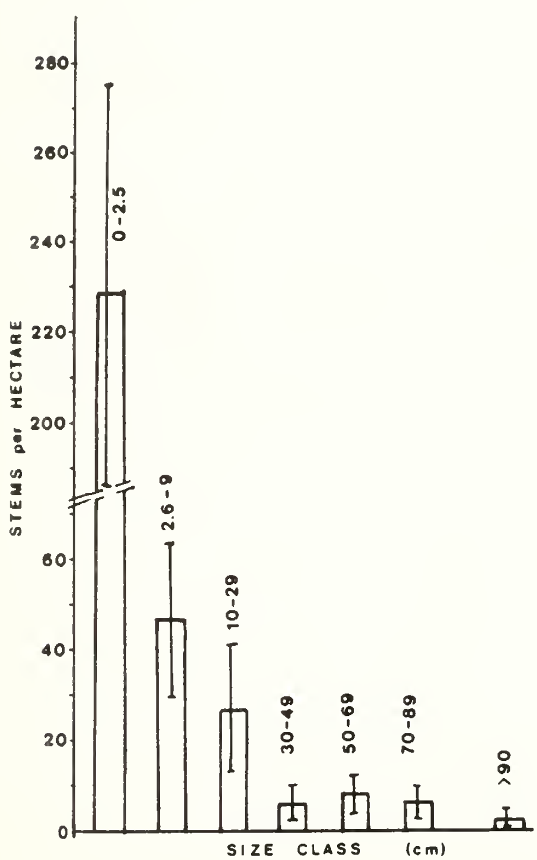


Figure 3--Size class distribution of Quercus lobata based on 98 200m2 circular quadrats.

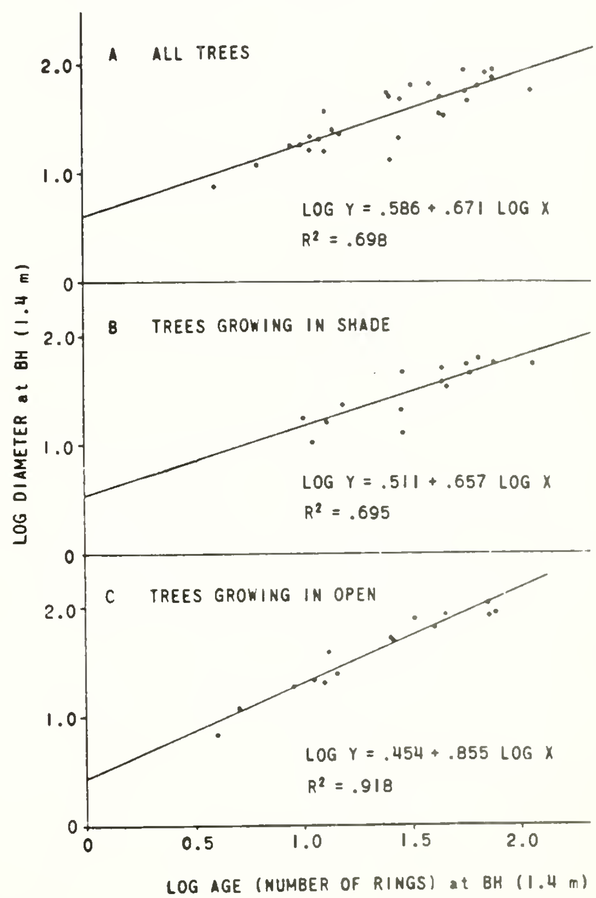


Figure 4--Regression analyses of tree ring and diameter data from cores of 29 randomly selected valley oak trees.

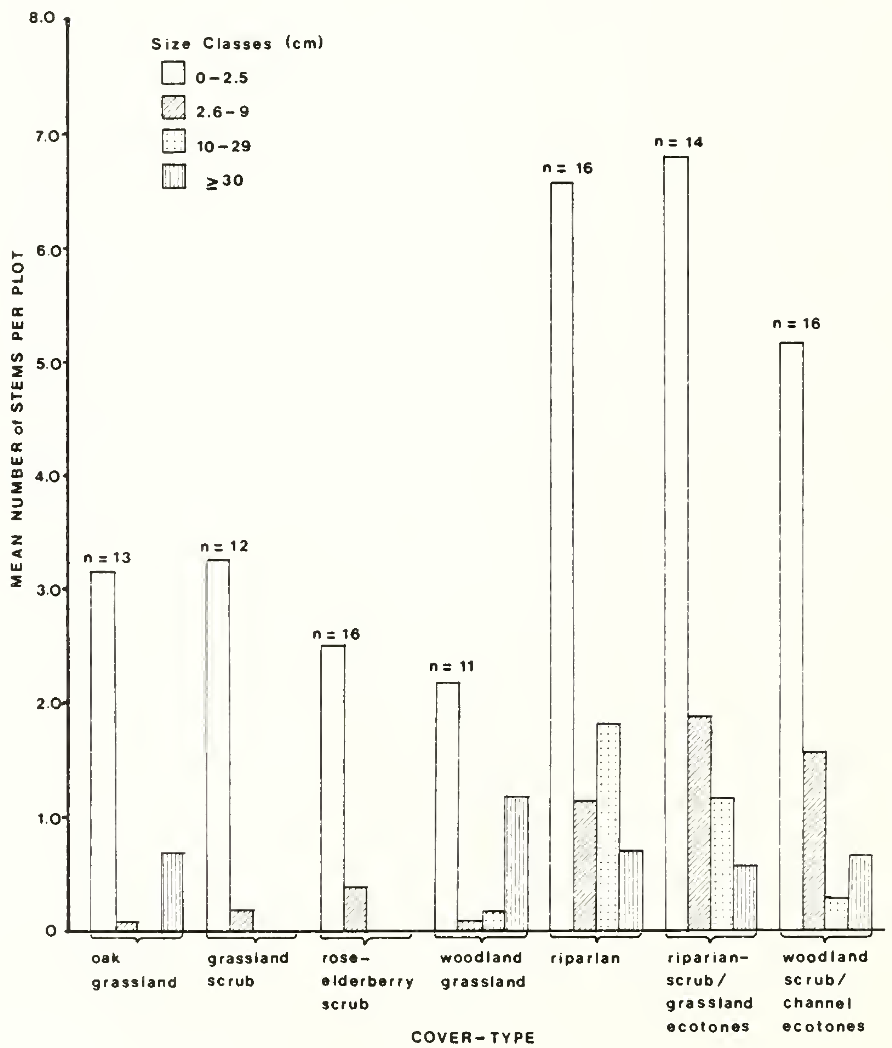
Table 5--Characteristics of the various diameter classes of *Quercus lobata* trees at Bobelaine Audubon Sanctuary based on 98 randomly located 200 m^2 plots.

Size Class (cm d.b.h.)	Mean no. per Plot	s.d.	Mean Density (stems/ha)	Age[1] Range (yrs.)	Mean Dia. (cm)	s.d.	n	Max. Dia. (cm)
0-2.5	4.58	5.59	228.6	1-9	-	-	449	-
2.6-9	.908	1.72	45.4	7-17	5.6	1.88	92	9
10-29	.551	1.41	27.6	18-37	16.8	4.31	54	26
30-49	.133	0.37	6.7	38-52	38.2	6.19	13	48
50-69	.163	0.47	8.2	53-66	60.8	5.81	16	68
70-89	.133	0.34	6.7	67-78	79.2	6.07	13	89
>90	.061	0.24	3.1	(89-108)[2]	126.3	11.9	6	144

[1] Calculated from the regression equation $\log Y = .586 + .671 \log X$, Figure 4.

[2] Outside range of values used to derive regression model.

Figure 5--Relative occurrence of size classes of *Quercus lobata* within cover types at Bobelaine Audubon Sanctuary. Based on 98 200m^2 circular quadrats located in a stratified random pattern throughout the Sanctuary. Sample sizes for each habitat type indicated by n.



0.001; saplings > 2.69cm d.b.h., rs = 0.322, P< 0.002) and the three smallest size classes showed highly clumped distributions. Valley oak occurrence did not correlate to canopy cover-class, though intermediate cover classes had greater numbers of seedlings and saplings.

CONCLUSIONS

Although Quercus lobata is largely perceived as a savanna/grassland species, results of this study indicate a strong association with more mesic riparian habitats. Although acorns and seedlings suffer similar high mortality rates in open woodland/grassland habitat at Bobelaine as those in savannas of the central Coast Range (Griffin 1971, 1976, 1980b), substantial regeneration occurs in localized ecotonal and riparian sites of this community. The primary small-mammal herbivores include California voles, house mice and rabbits. Gophers contributed minor losses. Insect damage was comparable to that noted in the south coast and combined with deer, birds and the above small mammals, there appears to be no shortage of acorn predators in the riparian grasslands.

The presence of greater numbers of seedlings and saplings in more mesic riparian and ecotonal sites providing adjoining shrub cover but reduced grass densities apparently enhances the probability of Q. lobata seedling establishment. Reduced numbers of seedlings and saplings in more xeric woodland and grassland habitats lacking shrub cover but supporting increased grass densities corroborates this conclusion. The more mesic ecotonal and riparian edge sites probably provide higher soil moisture levels during the critical summer drought period as a result of reduced grass densities, shading, and relatively shallow water table. Thus more oak seedlings survive during the critical first years of life. The patchy distribution of grassy areas, rodents and acorn sources within the riparian community probably contributes to wide variation in valley oak establishment and survival from site-to-site. Thus not all apparently suitable sites offer sufficient availability of acorns or protection from herbivores or desiccation.

The occurrence of Q. lobata seedlings in virtually all habitats of the sanctuary suggests that soil nutrients play a relatively minor role in determining the distribution of seedling oaks. The ability of valley oak seedlings to survive in shaded and/or nutrient-deficient sites may be enhanced by the large seed reserves as noted for english oaks (Grime and Jeffrey 1965, Grime 1979). The large seed reserves coupled with the localized occurrence of sapling trees in edge or forest gaps suggests that valley oak may possess a "gap-phase" or persistent seedling regenerative strategy (Watt 1947). The low level of sprouting ability in valley oak (Griffin 1980a,b; Jepson 1910) may further indicate a "gap-phase" life history strategy and affinity to more mesic habitats as implied by Muller (1951).

REFERENCES

Ceska, A.; Roemer, H. A computer program for identifying species-releve groups in vegetation studies. Vegetatio 23:255-277; 1971.

Dutzi, E. J. Valley oaks in the Sacramento Valley: past and present distribution. Davis, Calif.: Univ. Calif.; 1979. 97 p. Thesis.

Elliott, F. L. Growth rate of four species of oaks. Stanford, Calif.; Stanford Univ.; 1958. 83 p. Thesis.

Graves, W. C. Annual oak mast yields from visual estimates. In: Plumb, T., tech. coord. Proceedings of the Symposium on Ecology, Management, and Utilization of California Oaks, 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 270-274.

Griffin, J. R. Soil moisture and vegetation patterns in northern California forests. Res. Paper PSW-46. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1967. 20 p.

Griffin, J. R. Oak regeneration in the upper Carmel Valley, California. Ecology 52(5):862-868; 1971 late summer.

Griffin, J. R. Xylem sap tension in three woodland oaks of central California. Ecology 54(1):152-159, 1973 winter.

Griffin, J. R. Regeneration in Quercus lobata savannas, Santa Lucia Mtns., California. Am. Midl. Nat. 95(2):422-435; 1976 Apr.

Griffin, J. R. Sprouting in fire damaged valley oaks, Chews Ridge, California. In: Plumb, T., tech. coord. Proceedings of the Symposium on the Ecology, Management, and Utilization of California Oaks. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 216-219.

Griffin, J. R. Animal damage to valley

oak acorns and seedlings, Carmel Valley, California. In: Plumb, T., tech. coord. Proceedings of the Symposium on the Ecology, Management, and Utilization of California Oaks. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980b. 242-245.

Griffin, J. R.; Critchfield W. B. The distribution of forest trees in California. Res. Paper. PSW-82. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1976 revised. 118 p.

Grime, J. P. Plant strategies and vegetation processes. New York: Wiley and Sons; 1979.

Grime, J. P.; Jeffrey, D. W. Seedling establishment in vertical gradients of sunlight. J. Ecol. 53:621-642; 1965.

Jepson, W. L. The Silva of California. Univ. Calif. Memoirs 2:1-480: 1910.

Knudsen, M. Life history aspects of Quercus lobata Nee' in a riparian community, Bobelaine Audubon Sanctuary, Sutter County, California. Sacramento: Calif. State Univ.; 1984. 135 p. Thesis.

McClaran, M. P. Quercus douglasii stand age structure on grazed and ungrazed sites in Tulare County, California. Three Rivers, CA: Sequoia Nat. Hist. Assoc. 1983. unpubl. rep.

Matsuda, K.; McBride, J. R. Difference in seedling growth morphology as a factor in the distribution of three oaks in central California. Madroño. 33(3):207-216; 1986 July.

Motroni, R. Seasonal variation in bird numbers in a riparian forest, Sacramento Valley, California. In: Warner, R; Hendrix, K. M., eds. California Riparian Systems: Ecology, Conservation, and Productive Management. Davis: Univ. Calif. Press; 1984. 578-586.

Mueller-Dombois, D.; Ellenberg, H. Aims and methods of vegetation ecology. New York: John Wiley and Sons; 1974.

Muller, C. H. The significance of vegetative reproduction in Quercus.

Strahan, J. Regeneration of riparian forests of the Central Valley. In: Warner, R.; Hendrix, K. M., eds. California Riparian Systems: Ecology, Conservation, and Productive Management. Davis: Univ. Calif. Press; 1984. 58-67.

Thompson, K. Riparian forests of the Sacramento Valley, California. Ann. Assoc. Amer. Geog. 53(3):294-315; 1961.

Watt, A. S. Pattern and process in the plant community. J. Ecol. 35:1-22; 1947.

White, K. L. Structure and composition of foothill woodland in central coastal California. Ecol. 47(2):229-237; 1966 early spring.

Zar, H. A. Biostatistical Analysis. 2nd ed. New Jersey: Prentice-Hall; 1984.

Zuill, H. A. Structure of two cover types of Southern oak woodland in California. 43 p. Thesis.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Age Structure of Engelmann Oak Populations on the Santa Rosa Plateau[1]

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Abstract: Methods for age dating Engelmann oaks are described along with a presentation of the community age structure and growth rates. Annual ring counts, based on derived anatomical criteria, were made from increment cores and cut slabs taken at breast height. Age/size classes, established for comparative purposes, indicate an unnaturally low density of smaller size classes. Growth rates vary with topography, habitat, and possibly age. Mean growth rates of mature trees in valleys =.39 cm/yr compared to .44 cm/yr on hills and mesas.

Oak landscape, in particular the rolling oak-grasslands of the Engelmann oak (Quercus engelmannii Greene) phase of southern oak woodland, is a prominent symbolic feature of California. Engelmann oaks once flourished in the foothills of the San Gabriel Mountains from Pasadena to Pomona. There it was a landscape, raw material, and design symbol for the arts and crafts movement of 1890-1930. Today these trees have been destroyed and only a few small stands, such as in Huntington Gardens and the Los Angeles Arboretum, remain in the Los Angeles Area. Presently the Engelmann oak, along with the closely associated coast live oak (Q. agrifolia Nee), range in dense to scattered stands south from Los Angeles County and Santa Catalina Island to Riverside and San Diego Counties and northern Baja California (Thorne 1976; Plumb and Gomez 1983). Coast live oak is reported to be reproducing normally; enough to replace the present old trees when they die. However, Engelmann oak occurs more often in savanna-type habitats, often grazed by domestic livestock and deer (Griffin 1971, 1976). Thus grazing activity has restricted or eliminated natural reproduction of Engelmann oak trees on ranch and rural lands for over 100 years (California Department of Parks and Recreation [CDPR] 1983). This CDPR report also indicated that research is needed to foster reproduction and to protect representative examples of the Engelmann oak habitat.

The research conducted in this study, from July, 1985 - August, 1986, is a preliminary study concerned with developing criteria for age dating the Engelmann oak populations and to relate age to size-class increments of the mature oak stand. Hopefully, this will be a "start" to help determine the reproductive status of Engelmann oak and provide data necessary to foster reproduction and sound management of this unique ecosystem.

1. Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

2. Professor and graduate student, Loma Linda University, Riverside, California.

Study Site

The Santa Rosa Plateau, a topographic unit in the southern part of the Santa Ana Mountains of the Peninsular Ranges (Lathrop and Thorne 1985), was selected for this study because it is considered to be "typical" of the Engelmann oak phase of southern oak woodland in California (Griffin 1977). The soils of the grassland and the oak woodland communities are mostly loams from .5 - 1.2 m deep but include areas of deep clay loam and shallow claypan soils. Granitic and basaltic rocks outcrop occasionally in the grassland and frequently in the oak woodland. A particularly good feature of this site is the establishment of a 1,255 ha Santa Rosa Plateau Preserve by the California Nature Conservency in 1984, which has high natural resource value for communities. There is another 2,024 ha of oak woodland surrounding the preserve, also available for study, but it is currently subject to subdivision. The southern oak woodland on the plateau is topographically oriented, with a "savanna-type" woodland on hills and mesas, dominated by Engelmann oak and a "dense" woodland in valley riparian habitats where coast live oak tends to be superimposed on the Engelmann oak populations resulting in an increased total density (Snow 1972; Lathrop and Zuill 1984; Lathrop and Wong 1986).

METHODS

Field Observations and Collections

Annual rings of Engelmann oak, a drought-deciduous white oak, are not well defined, partly because the wood is diffuse porous and thus does not produce distinctly larger vessels at the beginning of the growing season. Aging of the oaks was accomplished by tree-ring analysis with standard guidelines and procedures in mind as outlined by Baillie (1982). Thirty and 40 cm Swedish increment borers were used to extract cores for annual ring counts, and supplemented with cut slabs of down dead trees which had fallen within recent years (up to 5). Cores were taken at breast height (1.4m) on live tree trunks and 5-7 cm thick slabs were cut at this height on down dead trees with a 50 cm power chain saw. Slabs, or "cross sections", are more feasible to obtain and are much better for counting rings than cores, because a larger area is available for inspection. Older trees with rotten centers make it difficult to extract the "borer" as well as a useable core. Friction on the metal borer, due to the high density of the wood, may cause the borer to snap, also contributing to the difficulty of aging solely by the use of cores. Since it is impractical to determine the age of all trees, representative samples were taken from trees in various ecological and competitve settings, including the two topographical settings which tend to have an ecological influence on Engelmann oak populations, hills and valleys. For each tree sampled, (either cores or slabs) habitat data was gathered, the tree location mapped, and the tree numbered with a metal tag to permit returning to collect any further data, if necessary. After discarding numerous samples with rotten centers, indistinguishable rings, or otherwise uncountable samples, 42 countable cores and 14 slabs, were obtained.

Laboratory Preparation and Analysis

Cores samples were glued into the groove of a wooden holder then sanded to a fine polish using 80 and 240 grits on a commercial belt sander, followed by hand sanding up to 400 grit. One side of the slabs were similarly sanded, but starting with a heavy duty body grinder using grits 16, 24, and 36. Ring counts were made by examination of the wood samples at magnifications of 10 - 80 X using a Zeiss dissecting microscope mounted on an extendable-arm. Consideration of the following points were essential in arriving at reliable ages: 1) develop criteria for counting rings; and 2) independent verification of ring counts.

Although rings in Engelmann oak are, for the most part, not well defined, we have found certain criteria useful for determining ring boundaries in this species. They include: 1) vessel association and size (fig. 1). Earlywood vessels are relatively large and radially arranged in bands (1 to 5 vessels). The bands with multiple vessels occasionally spread out like a funnel from a single vessel in the earlywood. The vessels, whether in multiple or single bands, become progressively smaller toward the end of the ring. However, vessel diameters can revert from small back to large within a growing season; 2) tracheid size and shape (fig. 1). Tracheids can be observed with higher magnification (up to 80 X). While some tracheid areas may become indistinct under the microscope, generally the tracheids in the earlywood or the beginning of the ring, appear white and larger that the latewood tracheids, which are dark and smaller. This distinction often causes a faint, but sharp line to form between the rings upon which earlywood vessels sit. Vessels are almost never bisected by this line; and

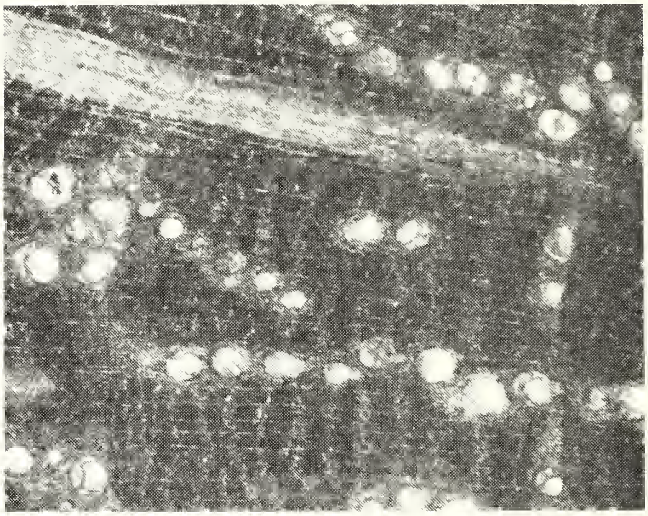

Figure 1--Micrograph of a transverse section of wood of Engelmann oak showing a portion of an annual ring with large vessels, concentric bands of tracheids and parenchyma, and a wide pith ray running diagonally through the upper part of the photograph.

3) distance between bands of parenchyma cells (fig. 1). Axial parenchyma cells form concentric bands which are relatively far apart in the earlywood and closer together in the latewood. Parenchyma bands, like vessel diameters, can revert from narrow spacing to wide several times within the growing season. Such evidence of "false rings" may be related to water availability during the growing season or to refoliation. It is assumed that false rings are mostly distinguishable as not representing a year's growth. Counting errors due to unclear rings, or deceptive false rings, of up to 5 percent may be inevitable in some trees. Independent confirmation of the accuracy of our ring counts were accomplished by examination of several cores containing fire scars from dated fires. Fires can leave visable scars on trees which begin to "heal over" the following growing season. The number of rings between the scar and bark should correspond to the number of years since the fire, which proved to be true in 3 of the 3 burn scar samples we were able to obtain.

Cross sections of wood have the advantage over cores for indistinct rings because if rings become unclear in a counting radius it is easy to follow the ring around the slab to a point where the rings become clear again and resume counting, which is not possible on the narrow strip of wood in core samples. Hopefully, any inaccuracies in age determination due to indistinct ring boundaries will be small and covered by the establishment of age-size categories which, for example all trees 30-40 cm dbh in a certain ecological setting, to fall within a certain age range.

We did not use extrapolation of the growth rate in the outer wood to the missing interval to estimate age for samples with missing rings, preferring to wait until we have more samples to better understand how and if growth rate changes as the tree matures. Thus our core and slab samples (hills N=35; valleys N=21) are actual ring counts. The age ranges indicated in figures 2 and 3, however, were arrived at by estimation using diameter and mean growth rates of the total samples.

The tree age data were analyzed separately for "hills" and "valleys". Following determination of the age of each sample, growth index and growth rate were calculated. Growth index (GI) is the number of rings per cm of diameter (rings/cm). Growth rate (GR) is the increase in diameter of the tree per year

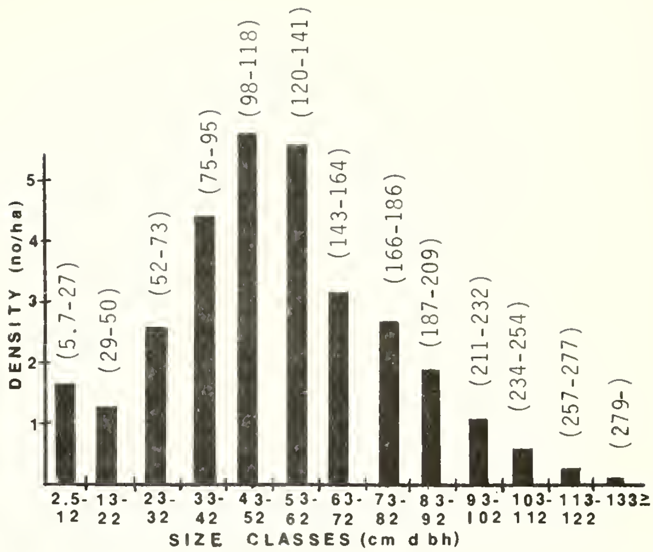

Figure 2--Bar graph comparing density (no/ha) with size classes (cm dbh) of Engelmann oak trees on hills of the Santa Rosa Plateau. Numbers in parentheses indicate the estimated range in ages (calculated on mean growth rate of .44 cm/yr, N=35) for trees within the size classes. Number of trees sampled for size-class data=306. Adapted from Lathrop and Wong (1986).

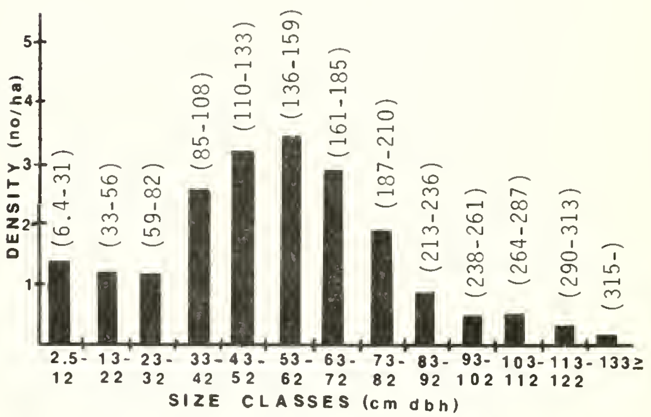

Figure 3--Bar graph comparing density (no/ha) with size classes (cm dbh) of Engelmann oak trees in valleys of the Santa Rosa Plateau. Numbers in parentheses indiacte the estimated range in ages (calculated on mean growth rate of .39 cm/yr, N=21) for trees within the size classes. Number of trees sampled for size-class data = 117. Adapted from Lathrop and Wong (1986).

(cm/yr). Mean growth rate was determined for hills (N=35) and for valleys (N=21) and used to estimate age ranges for the size classes of Engelmann oak populations on the plateau (figs. 2 and 3). The data for density by size classes (figs. 2 and 3) are adapted from Lathrop and Wong (1986) in which trees were measured by the point-quarter method (Brower and Zar 1984). Linear regression analysis was used to compare growth rate age.

RESULTS

Ring data, used to determine age, were collected from cores and cross sections from representative trees in each of the two main habitats for Engelmann oak populations on the Santa Rosa Plateau. Counting annual rings in Engelmann oak proved helpful for age determination when samples could be collected and prepared properly. However, the rings may not always be well defined and a fine polished finish and "very good" lighting are essential. Multiple counts generally 3, 4, or even more, within 10 percent error were used to determine age. Age data for the species indicate wide variation in growth rate with habitat, topographic site, and ecological setting. Ages of our samples ranged from 4 thru 166 years. Mean growth rate for trees in valleys (GR=.39 cm/yr) was slightly lower than on hills (GR-.44 cm/yr). Summary data showing diameter by size-class, age, growth increment, and growth rate is presented in tables 1 and 2 for hills and valleys respectively. The mean age for the size-class 2.5-12 cm dbh is the same for both hills and valleys (18.4 yrs) but mean ages for the larger size-classes are greater in valleys than on hills (tables 1 and 2), further indication that mature trees tend to grow slower in valleys compared to hills. Our age data for Engelmann oak on the Santa Rosa Plateau compares favorably with ages for this species reported by Snow (1972). Linear regression analysis of growth rate with age gave some indication, though not statistically significant, that growth rate decreases with age (r= -0.321, dp= .275 [N=35] for hills; r= -0.285, dp= 360 [N=21] for valleys).

Due to the "pilot" nature of this study and the difficulty in extracting cores from older, larger trees, most of the actual ring counts are from smaller diameter trees, with only a few slabs cut from medium sized down trees which could be found without rotten center (tables 1 and 2). While ring samples from many larger trees are planned as a continuation of this study, it is important to begin to look at a probable future stand development based on present age/size-class increments. Figures 2 and 3 are bar graphs showing density of Engelmann oak by 10 cm size-class increments as adapted from Lathrop and Wong (1986). The mean growth rates (.39±.16 cm/yr [N=21] and .44±.16 cm/yr [N=36] for valleys and hills respectively) were used to extrapolate the estimated age range for the various size-class increments (figs. 2 and 3). Categorizing the size classes of trees by density and age can help to identify the relative abundance of a particular size class or classes and in turn give some indication as to whether the population will maintain the present densities for all size classes in the future.

Table 1. Diameter and growth ring data of _Quercus engelmannii_ trees by size-class on hills at the Santa Rosa Plateau, Riverside County, California. DBH=diameter breast height @ 1.4m. N 1 with means±lsd. GI=growth index; GR= growth rate.

N	Size-class DBH (cm)	Age (yrs)	GI (rings/cm)	GR (cm/yr)
19	2.5-12	18.4±9.2	2.5±1.4	.46±.20
9	13-22	41.5±12	2.7±0.8	.41±.15
4	23-32	43.2±6.9	2.7±2.3	.50±.22
1	38	70	1.8	.54
1	52	117	2.2	.44
1	65	166	2.5	.39

Mean growth rate total N (35)=.44+16 cm/yr

Table 2. Diameter and growth ring data of _Quercus engelmannii_ trees by size-class in valley sites at the Santa Rosa Plateau, Riverside County, California. DBH=growth index; GR=growth rate.

N	Size-class DBH (cm)	Age (yrs)	GI (rings/cm)	GR (cm/yr)
10	2.5-12	18.4±2.7	3.4±1.8	.38±.19
5	13-22	49.4±31	2.6±1.5	.46±.17
4	23-32	90.7±41	3.3±1.3	.35±.14
1	42	88	2.1	.48
1	64	196	3.1	.33

Mean growth rate, total N (21)=.39+.16 cm/yr

DISCUSSION

The size-class categories for 2.5 - 32 cm dbh in figures 2 and 3 have relatively low densities compared to the mid-size classes from 33 - 62 cm dbh. Fewer large-size (62 - 132 cm) than mid-size trees could be attributed to natural mortality in the life of the stand, but the present sparse density for the groups less than 32 cm is due to some other factors (e.g. lack of acorns, poor seedbed, impact of grazing, poor seedling survival, or some other mortality) (Lathrop and Wong 1986). By the time the current smaller size classes grow to the mid-size classes, the density of the mid-size classes in the future woodland will be much lower than at present, indicating a decline in overall population density of Engelmann oak in the future on the Santa Rosa Plateau.

Engelmann oaks do not have well defined annual rings, partly because they do not produce distinctly larger vessels at the beginning of the growing season and partly because there are often areas in the counting radii where the rings are extremely close together, indicating alternate periods of high and low growth rates during the life of the tree. It is conceivable that those specimens with the slowest growth rate end up being discarded as uncountable, thus introducing a systematic error in the results. This may be true, to a small extent, but if so, it is offset by the fact that high and medium growth rate samples can be uncountable as well. For this reason, preliminary study of aging in the Engelmann oaks has concentrated on developing criteria for collection, preparation, and counting techniques. We feel that we have a good start on this problem and will develop the techniques, collection and preparation even further in the next few years. One particular problem that needs attention, is getting adequate samples from larger trees in order to determine to what extent growth rate changes with age. Our samples, which range up to 65 cm dbh, give some indication that growth rate decreases with age, but there are many trees of this species that have diameters over 130 cm dbh up to 173 cm. Since Engelmann oaks are not usually harvested for commercial purposes, such a source of good counting samples is not readily available. Thus we need to rely on recently down dead trees to collect cross sections for counting rings, necessitating larger chain saws and luck in locating solid-trunked trees. Cores from the outer portions of large trees may eventually prove useful for determining age in relation to growth rate. What is planned for this project over the next few years, is to get enough actual ring counts from a large number of trees over a greater range of diameters and from a wider geographic area (e.g. Camp Pendleton, Catalina Island, Ewing Oak Preserve, Black Canyon of the USFS) which data can then be used to estimate ages of trees with rotten centers or partially uncountable rings.

CONCLUSION

Counting annual rings in Engelmann oak can be difficult due to the rings not being well defined and often obscure, but by making proper collections, sanding them to a fine finish, and using good light sources with magnification from 10 - 80 X, rings can be counted with a fair degree of accuracy. Cores are extracted better after the trees have responded to the rainy season, but increment bore samples are difficult to obtain on trees larger than 30 cm dbh due to the high density of the wood and to the rotten centers common in older trees. Thus, it is necessary to cut cross sections from large recently fallen trees to determine age and growth rates in larger-sized trees. In order to adequately age date the Engelmann oak populations in southern oak woodland, larger sample sizes over a greater diameter and geographical range will be needed to determine statistically valid growth rates in order to estimate the number of rings from the countable radii for larger trees with missing centers and/or distances of uncountable rings.

REFERENCES

Baillie, M. G. L. Tree-ring dating and archaeology. Chicago, Illinois; The University of Chicago Press; 1982; 274 p. Brower, James E.; Zar, Jerrold H. Field and laboratory methods for general ecology. Dubuque, Iowa; Wm. C. Brown Publishers; 1984; 222p.

California Department of Parks and Recreation. Mesa oaks reserve, feasability study. Department of Parks and Recreation, State of California-the Resources Agency. Sacramento; 1983; 55 p.

Griffin, James R. Oak regeneration in the upper Carmel Valley, California. Ecology 52(5):862-868; 1971 late summer.

______. Regeneration in Quercus lobata savannas, Santa Lucia Mountains, California. Amer. Midl. Natur. 95(2): 422-435; 1976 Apr.

______. Oak woodland. In: Barbour, M. G. and Major, J., eds, Terrestrial vegetation of California. New York;

Wiley-Interscience; 1977:338-415.

Lathrop, Earl W.; Wong, Brian. Stand characteristics of southern oak woodland on the Santa Rosa Plateau, Southern California. Crossosoma 12(4): 1-7; 1986.

______; Zuill, Henry A. Southern oak woodlands of the Santa Rosa Plateau, Riverside County, California. Aliso 10(4);603-611; 1984.

Plumb, Timothy R.; Gomez, Anthony P. Five southern California oaks: identification and post-fire management. Gen. Tech, Report PSW-71. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1983. 56 p.

Snow, Gerald Eldon. Some factors controlling the establishment and distribution of Quercus agrifolia Nee' and Quercus engelmannii Greene in certain southern California oak woodlands. Corvalis, OR: Oregon State University; 1972. 105 p. Dissertation.

Thorne, Robert F. The vascular plant communities of California. In: Latting, J. ed.. Proceedings, Plant Communities of Southern California symposium; 1974, May 4, Fullerton, CA. Calif. Native Plant Soc. Spec. Publ. No. 2. Berkely, CA; 1976; 1-36.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Vegetation Dynamics of the Northern Oak Woodland[1]

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Abstract: The apparent invasion of northern oak woodland by Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco), an element of the mixed-evergreen forest, has raised concern among public and private land managers regarding the future of the oak woodland type throughout the outer North Coast Range. As part of an on-going project in Sonoma County, California, we correlated physical and vegetational parameters within the oak woodland type with the presence of Douglas-fir seedlings and saplings. Significant negative correlations were found between Douglas-fir seedling and sapling densities and the distance to a seed source, the cover of annual grasses and total plant cover. Significant positive correlations were found between Douglas-fir seedling and sapling densities and leaf litter cover and between Douglas-fir sapling density and the presence of larger trees of any species on the sample plots. These results suggest that soil moisture, the rate of soil moisture depletion, and evaporative stress are important factors in the establishment of Douglas-fir within the oak woodlands of Annadel State Park.

Our observations of vegetation patterns in the southern portion of the range of Northern Oak Woodland reveal an increased presence of Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) seedlings and saplings and a noticeable lack of oak regeneration beneath the oak canopy. At some locations Douglas-fir has grown up through the canopy and appears to be shading out the oaks. This phenomenon is very much in evidence at Annadel State Park in Sonoma County, California. Park management is concerned with the potential replacement of the Northern Oak Woodland by Douglas-fir forest, particularly because such vegetation changes may be the direct result of disruption of natural processes through past management.

Vegetation changes following changes in management objective (e.g., elimination of grazing, fire suppression, termination of wood cutting) have been documented for a number of vegetation types in coastal California (McBride and Heady, 1968; McBride, 1974; McBride and Stone, 1976). Comparatively little work has been done on changes in oak woodland/mixed evergreen forest types in the California Coast Ranges. Wells (1962) concluded that chance is the major factor controlling the distribution of oak and other vegetation types in the San Luis Obispo area. Waring and Major (1964) demonstrated a close correlation between certain environmental variables and the distribution of various vegetation types in the redwood region of Humbolt County. Griffin (1977) and Plumb and McDonald (1981) reviewed the general ecology of several oak woodland types in California, but did not develop a comprehensive analysis of vegetation dynamics in these types. Griffin attributed the current lack of regeneration, which might provide clues to possible vegetation changes, to intensive seed and seedling predation on the part of rodents and deer. Sawyer et al. (1977) describe the grassland-woodland-forest mosaic of the north coastal region as poorly understood and in need of investigation.

Several recent studies have focused on the oak woodland and hardwood forest types in Sonoma County with particular reference to Annadel State Park. Anderson and Pasquinelli (1984) described the northern oak woodland at several sites along a moisture gradient within the county, including two sites in Annadel. They concluded that high oak canopy densities and lack of oak regeneration may result in the future dominance of mixed evergreen forest species at the more mesic end of the gradient. Tunison (1973) investigated the distribution of oak woodland and mixed evergreen forest types on Bennett Mountain in Annadel State Park. Noting the dominance of young Douglas-fir and bay (Umbellularia californica [H.& A.] Nutt.) in the understory of many oak-dominated stands, he tentatively concluded that all of these oak types are seral to mixed evergreen forest. Tunison further suggested that this recent invasion of Douglas-fir and bay is the result of the development of a closed oak canopy due to previous management. Barnhart (1978) has suggested a similar vegetation change, although he

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points out that the complex nature of the coast range vegetation makes it difficult to document successional trends. Wainwright and Barbour (1984) have demonstrated the diverse nature of the mixed evergreen forest type in Annadel, including the invasion of the oak woodland type by Douglas-fir. They did not develop any conclusions relative to successional relationships, but did point out the need for further descriptive work of the forest and woodland communities of the region and the necessity of studying the dynamic relationships between the forest and woodland types.

The development of appropriate management programs to prevent replacement of the northern oak woodland will depend upon an understanding of the variables influencing the establishment of both Douglas-fir and oak. The objective of this study was to determine the correlation between selected site variables and Douglas-fir regeneration. These variables included both physical and vegetational characteristics. Identification of correlations between the various variables and regeneration should lead to a preliminary understanding of the dynamics of the northern oak woodland.

This report is of necessity preliminary in nature, since much of the field work is currently in progress. Here we report only the correlation of certain general physical site variables and vegetation parameters with the presence of young Douglas-fir within the oak woodland.

STUDY AREA

Annadel State Park is located immediately southeast of Santa Rosa, Sonoma County, California, in the Sonoma Mountains. This north-south trending range, primarily composed of Pliocene Sonoma Volcanics above older sediments (Jenkins 1951) is in the eastern portion of the county ca. 30km from the Pacific coast. Climate patterns are typically Mediterranean, with mild winter temperatures (January mean daily minimum 2-3^{o}C) and hot summer temperatures (July mean ated by morning fog. Total annual precipitation is ca. 750mm/year with dry summers and wet winters (January mean 150mm) (U.S. Weather Bureau 1964).

The vegetation of the park, typical of that found throughout the southern North Coast Range, is a complex mosaic of communities including coastal prairie, chaparral, northern oak woodland, and mixed evergreen forest (Munz and Keck 1950). Mixed evergreen forest occurs on northerly slopes and in moist drainages throughout the park, integrating with northern oak woodland, particularly in the center of the park. Northern oak woodland is predominant in the southwestern two-thirds of the park, although tree densities and composition vary with aspect. Oregon Oak (*Quercus garryana* Dougl.) occurs in relatively high densities on north-facing slopes, while south-facing slopes support more open savannas of Oregon Oak-Blue Oak hybrids (*Q. x explingii* C.H. Mull). Chaparral occupies relatively small areas, usually on southern or western exposures and rock outcroppings. The prairie and grassland communities form small to fairly extensive meadows throughout the park. It is important to note that these vegetation types form a mosaic; areas occupied by a given type are often small and boundaries between types often abrupt.

Historically, the area in which Annadel is located was extensively utilized by European settlers and their descendents (Futini 1976). Major types of activities included cattle ranching beginning in the 1830's and dominating activities from 1930 to 1970. Cobblestone quarrying around the turn-of-the-century and extensive cutting of hardwood for cordwood and charcoal in the 1920's also occurred. These activities ceased when the park was established in 1972.

METHODS

One objective of the study was to determine the spatial relationships between Douglas-fir trees of seed bearing age and Douglas-fir seedlings occurring in oak dominated stands. This objective determined the sampling pattern used in the study. Thirteen large Douglas-fir trees (>80cm DBH) occurring in oak woodlands were selected from a population of over 100 similar trees observable on aerial photographs. Trees selected were at least 300m away from any other

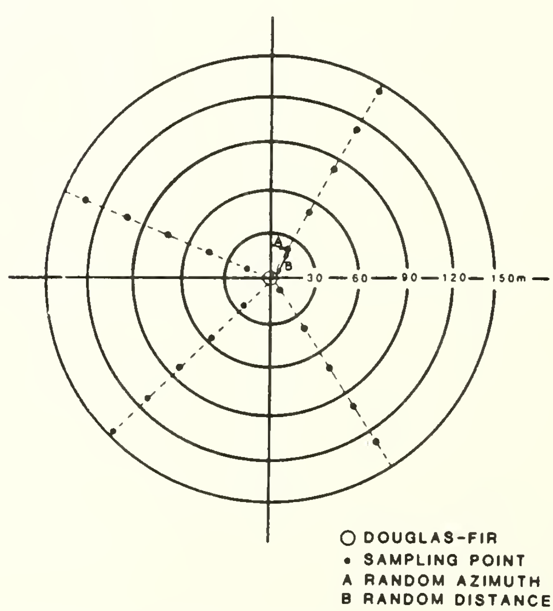

Figure 1--Location of plots around large Douglas-fir tree.

tree chosen and a similar distance from any stand of Douglas-fir. Each isolated tree was located on the ground and was used as a center around which sampling points were located. Four directional zones based on compass readings NE=0 to 90°; SE=90 to 180°; SW=180 to 270°; NW=270 to 360°) were established around each tree (Fig. 1). Each of these directional zones was divided into five concentric arcs 30m wide. An initial sampling point was located in each of the four direction zones by choosing a random azimuth and a random distance (from 0.5 to 30m) from the large Douglas-fir. Subsequent sampling points within that directional zone were established at 30m intervals along the same random azimuth. This procedure, which was repeated for each of the thirteen large Douglas-fir trees, was adopted to insure that plots would be located at varying distances up to 150m and in varying directions away from a Douglas-fir tree of seed producing age. Using this procedure, 20 sampling points were located around each large seed tree for a total of 260 points.

At each sampling point nested square quadrants ($10m^2$ and $100m^2$) were established in order to determine the density of tree saplings and seedlings and ground cover characteristics. The $10m^2$ plots were used to estimate the percentage of ground cover in various categories: annual grass, perennial grass, broad-leaved herbaceous plants, ferns, leaf litter, base of tree, limbs and logs, rocks, and bare ground. Tree seedlings (plants <1cm in diameter at ground-level) and saplings (plants >1cm in diameter at ground level and <1.4m tall) were recorded from $100m^2$ quadrats centered at the sampling point. In addition, percent cover of shrubs was determined using the line intercept method (Bauer, 1943) along two diagonal lines connecting opposite corners of the $100m^2$ plot. Although this approach gives stronger weight to vegetation in the center of the plot, it was used because of the low density and frequency of shrubs. The distances from each plot center to the nearest Douglas-fir tree in each of three diameter ranges (10-19.9cm; 20-39.9cm; and greater than 40cm DBH) were also measured. Topographic conditions (e.g., aspect, percentage slope) were recorded at each sampling point.

The field data were used to establish correlations between each variable and the density of both Douglas-fir seedlings and saplings. Pairwise scatterplots were run between every possible combination of dependent variable (Douglas-fir seedling density and sapling density) and independent variable (percent ground cover in each category, total living ground cover, percent shrub cover, topographic condition, and distance to seed tree) in order to gain a preliminary understanding of the relationships among the variables. Subsequently, correlation analysis was used to determine the degree of association between these variables. "$\log_{10}$," "square root," and "arcsine" transformations were applied to all the data to improve the linearity of the relationships (Sokal and Rohlf 1981).

RESULTS AND DISCUSSION

Correlation analyses yielded generally low correlation coefficients (table 1). These low correlations may be be due to the difficulty of fitting a straight line to a curvilinear distribution. Several of the correlation coefficients were statistically significant. Slightly higher values for $\underline{r}$ and $\underline{r}^2$ were obtained with the "square root," "arcsine," and "$\log_{10}$" transformations. Furthermore, additional relations were shown to be significant, or significant at higher levels, with these transformations. However, both $\underline{r}$ and $\underline{r}^2$ values remained relatively small ($\underline{r}$ <.35; $\underline{r}^2$<.13). Only the non-transformed data will be presented in this report.

Although the significant statistical correlations found in this study had small $\underline{r}$ and $\underline{r}^2$ values, they may nevertheless be useful indicators of relationships which merit further study. In addition, they may help us to understand the importance of various vegetation and site factors in controlling the invasion of oak woodlands by Douglas-fir at Annadel State Park.

The negative correlation found between the distance to large (>40cm DBH) Douglas-fir trees and the density of Douglas-fir seedlings and saplings suggests the importance of seed source in the invasion of oak woodlands by Douglas-fir. The scatter diagrams (Figs. 2 and 3) depict a curvilinear relationship which is typical of dispersal patterns for wind-disseminated propagules (Wolfenbarger, 1959; Roe, 1967; Harper, 1977). The lack of significant correlations between seedling or sapling density and Douglas-fir trees <40cm DBH may be due to the lower seed-producing capacities of smaller and younger trees. Open grown Douglas-fir trees begin producing appreciable amounts of seeds between their age 20 and 30, but maximum seed production occurs between the ages of 200 and 300 years (Isaac 1943).

The correlation between the density of Douglas-fir seedlings and the total number of seedlings of other tree species (table 1) suggests that conditions favorable for the establishment of Douglas-fir seedlings are also favorable for the establishment of other tree species. This interpretation should be viewed in the context of the study site, where seedbeds generally result from an undisturbed understory. Such conditions differ considerably from those following destructive overstory fires, hurricane-caused blowdowns, or clearcut logging in the Pacific Northwest, where high densities of Douglas-fir seedlings are not associated with high densities of seedlings of other tree species (Isaac, 1938 & 1940). Within oak woodlands occurring in Mediterranean climatic regions,

Table 1--Correlation analysis of independent and dependent variables (Douglas-fir seedling and sapling density) relating to Douglas-fir establishment in oak woodlands at Annadel State Park.

	Dependent Variable							
	D.F. Seedling Density				D.F. Sapling Density			
Independent Variable	r	r^2	P-value	Signif.	r	r^2	P-value	Signif.
Total No. Seedlings[1]	.1576	.0248	.011	*	-.0919	.0084	.140	
Total No. Saplings[1]	.0093	.0001	.881		-.0366	.0013	.557	
Total No. Seedlings and Saplings[1]	.1068	.0114	.086		-.0886	.0078	.154	
Distance to Nearest Douglas-fir (10-20cm) DBH	-.0788	.0062	.267		-.0554	.0031	.489	
Distance to Nearest Douglas-fir (20-40cm) DBH	-.1259	.0158	.058		-.0460	.0021	.489	
Distance to Nearest Douglas-fir (>40cm) DBH	-.2304	.0531	.000	***	-.1831	.0335	.005	**
Percent Ground Cover:								
Annual Grass	-.1479	.0219	.017	*	-.1563	.0244	.012	*
Perennial Grass	-.1053	.0111	.090		-.1161	.0135	.062	
Forbs	-.0138	.0002	.824		-.0107	.0001	.864	
Ferns	-.0484	.0023	.437		-.0533	.0028	.392	
Bare Soil	-.0101	.0001	.872		-.0484	.0023	.437	
Base of Trees	.0426	.0018	.494		.1705	.0291	.006	**
Leaf Litter	.2009	.0404	.001	**	.2051	.0421	.001	**
Rock	.0188	.0004	.763		.0400	.0016	.521	
Log	-.0559	.0031	.369		-.0724	.0052	.245	
All Living	-.2161	.0464	.000	***	-.2245	.0504	.000	***
Percent Shrub Cover	-.0451	.0020	.470		-.0370	.0114	.553	
Aspect	.0803	.0064	.198		.0116	.0001	.852	
Slope	-.1086	.0118	.081		-.0268	.0007	.668	

[1]Not including Douglas-fir
*p <.05
**p <.01
***p <.001

undisturbed understory and overstory conditions may provide favorable sites for seedling establishment by reducing soil moisture depletion during the late spring and early summer and by minimizing evaporative stress due to the shading of the seedbed.

The various statistically significant correlations between the percentage of different ground cover types and the densities of Douglas-fir seedlings and saplings are interpreted as indicators of the importance of soil moisture and its rate of depletion for the establishment of Douglas-fir within the oak woodland. The negative correlations found with annual grass and all living ground cover are further interpreted as indicators of the importance of competition for soil moisture in the establishment of Douglas-fir (table 1).

The positive correlation between leaf litter cover and Douglas-fir seedling and sapling density may also be interpreted in terms of moisture availability and reduced evaporative stress (table 1). Specifically, the larger the area covered by leaf litter on the sample plots, the smaller the cover by living plants. This would suggest reduced competition for soil moisture. In addition, higher percent cover by leaf litter is also associated with greater crown cover by trees, which in turn would reduce the evaporative stress over the seedbed. Mulching may also be a factor in the retention of soil moisture. Several authors (Munger 1927; Isaac 1938 and 1949; Isaac and Dimock 1958; Fowells 1965) have similarly suggested that Douglas-fir seedlings are sensitive to drought and high levels of evaporative stress.

Finally, a positive correlation exists between the base of tree parameter (i.e., at least a portion of a tree base within the sampling area) and Douglas-fir sapling density, but no significant correlationis found relative to seedling density (table 1). This suggests that seedlings can become established under proper moisture and understory conditions, but that survival into the sapling stage requires further environmental amelioration afforded by the presence of "nurse trees."

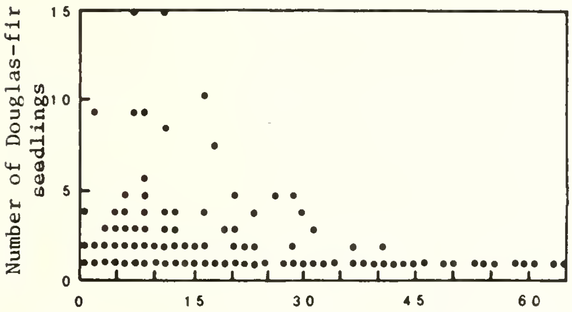

Figure 2--Relationship between the number of Douglas-fir seedlings on 100m^2 quadrants and the distance to the nearest Douglas-fir tree >40cm DBH.

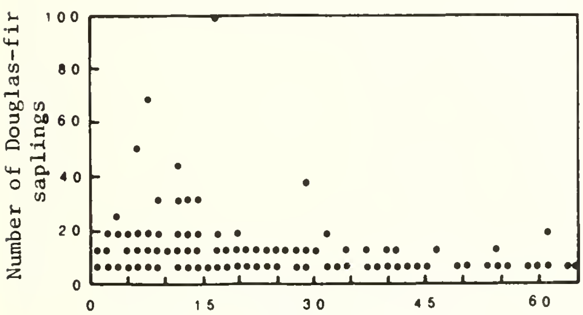

Figure 3--Relationship between the number of Douglas-fir saplings on 100m^2 quadrants and the distance to the nearest Douglas-fir tree >40cm DBH.

We hypothesize that soil moisture, the rate of soil moisture depletion and evaporative stress are the primary environmental factors controlling Douglas-fir establishment within oak woodlands. The importance of soil moisture, as suggested by our preliminary findings, raises the question of the significance of annual variations in precipitation for the establishment of Douglas-fir in the oak woodland. Initial estimates of seedling age obtained during this study indicate that most of the seedlings became established in 1981 and 1982. These were years of above average rainfall (November thru April 1981-82 was 72% above average; same period 1982-83 was 90% above average [NOAA 1981-83]).

We hypothesize that oak woodlands in the vicinity of Annadel State Park will experience periodic invasions of Douglas-fir during years of above average rainfall and/or years of reduced moisture stress. Furthermore, in the absence of periodic wildfire or other destructive forces, Douglas-fir will increase within these oak woodlands to eventually dominate and replace the oaks. The rate of invasion and replacement of oak woodland will vary from site to site within the vegetation mosaic, the fastest rates occurring on those sites characterized by the proximity of large Douglas-fir seed trees, increased oak canopy cover and understories with reduced herbaceous plant cover and predominance of litter.

REFERENCES

Anderson, M.V. and Pasquinelli, R.L. Ecology and management of the northern oak woodland community, Sonoma County, California. Rohnert Park, CA: Sonoma State University; 1984. 125 p. M.A. Thesis.

Barnhart, S.J. The ecology of the central coast woodlands of California. Available from Life Sciences Department, Santa Rosa Junior College, Santa Rosa, CA 95401; 1978. 25 p.

Bauer, H.L. The statistical analysis of chaparral and other plant communities by means of transect samples. Ecology 24:45-60; 1943 January..

Fowells, H.A. Silvics of forest trees of the United States. Agriculture Handbook No. 271. Washington, D.C.: U.S. Department of Agriculture; pp. 547-553. 1965.

Futini, J.S. Annadel: the history behind the park, 1837-1971. Rohnert Park, CA: Sonoma State University; 1976. 215 p. M.S. Thesis.

Griffin, J.R. Oak woodland. In M.G. Barbour and J. Major (eds.) Terrestrial Vegetation of California. New York: J. Wiley and Sons; 1977. pp. 383-415.

Harper, J.L. Population biology of plants. New York: Academic Press; 1977. pp 36-49.

Isaac, L.A. Factors Affecting establishment of Douglas-fir seedlings. Agriculture Circular 486. Washington, D.C.: U.S. Department of Agriculture; 1938. 45 p.

Isaac, L.A. Vegetative succession following logging in the Douglas-fir region with special reference to fire. J. Forestry 38:716-721; 1940 May.

Isaac, L.A. Reproductive habits of Douglas-fir. Washington, D.C.: Charles Lathrop Pack Foundation; 1943. 107 p.

Isaac, L.A. Better Douglas-fir forests from better seed. Seattle, WA: Univ. Washington Press; 1949. 64 p.

Isaac, L.A. and E.J. Dimock. Silvical characteristics of Douglas-fir. Silvical Serv. 9.

Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1958. 18 p.

Jenkins, O.P., ed. Geologic guidebook of the San Francisco Bay counties. Bull. 154. San Francisco, CA: California Div. Mines; 1951. 269 p.

McBride, J. Plant succession in the Berkeley Hills, California. Madrono 22(7):317-329; 1974 July.

McBride, J. and H.F. Heady. Invasion of grassland by Baccharis pilularis, D.C. Jour. Range Mgt. 21:106-108; 1968 January.

McBride, J.R. and E.C. Stone. Plant succession on sand dunes of the Monterey Peninsula, California. American Midland Naturalist 97(1):118-132; 1976 January.

Munger, T.T. Timber growing and logging practice in the Douglas-fir region. Bulletin 1493. Washington, D.C.: U.S.Department of Agriculture; 1927. 42 p.

Munz, P.A. and D.D. Keck. California plant communities-supplement. El Aliso 2:199-202. 1950 January.

NOAA. Climatological Data: California. Ashville, NC: Environmental Data and Information Service 1981, 82, 83.

Plumb, T.R. and P.M. McDonald. 1981. Oak management in California. Gen. Tech. Rep. PSW-54. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S.Department of Agriculture, 1981. 11 p.

Roe, A.L. Seed dispersal in a bumper spruce seed year. Research Paper 39. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1967. 10 p.

Sawyer, J.O., D.A. Thornburg, and J.R. Griffin. Mixed evergreen forest. In: M.G. Barbour and J. Major, eds. Terrestrial Vegetation of California. New York: Wiley-Interscience; 1977. pp. 359-381.

Sokal, R.R. and F.J. Rohlf. Biometry 2d ed. New York: W.H. Freeman and Co.; 1981. 469 p.

Tunison, J.T. A synecological study of the oak-dominated communities of Bennett Mountain, Sonoma County, California. Rohnert Park, CA: Sonoma State University; 1973. 143 p. M.A. Thesis.

U.S. Weather Bureau. Climatic summary of the United States-supplement for 1951 through 1960, part 4: California. Washington, D.C.: U.S. Weather Bureau; 1964.

Wainwright, T.C. and M.G. Barbour. Characteristics of mixed evergreen forest in the Sonoma Mountains of California. Madrono 31:219-230. 1984 March.

Waring, R.H. and J. Major. Some vegetation of the California Coastal redwood region in relation to gradients of moisture, nutrients, light and temperature. Ecol. Monogr. 34:167-215. 1964 January.

Wells, P.V. Vegetation in relation to geological substratum and fire in San Luis Obispo quadrangle, California. Ecol. Monogr. 32:79-103. 1962 January.

Wolfenbarger, D.O. Dispersal of small organisms. Lloydia 22:1-40. 1959 January.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Northern Oak Woodlands—Ecosystem in Jeopardy or Is It Already Too Late?[1]

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Abstract: The bald hills component of the northern oak woodland differs from other California oak woodlands in its structural relationship with grasslands. This woodland consists of a patchy mosaic of Oregon white oaks (*Quercus garryana* Dougl.) unevenly interspersed with grassland. The present stand distribution, reproduction and structure reflect past history of livestock grazing, periodic burning, fire suppression and logging activities. One-third of the prairie/oak woodland acreage that was within the present Redwood National Park in 1850 has converted to conifer forest since the beginning of white settlement. Half of the remaining oak woodlands are likely to convert within the next 20 to 30 years. This encroachment, historically controlled by fire, can be limited effectively by prescribed burning. Conifer encroachment will continue throughout the extent of bald hills oak woodlands unless management priorities and practices are altered to retain this unique component of California oak woodlands.

Extensive open grasslands and oak woodlands occur naturally adjacent to the dense coastal redwood (*Sequoia sempervirens* [D. Don] Endl.) forests. Griffin (1977) segregated the northern oak woodland as described by Munz (1973) into two distinct elements: one a continuation of the interior foothill woodland and the other a structurally distinct, geographically isolated coastal community known as "bald hills" oak woodlands. The latter are characterized by a patchy mosaic pattern of dominance by either Oregon white oak (Quercus garryana Dougl.) or grass, not the balanced mixture of oaks and grassland found elsewhere in California (Clark 1937). Bald hills oak woodlands are found in the Coast Ranges of California from Humboldt and Trinity counties south to Napa County. About 250 hectares (600 acres) of bald hills oak woodlands are located in Redwood National Park (RNP) along the ridge crest on the east side of the Redwood Creek basin in northern Humboldt County. South, southwest and west-facing moderately steep slopes with earthflow terrain support bald hills prairie and oak woodland vegetation.

Conifers, especially Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), are encroaching on these prairies and oak woodlands in RNP. Continued encroachment could result in the eventual replacement of much of the oak woodland community by conifer forest. Restoring and perpetuating the scene encountered by the first European visitors and preserving natural diversity are consistent with Park Service policies (U.S.D.I 1987). This paper discusses factors that have influenced the bald hills community, findings of ecological studies in the oak woodlands within the park, implications for woodlands outside the park, and management options for re-establishing processes which perpetuated the bald hills ecosystems before European settlement.

HISTORICAL PERSPECTIVES AND PRESENT STATUS

Land Use Changes

The bald hills were at least seasonally inhabited for over 6,000 years before European settlement (Hayes 1985, Wallace 1978a). Archeological evidence provides proof that Native Americans (Chilula) had villages, seasonal camps and ceremonial sites in the bald hills (Goddard 1914, King and Bickel 1980). The Chilulas depended mainly on hunting and gathering for subsistence. Since the primary food sources were deer, elk and acorns, the bald hills were important regions (Goddard 1914). Burning, especially along the prairie/oak woodland margins, stimulated fresh vegetation growth which not only attracted wildlife but provided superior basket materials (Baumhoff 1978). Burning to keep Douglas-fir from advancing into the prairies and oaks was also an objective (Thompson 1916). The Chilulas and other nearby Native Americans apparently set fire to prairies and oak woodlands frequently, but it is not known when aboriginal burning began in the area or at what intervals it was practiced (Thompson 1916).

Native Americans had little contact with whites until two large-scale expeditions crossed through the area in 1828 and 1849 (Bearss 1969). In 1850,

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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gold miners and pack traders began regularly carrying supplies to Trinity County mines over trails which passed through the bald hills (Wistar 1937). Hostilities between whites and the Chilulas quickly ensued, especially when white settlers established homesteads in the highly desirable Native American territory in the bald hills (Goddard 1914). By 1864, after years of fighting and abortive attempts by the Army to relocate the Chilulas, the few surviving were finally removed from the area and white settlement resumed (Wallace 1978b, Greene 1980). Homesteaders rapidly developed a thriving stock industry of grazing sheep, cattle, horses and mules in areas now within RNP (Greene 1980). Grazing continued on park lands at various intensities from 1865 to 1982.

Some burning was done during the early settlement period but was eventually discontinued and replaced by a policy of suppressing fires, especially wildfire (Stover 1983). Lightning-ignited fires did originate in the bald hills but probably more frequently burned into the area from the drier interior. Post-settlement land use of the bald hills consisted mainly of cutting oaks for firewood and fencing materials and grazing. Commercial conifer logging that began downslope of the bald hills in the 1950's had little direct effect on the oak woodlands, although logging roads were constructed through some oak stands, and several prairies were systematically planted with conifers.

Changes in Stand Structure, Vegetation Patterns and Regeneration

The present bald hills oak woodlands differ from those in 1850 in several ways. The change in human disturbance due to settlement and the removal of Native Americans modified conditions in the bald hills. Vegetation patterns created or perpetuated by natural factors or the activities of Native Americans are considered part of the natural system, so a reference date of 1850 was used for mapping and interpreting vegetation changes within the park (U.S.D.I. 1987).

Historical patterns were determined by sampling and mapping the existing vegetation patterns, aging standing and harvested conifer forests, determining fire histories from fire scars (Sugihara and Reed 1987a), consulting RNP soils personnel (Popenoe 1986, Sturhan 1987) and reviewing literature on cultural resources, early exploration and settlement and nearby palynological investigations (West 1983). Pathways leading to ecosystem modification were interpreted from individual plant and entire community responses to grazing and other animal use, various burning regimes, climatic changes and competitive interactions between species.

Stand Structure

Based on descriptions by early explorers (Carr 1891) and our own stand structure data (Sugihara et al. 1983), we believe the presettlement oak stands in the bald hills were fairly open and composed of single-stemmed, regularly-spaced trees. These stands are thought to have contained trees of all sizes and ages that originated from acorn reproduction whenever openings in the canopy occurred. The stands had well-developed, rounded crowns forming a closed canopy. Glades interspersed within the oak stands formed the distinctive bald hills mosaic pattern.

Baumhoff (1978) felt that prior to 1900, the oak woodland areas in the North Coast Ranges were relatively open due to Native American burning in pre-settlement times and by white settlers later. He perceived that Native American practices would have contributed to a dynamic equilibrium between trees, grasses and shrubs resulting in open parklands that were highly productive for the hunter-gatherer society. When frequent burning was discontinued, brush became thicker and the oak stands consequently became more susceptible to devastating fires. Thilenius (1968) concluded that the dense white oak forests in the Willamette Valley of Oregon also developed from more open savannah stands when fire was discontinued. Although the stands Thilenius studied were more similar to interior foothill woodlands of California than bald hills woodlands, they did show the effect that changing the burning regime had on stand structure.

Increased stand densities are now more typical but some older trees with an open-grown form are still found mixed with trees grown in closed stand conditions. The most wide-spread stands today are fairly dense (740 to 2,550 trees/ha), even- aged (80 to 120 years old), have medium-size (mean 16.7 cm), clustered trunks and narrow forest-form crowns (Sugihara and Reed 1987a). Fire histories and growth rates confirm that most of these stands originated by sprouting of damaged trees after fires in the post-settlement period and not from acorns. Younger trees, less than 40 years old, form extremely dense stands in a few areas and are the result of sprouting after more recent stand-replacing fires (Sugihara and Reed 1987b, these proceedings). Each of these stand structures can be distinguished by differences in shrub and herbaceous cover as well as by the understory species present. The oak woodlands support a highly diverse flora and the nearly 300 species represented far exceeds that of any other vegetation type in the park.

Vegetation Patterns

The 1850 prairie/oak woodland system extended almost continuously from Elk Camp (11 km inland) to what is now the south park boundary (23 km inland). The interface between the bald hills vegetation and that of the surrounding redwood forests was relatively stable and often quite abrupt. These ecotones usually corresponded to natural topographic features, such as spur ridges and slope changes which acted as natural fire breaks. Redwoods up to 5 meters in diameter were found next to open prairies and oak woodlands. One-third of the area supporting bald hills vegetation in 1850 was mapped as conifer forest in 1983. The actual proportion of oak woodland to grassland in 1850 is unknown. Since oaks tend to be on prairie margins and are more actively encroached by conifers than intact grasslands, it is likely that the proportion of oaks was higher in 1850 than at present. Stands of Douglas-fir now fragment the prairies and oak woodlands into discontinuous units and redwoods are often distant from open prairies.

Fluctuations in the boundaries between bald hills vegetation and conifer forest undoubtedly occurred before 1850, but we believe that frequent fires probably prevented the persistence of the fire-intolerant conifer seedlings. With fire eliminated from the system, conifer establishment lacked effective control and Douglas-fir became dominant in widespread areas where it had not previously survived.

Grazing probably played a major role in increasing the rate of encroachment. As Stein (1980) suggested for the Willamette Valley, livestock grazing in the bald hills probably also kept the understory more open and subject to rapid invasion than during undisturbed successional development. Grazing would have reduced the height of grasses and forbs and heavy trampling provided good seed sites for conifer establishment. The current high rate of encroachment may decrease with less grazing disturbance.

Regeneration

Problems in oak regeneration exist throughout California's oak woodlands. Highly variable annual acorn crops and inconsistent seedling production are characteristic of many oak species, including Oregon white oak. Oregon white oak successfully reproduces by both seed and sprout, but true seedlings were less abundant in our sampling than sprouts. Land use and management practices affect seedlings and sprouts differently. Activities which reduce predator populations, increase grazing pressure, or promote dense stands tend to effectively decrease acorn production or seedling survival. Activities which reduce grazing pressure or rodent populations would promote seedling establishment. Periodic fires or cutting would increase sprout production and fires would also thin the sprouts produced after previous fires.

Our oak stand structure data indicate that regeneration has been more prevalent from sprouts than by acorns in post-settlement times (Sugihara and Reed 1987a). Clustered trees characterize the majority of oak stands in the park. Uniform size and age within stands and rapid growth to breast height make sprout origin credible. We found vigorous sprouting after burning to be common for Oregon white oak. Some sprouts resulting from fires are more like criss-crossing rhizomes extending several meters before emerging from the humus. These produce clusters up to 5 meters in diameter or widely spaced individuals quite distinct from the parent tree.

There has been relatively little oak invasion into grasslands during the post-settlement period because the primary mechanism for oak reproduction has been vegetative sprouting. We observed greater numbers of seedlings since grazing has ceased but no evidence of massive acorn dispersal into the prairies has been seen. Greater wildlife use since cattle are no longer in the area may also affect acorn dispersal.

FOREST ENCROACHMENT - A RESOURCE IN JEOPARDY?

Douglas-fir invasion into the oak woodlands and on prairie margins, road cuts and disturbed areas has progressed for many decades. With fire eliminated from the system, conifer encroachment lacks natural control and has exceeded ecotone fluctuations. Much of the conifer encroachment in the bald hills can be directly attributed to recent human activities (i.e. road building, fire suppression, grazing, and timber harvesting and regeneration).

Douglas-fir occurs throughout oak woodlands in the park as scattered individuals, large concentrations, and closed canopy stands overtopping the oaks. Field mapping and vegetation sampling show that about half of the current oak woodlands already contain enough established Douglas-fir seedlings to dominate the canopy within 20 to 30 years (Sugihara and Reed 1987a). In this region, young Douglas-fir can easily grow a meter a year and quickly overtop oaks 15 m in height. Oaks cannot survive for long or reproduce under the dense shade and the shrub and herb understory is completely shaded out. Once conifers overtop and eliminate oaks, the site becomes conifer forest. Former oak stands have been overtopped by dense, even-aged Douglas-fir canopies in several areas. Redwood seedlings are found frequently in the understory after about 100 years of Douglas-fir stand development. Succession is eventually to redwood/Douglas-fir forest (Sawyer et al. 1977).

Invading Douglas-fir stands 40 to 80 years old that bordered much of the oak woodland were large enough to be logged prior to park acquisition. Vegetation response after logging was similar to that following clearcutting of an old-growth conifer forest. The colonizing vegetation consisted mainly of a dense shrub layer and many conifer seedlings, but few woodland species. Since clearcuts regenerate to conifer forest instead of oak woodland, cutting perpetuates the conversion of oak woodland to conifer forest.

Extensive observation of bald hills oak woodlands and prairies revealed that Douglas-fir encroachment was not limited to Redwood National Park. Encroachment is typical and even more advanced in southern Humboldt and Mendocino counties. Barnhart et al. (1987) noted that similar encroachment near the southern end of the northern oak woodland corresponded to periods of above-average rainfall. Douglas-fir forests have overtaken extensive areas that were once oak woodlands and prairies. Because management objectives and practices on lands outside the park are not likely to change significantly, conversion to conifer forest will probably continue and most of the land will be used for timber production. There is little doubt that the northern oak woodland is in jeopardy. Maintained in presettlement times as a fire-sustained climax, we believe that the drastic reduction in fire frequency in the bald hills has tipped the ecological balance in favor of Douglas-fir and, eventually, redwood/Douglas-fir forest. Without regular fires to eliminate conifer seedlings before they become fire-resistant, we see little chance of perpetuating the bald hills ecosystem.

WHAT DOES THE FUTURE HOLD? - IS IT ALREADY TOO LATE?

Although heavily encroached, substantial areas of bald hills oak woodland can still be restored and maintained as natural openings and valuable wildlife habitat in the otherwise densely forested redwood region. Prescribed fire on a regular basis can effectively exclude further Douglas-fir re-establishment (Sugihara and Reed 1987b, these proceedings).

The restoration phase is likely to be the most costly, visually unpleasant, and certainly the most controversial part of oak woodland management. To return the community to a fire-maintainable condition, large individual trees and stands too dense to carry a fire should either be cut or girdled. Both methods have been successful in RNP (Sugihara and Reed 1987a). Cutting kills the trees immediately but produces large residues of slash. Girdling takes longer to kill the trees but produces less slash at any one time and creates snags for wildlife habitat. Both methods can be effective and may be used in appropriate cases. Vigorous restoration, but extremely cautious initial burning, are suggested for areas with many conifers.

Experience with prescribed fires in RNP has demonstrated potential for restoring the ecosystem to a stable equilibrium (Sugihara and Reed 1987b, these proceedings). Douglas-fir saplings less than 3 meters tall were killed by low-intensity surface fire. The trees reach a thick barked, fire-resistant size of greater than 3 meters in about ten years. The bark insulates the cambium from heat damage, and the trees have grown large enough to shade out the herbaceous understory, reducing the amount of fuel adjacent to the trunk. A fire every five years would probably keep the woodlands free of threatening conifers and compensate for less than complete burns. It is necessary to remove most Douglas-fir from the system to restore ecotones maintainable by fire.

Without changes in management policy, many areas of northern oak woodland will convert to conifer forest. Extensive tracts have already been lost and the rate of forest encroachment appears to be increasing with time. The fate of the remaining restorable oak woodlands should be determined soon or there will be little resource to manage. Many oak woodlands are progressing beyond the stage where restoration is practical. In RNP, we have the opportunity to restore part of the bald hills oak woodlands to an equilibrium, reintroduce processes that shaped the natural vegetation patterns, and protect a plant community that is rapidly diminishing in extent.

REFERENCES

Barnhart, Stephen J; McBride, Joe R.; Cicero, Carla; da Silva, Paul; Warner, Peter. Vegetation dynamics of the northern oak woodland. 1987. [These proceedings].

Baumhoff, Martin A. Environmental background. In: Heizer, Robert F., ed. Handbook of North American Indians, California, volume 8; Washington, D.C.: Smithsonian Institute; 1978:16-24.

Bearss, Edwin C. History, basic data - Redwood National Park, Del Norte and Humboldt counties, California. Washington, D.C.: Washington Regional Office, National Park Service, U.S. Department of the Interior; 1969. 433 p.

Carr, John. Pioneer days in California. Eureka, CA: Times Publishing; 1891.

Clark, Harold W. Association types in the North Coast Ranges of California. Ecology 18(2):214-230; 1937 April.

Goddard, Pliney Earle. Notes on the Chilula Indians of northwestern California. Berkeley, CA: University of California publications in American Archaeology and Ethnology 10(6):265-288; 1914 April 3.

Greene, Linda W. Historical overview of the Redwood Creek basin and bald hills regions of Redwood National Park, California. Denver, CO: Denver Service Center, National Park Service, U.S. Department of the Interior; 1980. 52 p.

Griffin, James R. Oak woodland. In: Barbour, M. G.; Major, J., eds. Terrestrial vegetation of California. New York, NY: Wiley Interscience; 1977:384-415.

Hayes, John F. An analysis of Redwood National Park artifacts. Crescent City, CA: Redwood National Park, National Park Service, U.S. Department of the Interior; 1985. 143 p.
King, A. G.; Bickel, P. McW. Resource evaluation at nine archeological sites, Redwood Creek basin, Redwood National Park, California. Arcata, CA: Redwood National Park, National Park Service, U.S. Department of the Interior; 1980.
Munz, Phillip A; Keck, David. D. A California flora with supplement. Berkeley, CA: Univ. of California Press; 1973. 1681 p. and 244 p.
Popenoe, James H. Soil Scientist, Redwood National Park. [personal communication] 1986.
Sawyer, John O.; Thornburgh, Dale A.; Griffin, James R. Mixed evergreen forest. In: Barbour, M. G.; Major, J. eds. Terrestrial vegetation of California. New York, NY: Wiley Interscience; 1977:359-381.
Stein, William I. Oregon white oak - 233. In: Eyre, F. H., ed. Forest cover types of the United States and Canada. Washington, D. C.: Soc. Amer. For.; 1980:110-111.
Stover, A. M. Landowner, Orick, CA. [personal conversation with Mary M. Hektner]. 1983.
Sturhan, Nancy K. Soil temperature and moisture gradients in several vegetation types in Redwood National Park. Arcata, CA: Humboldt State University; Master's Thesis. 1987. [In preparation].
Sugihara, Neil G.; Reed, Lois J. Ecology and management of bald hills oak woodlands in Redwood National Park. 1987a. Unpublished draft.
Sugihara, Neil G.; Reed, Lois J. Prescribed fire for restoration and maintenance of bald hills oak woodlands. 1987b. [These proceedings].
Sugihara, N.G.; Hektner, M.M.; Reed, L.J.; Lenihan, J.M. Oregon white oak woodlands of Redwood National Park: description and management considerations. In: Van Ripper III, C.; Whittig, L.D.; Murphy, M.L., eds. Proceedings, first biennial conference on research in California's national parks; 1982 September 9-10; Davis, CA: Cooperative Park Studies Unit, Univ. of California, Davis; 1983:177-182.
Thilenius, John F. The *Quercus garryana* forests of the Willamette Valley, Oregon. Ecology 49(6):1124-1133; 1968.
Thompson, Lucy. To the American Indian. Eureka, CA: Cummins Print Shop; 1916. 214 p.
United States Department of the Interior. Resources Management Plan. Crescent City, CA: Redwood National Park, National Park Service; 1987. 72 p.
Wallace, William J. Post-pleistocene archeology, 9000 to 2000 B.C. In: Heizer, Robert F., ed. Handbook of North American Indians, California, volume 8; Washington, D.C.: Smithsonian Institute; 1978:25-36.
Wallace, William J. Hupa, Chilula, and Whilkut. In: Heizer, Robert F., ed. Handbook of North American Indians, California, volume 8; Washington, D.C.: Smithsonian Institute; 1978:164-179.
West, G. James. Pollen analysis results. In: Hildebrandt, William R.; Hayes, John F., eds. Final report, archaeological investigations on Pilot Ridge, Six Rivers National Forest. Eureka, CA: Six Rivers National Forest, Forest Service, U.S. Department of Agriculture; 1983 July; 3.17-3.31.
Wistar, Isaac J. Autobiography of Isaac Jones Wistar, 1827 - 1905, half a century in war and peace. Philadelphia, PA: Wistar Institute of Anatomy and Biology; 1937.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Silviculture, Ecology, and Management of Tanoak in Northern California[1]

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Abstract: Considerations of economic potential, past utilization, habitat, ecology, and silviculture are brought together in nine recommendations for managing tanoak in northern California. These include seeding acorns point up, establishing new stands from root crown sprouts, thinning existing young-growth stands, beginning stands from nursery stock planted at different spacings and learning spacing and growth relationships, and committing large enough areas of land to management of tanoak to support manufacturing plants.

Tanoak (Lithocarpus densiflorus [Hook. & Arn.] Rehd.) is an enigma to forest managers. On one hand, it has a dense, hard, attractive wood that can be manufactured into a variety of products. On the other hand, it is a vigorous competitor to young conifer seedlings, and often is responsible for inadequate stocking of pine and fir plantations.

This paper brings together the economic and biological information that is available on tanoak and synthesizes it into recommendations for managing the species. The recommendations are needed. They should be regarded with caution, however, because some information is from a single source and some is lacking. Wherever possible, the management recommendations are supported by the opinions of numerous people who have worked with tanoak for many years.

Emphasis in this paper is placed on the management of tanoak for wood products, and in particular on why the species is considered to have economic promise. Emphasis also is placed on the biological factors that portray how tanoak becomes established and develops as a tree or stand. Scarcely mentioned is the use of tanoak for wildlife, watershed, or amenity values. Although these values are important, and currently may be even more important than for wood products, space and a general lack of information do not permit discussion. The shrub form of tanoak (var. echinoides R. Br.), although of fairly extensive distribution, is not considered in this paper.

ECONOMIC IMPLICATIONS

Tanoak is considered a "commercial" forest species in all three forest districts in California by the California State Board of Forestry. It is considered to have economic promise for wood products for several reasons: (1) a history of utilization for a large number of wood products, (2) a fairly extensive distribution in southwestern Oregon and California, (3) a large volume of wood, and (4) a number of wood characteristics that compare favorably with heavily utilized eastern species.

History of Utilization

Shortly after the California Gold Rush in 1849, the bark of tanoak became a major source of tannin for curing leather. This was probably the first commercial use of the species and constituted an important early industry in California. Soon after, the potential value of tanoak wood also was recognized: "there is some tall and tough oak on the northern coast which probably will begin to come into the market next year" (Anonymous 1853). By 1891, the wood of tanoak was described in glowing terms: "It is not generally known that this is one of the most beautiful of all the hardwoods of America or, for that matter, of any other country. No other oak begins to vie with it for beauty of grain" (Anonymous 1891). In 1908, taxonomist George Sudworth (1967) noted "the promise it gives of furnishing good commercial timber in a region particularly lacking in hardwoods."

This and other publications note the likelihood of wood products from tanoak as being a source of wealth. Companies and individuals have heeded this siren song and built processing and manufacturing businesses. Few were profitable for long. One of the principal reasons for failure of these operations was lack of a consistent and reliable source of quality raw material (Hall 1982). A supply of tanoak logs would be found and a company formed to manufacture products from them. However, the supply of logs either did not have the anticipated quality or did not last long enough to sustain the industry. Over the years the wood has been used for flooring, panelling, veneer, plywood, pallets, boat parts, pulp, crossties, decking, fuelwood, and mine timbers (Economic Development Administration 1968). Even baseball bats known as "Oregon Slammers" have been made of tanoak (Mast 1968). Recently, tanoak is being considered for waferboard, as a laminate for

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, California Polytechnic State University, San Luis Obispo, California.

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use in sporting goods such as tennis racquets (Cole 1984), and for cogeneration of electricity (Perry 1983).

Distribution

Tanoak ranges from just north of the Umpqua River in the Cascade Mountains of southwestern Oregon southward through the Klamath Mountains and California Coast Range to extreme western Ventura County (Griffin and Critchfield 1972). It is particularly abundant and grows well in Curry, Josephine, Del Norte, Humboldt, and Mendocino Counties. Inland, the species ranges from the lower slopes of Mt. Shasta southward to Mariposa County in the Sierra Nevada. The species is particularly abundant and grows well in Butte and Yuba Counties.

The distribution of tanoak over the landscape is best described as being scattered. Although trees are found as individuals and in clumps and groves, they also form extensive stands, particularly where disturbance from fire or logging has occurred.

Inventory

Best available data (Bolsinger 1987) show that in California, tanoak dominates on more than 350,700 ha (861,000 acres). Over 94 percent of these acres are classed as timberland, rather than woodland--a higher proportion than for any other hardwood species. Tanoak and Pacific madrone stands were the densest of all hardwood species. Total tanoak volume in trees at least 13 cm (5 inches) in diameter at groundline is 54,902 m^3 (1,940,000 ft^3) or 15.5 percent of the total hardwood volume in California. Net annual growth of tanoak was 3.5 percent of inventory, which along with California-laurel (Umbellularia californica [Hook. & Arn.] Nutt.) was highest of all California hardwoods. These numbers indicate a large and increasing inventory of wood. They can be misleading, however, because the trees and stands are scattered and volume per acre often is low. Also, rot and crook often are present and only part of each tree can be utilized. Consequently, logging and processing costs are high.

Wood Characteristics

The wood of tanoak was compared with 19 eastern and western hardwoods and ranked among the best in terms of strength, hardness, and resistance to compression bending and shock (Sander 1958). Tanoak wood also was compared with 33 eastern and western hardwoods for machining and related characteristics. It compared favorably in planing, shaping, boring, and mortising (Davis 1962). The wood also has characteristics of grain and figure to produce a good grade of veneer and plywood (Pfieffer 1957).

BIOLOGICAL IMPLICATIONS

Habitat Conditions

Soils on which tanoak grows are generally deep, well-drained, and loamy, sandy, or gravelly. Rarely is the tree found on shallow soils. In the Coast Range, best development is between elevations of 152 to 915 m (500 to 3,000 ft), especially on northerly and easterly slopes in the north and from 732 to 1434 m (2,400 to 4,700 ft) on westerly slopes near its southern limit. Elevations in the Sierra Nevada where the species prospers range from 580 to 1525 m (1,900 to 5,000 ft) (Roy 1957).

As a whole, tanoak requires a relatively high level of moisture and mild temperatures. Annual precipitation is seasonal and varies throughout the natural range from 1016 to 2540 mm (40 to 100 inches). Most moisture falls as rain from November through March. Average mean daily temperatures range from 2°C to 6°C (36°F to 42°F) in January and from 16°C to 23°C (60°F to 74°F) in July (Roy 1957). Good sites for tanoak are best described as humid with plentiful moisture from rain, high humidity, fog, or low clouds. Tanoak benefits from these conditions because they decrease evapotranspirational demand and ameliorate temperature extremes. On poor sites or near the warmer limit of its natural range, the species grows in shady and sheltered habitats or in riparian zones where moisture demands are less. In general, tanoak is a reliable indicator of productive sites in southwest Oregon (Atzet 1986).

Ecology and Adaptation

The most common arborescent associates of tanoak are Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) and Pacific madrone (Arbutus menziesii Pursh). These species and tanoak, along with several other conifers and hardwoods, often form a complex forest mosaic because of geological and topographical diversity and because of successional patterns compounded by fire and logging. In early seral stages, tanoak forms pure stands, but more commonly it grows in mixtures with other conifers and hardwoods. At maturity, mixed stands of primarily two differing structures are formed. One is an open Douglas-fir canopy over a more continuous lower stratum of tanoak, Pacific madrone, and perhaps other hardwoods (Sawyer 1980). The other is essentially an uneven-aged Douglas-fir and tanoak forest with both species, and perhaps other hardwoods, reproducing in various-sized gaps at different times and forming an irregular canopy of varying age and species composition (Thornburgh 1986).

Tanoak stands develop differently if they begin from seeds rather than sprouts. Reproduction from seed occurs mainly in the understory of mixed hardwood and conifer stands, where a few tanoak seedlings become established each year and their stocking increases slowly over time. Plants remain small for extended periods and are susceptible to dieback, damage, and death. They are remarkably tolerant of shade. Barring disturbance, stand development is drawn out and may take scores of years. Eventually the stands that do form are unevenaged and have variable vertical structure (McDonald 1978, Tappeiner and McDonald 1984). If regeneration is from sprouts that form at the base of cut or burned trees, growth is more dynamic. Robust stems develop quickly and grow rapidly in the more open, sunlit environment of disturbed areas. In most instances, tanoak rootcrown sprouts avoid overtopping because of rapid growth, which is fueled at least in part, by portions of the parent tree root system. Consequently, in clearcuttings or burns, tanoak often forms nearly pure, dense, evenaged stands. With time, these thin somewhat but still remain quite dense.

In most areas, propagation of tanoak is from rootcrown sprouts, although occasional seedlings and seedling-sprouts eventually become trees, produce seed, and keep the species in tune with the ever-changing environment.

Because tanoak often grows in stands with variable vertical structure and also tends to grow in mixtures with other conifers and hardwoods, birds and small mammals generally are abundant in tanoak stands (Atzet and others 1984). The northern flying squirrel, Allen's chipmunk, and dusky-footed woodrat are closely tied to tanoak (Raphael 1987). Hiding, nesting, and thermal cover are provided and acorns are a valuable food source.

As a member of the group of plants called "broad sclerophylls," tanoak is considered by many to be a species that is well adapted to a wide variety of environments, including those that are hot and dry. At least part of the reason for this consideration is found in the fossil record. Paleobotanists have traced tanoak back to the Mascall Flora of the Miocene epoch of 12 to 26 million years ago (Cooper 1922). The species has survived volcanism, glaciation, upheaval, and subsidence in at least part of its present range. Consequently, adaptations to heat, cold, and drought are likely to be part of tanoak's genetic makeup. Adaptations to cope with drought are externally manifest in thick leathery leaves, sunken stomates, and large root systems.

Silviculture

Seed Production

Tanoak sprout clumps produce a fair amount of acorns as early as 5 years and trees produce viable acorns in abundance after age 30 or 40 (Roy 1957). Seed production by mature tanoak trees is frequent and prolific. On a good site in northern California where records of seed production were kept for 24 years, tanoak had four bumper, six medium, and three light seed crops. On this same site, one 16-inch d.b.h. tree had the equivalent of 2.72 million acorns per ha (1.1 million/acre) beneath it in a bumper seed year. The acorns were 79 percent sound (McDonald 1978). Producing large amounts of seed could be a worthwhile strategy. Grinnell (1936) noted that "it is not extravagance, but good investment, for the oaks to provide subsistence for a continuing population of animal associates." The birds and animals that distribute acorns could well have been the means by which tanoak survived the catastrophic geological events of millennia ago. Although it fairly "rains" acorns in a year of a bumper seed crop, acorn production of tanoak is best characterized by being frequent and of low intensity. At least some acorns are produced every other year. And even though acorns may be plentiful in the fall, few remain by spring. Many are killed by insolation and freezing, but even if embryo-dead, are still prime food for birds and animals. The key to remaining viable and escaping consumption is to be quickly covered or hidden.

After acorns fall, their position on the ground is variable; some are oriented point up, some point down, and some on their side. The various positions serve to lengthen the germination period. This increases the odds that weather will be favorable and that consumers will be absent or miss some acorns sometime during this period. To test the effect of acorn position on germination speed and capacity, 844 tanoak acorns were seeded point up and 772 point down in a large field test in northern California. Seeding took place from January 6 through February 11. New seedlings were recorded at 2-week intervals after emergence began. Acorns seeded point up germinated much faster--by April 29, 316 seedlings were present before the first seedlings from point-down acorns began to emerge from the soil. Maximum germination was achieved by July 18 for acorns placed point up, but not until September 18 for those placed point down. Almost three times as many seedlings originated from acorns placed point up (McDonald 1978).

Regeneration from Seed

Establishment of tanoak from seed is best accomplished in the duff and litter beneath existing conifer and hardwood stands. Here, tanoak regeneration is characterized by a slow, steady accumulation of seedlings. On a good site in northern California new seedlings ranged from 54 to 603 per ha (22 to 244/acre) in 9 of 11 years recorded. (No acorns were produced in 2 of the years.) And even though tanoaks 4 years and older declined from 2031 to 1811 per ha (822 to 733/acre), the number of new seedlings exceeded the number lost and the total number of seedlings on the forest floor continued to increase (McDonald 1978).

In disturbed stands, such as by fire or clearcutting, tanoak regeneration from seed is sparse or absent. Seed predators and a hostile environment insure that the proportion of seed that produces seedlings is low. Seed predation limited tanoak establishment in four clearcuttings in southwestern Oregon. In three annual sowings, over 99 percent were lost (Tappeiner and others 1986).

In a large shrub-free clearcutting in northern California, survival and growth of tanoak seedlings from seed was poor. After 10 years, survival was only 30 percent in spite of fertilization with about 0.1 kg (0.25 lb) of 16-20-0 fertilizer each year for 6 years, irrigation with about 1.9 L (0.5 gal) of water per seedling at 2-week intervals during the summer, and shading of some seedlings with shingles (McDonald 1978). Tanoak seedlings averaged 1.3 m (4.3 ft) tall after 10 years. Dieback of stems was pronounced. Inadequate moisture and a generally unfavorable environment were the primary causes of tanoak seedling mortality and lack of growth.

Seedling Growth and Development

Early growth of seedlings is concentrated more in roots than shoots. Root length after one growing season is conservatively estimated to be several times that of shoot length. Shoot growth generally is slow and unpredictable. In a sunny environment, shoots average about 3.3 cm (1.3 inches) per year; in a shady environment about 4.4 cm (1.7) inches per year. Capability to sprout from below ground develops at an early age in tanoak seedlings. In northern California, shoots of several hundred week-old seedlings were killed by a late spring frost. Seventy-five percent of them, however, sprouted with two to four stems (McDonald 1978).

Barring injury, each seedling consists of a single stem for the first 5 to 12 years, and then forms a burl just below ground. Burl size is strongly related to age and site quality (Tappeiner and McDonald 1984). One to five stems often emerge from this burl after the first dieback. The sprouted plants are called seedling-sprouts, and generally are referred to as such if they arise from stems less than 2.5 cm (1.0 inch) at groundline. For unknown reasons the stems die back to the burl at least 3 to 5 times by age 60. Seedling-sprouts also grow slowly. At age 20, seedling-sprouts average only 51 cm (20 inches) high and at age 40 about 163 cm (64 inches) (Tappeiner and McDonald 1984).

Regeneration From Sprouts

Root crown sprouts (defined as being from stems greater than 2.5 cm or 1.0 inch at groundline) develop from dormant buds located on the root crown or burl. Being below ground increases the chance that at least a few buds will escape harm. These buds connect with the primary xylem and move outward to the extent that the tree grows in radius each year. Some of the buds divide as they progress outward and thus the number of subsurface buds increases as the tree grows. If sprouts from the dormant buds are killed and the bark and inner tissue of the tree are injured, callus tissue forms at the terminating point of the radial trace. This callus tissue then serves as the source of many new buds, which are adventitious because they do not have a continuous bud trace all the way to the pith. In either case, the number of buds, and hence potential sprouts, is tremendous. As many as 1,400 buds have been observed on a large tanoak stump (Roy 1957).

Because the sprouts are initially nourished by the root system of the parent tree, sprout growth is rapid and strongly related to parent tree diameter. In southwestern Oregon, trees 2 to 10 cm (1 to 4 inches) d.b.h. produced sprout clumps 1.1 m (3.6 ft) wide and 1.5 m (4.9 ft) tall 6 years after cutting, while trees 21 to 30 cm (8.3 to 11.8 inches) d.b.h. produced clumps 2.6 m (8.5 ft) wide and 2.2 m (7.2 ft) tall in 6 years (Tappeiner and others 1984). In northwestern California, 6-year-old sprouts averaged 3.1 m (10 ft) tall and equally as wide (Roy 1957). In northern California, 10-year-old sprouts were 5.8 m (19 ft) tall and 3.1 m (10 ft) wide (McDonald 1978).

To better understand the variation in growth that appeared in tanoak seedlings and sprouts, internal moisture stress or xylem sap tension was examined over a 24-hour period beginning early in the morning. In one test involving 7-year-old sprouts growing on a fully exposed site, tension increased rapidly at first light and was nearly at peak by sunrise. Tension in excess of 25 atmospheres continued for 14 hours (McDonald 1978). This long duration of high stress indicates that stomates of tanoak are sensitive to light--they open at low light levels and stay open, thus losing valuable moisture by transpiration.

In addition to sprouts from the root crown, another type of vegetative growth called "stool" sprouts occurs on tanoak stumps. These sprouts originate on the vertical side of the stump or from the cambium on the horizontal surface. They are weakly attached and often peeled from the stump by wind and snow or from rubbing by passing animals. They also have a high incidence of rot which bridges from rotting stump to pith of sprouts. Rarely does this transfer of rot occur in root crown sprouts. To minimize stool sprouting, stumps should be no higher than 20 cm (8 inches) above ground.

Nearly all tanoak stumps sprout after the tree is burned or cut and rarely do all the sprouts die. In southwestern Oregon, for example, records have been kept on 1200 stumps on three sites for 6 years and no mortality has been recorded (Tappeiner 1986). Initial number of sprouts may exceed 100 depending on size and vigor of the tree. Generally, trees greater than 30 cm (12 inches) d.b.h. have enough stump circumference to support a large number of sprouts. And vigorous trees, after cutting, produce more vigorous sprouts than do slower growing trees. Number of sprouts is lower if debris is piled against the stump or if the stump is old and thick bark covers the dormant buds. Consequently, number and vigor of sprouts probably is highest in clearcuttings where slash has been broadcast burned. Here, buds are uninhibited by debris and warmed by the sun. Number of sprouts and rapidity of growth appear to be unaffected by site quality, at least for the first 5 or 6 years.

Because tanoak has the reputation of growing well in partial shade, sprout density and growth were examined in a shelterwood cutting. The original stand was a mixture of 60-year-old tanoak, California black oak, and Pacific madrone, with an average basal area of 46 m^2/ha (198 ft^2/acre), and an average of 1628 stems per hectare (659 per acre) greater than 5 cm (2 inches) d.b.h. Tanoak comprised 63 percent of the stand. Trees averaged five or six rings per centimeter (12 to 15 rings per inch) with the annual growth rate in slow decline. Fifty percent of this basal area was removed to form the shelterwood. After 10 years, average height of tanoak sprouts was 2.4 m (8 ft) and width was 2.4 m (8 ft) (McDonald 1978)--or 42 percent of average height of dominant sprouts in the clearcutting nearby. Roots of overstory trees were probably denying resources to the sprouts, and even though the species is tolerant of shade, light levels could have been low enough to inhibit growth.

Thinning

Thinning tanoak sprouts appears to be impractical at least until number of sprouts per stump has declined greatly. If thinned before age 10 to leave several sprouts evenly spaced around the stump, large numbers of new sprouts quickly appear. No effective reduction in density occurs (McDonald 1978).

Growth of sprouts is increasingly influenced over time by the number of sprouts per clump and the number of clumps per hectare. Number of sprouts per clump declines rapidly and 60 to 90 percent die by age 20. Those that remain, however, increase greatly in crown width and height. In general, sprout height increases as the number of clumps of rapidly growing sprouts increases. With age, stand density becomes important and trees grow faster with better form if all grow up together, that is, if crowns are in codominant position.

Thinning 20- to 60-year-old tanoak stands to various density levels may be a viable silvicultural practice. The stand in northern California that had an average basal area of 46 m^2/ha (198 ft^2/acre), noted earlier, was thinned to six different basal areas that ranged from 19 to 32 m^2/ha (85 to 141 ft^2/acre) Wood from the thinning was sold as fuelwood. After 8 years, maximum cubic volume growth (6 m^3/ha or 85 ft^3/acre each year) occurred in stands thinned to 23 to 29 m^2/ha (102 to 125 ft^2/acre) (McDonald 1980). The environment of stands thinned below 23 m^2/ha (102 ft^2/acre) apparently is too open for tanoak. Increased exposure causes decline and eventually death to the top one-third of the tree. Acorn production is reduced drastically during this process. Another finding was that tanoak growth, at least for the age of tree in the study, is about equal whether trees are single or in clumps of two to four stems. Consequently, the forester incurs no penalty of decreased growth if clumps of 2 to 4 well-formed stems are left for future harvest.

MANAGEMENT RECOMMENDATIONS

Because tanoak and conifers intermingle over much of tanoak's natural range, and control of sprouting tanoak is difficult and expensive, management of both on the same acre of land seems logical. For example, dense stands of young tanoak could be thinned and Douglas-fir interplanted. Tanoak productivity would be increased while Douglas-fir was becoming established. Tanoak could be harvested earlier in the rotation--freeing the Douglas-fir for rapid growth. The net result could be a higher total yield from the land.

As mentioned earlier, watershed, wildlife, and amenity values are important considerations in tanoak stands. Wildlife values are particularly important. When comparing tanoak and conifer stands, total stand value provides a better estimate of worth. Inclusion of nontimber values could lessen differences between tanoak and conifer stands.

Although tanoak exhibits many characteristics of a broad sclerophyll species, contradictions are present. The preferred environment of tanoak is anything but the hot and dry landscape home to so many sclerophylls. Shading, however gotten, seems to be needed. Tanoaks develop best where large numbers of clumps and large numbers of stems per clump, both of which provide shade, are present. Even the burgeoning root crown sprouts develop best if all grow up together. And fully developed crowns of mature trees decline and eventually die if exposed by removal of codominant members. Seedling and seedling-sprout development is particularly perplexing. Seedling morphology (thick leathery leaves, sunken stomates, presence of minute hairs) and allocation of resources (emphasis on root biomass) follow the pattern of sclerophylls. Tanoak even has capability to form clumps of stems at a remarkably early age and does so at the slightest excuse--presumably for mutual shading of leaves. Still, the plants die. Inability to close stomates probably contributes to this process, but other factors must be involved. Until more information on the physiology of tanoak becomes available, guidelines for its propagation cannot be firm.

Nevertheless, much knowledge on tanoak is available and recommendations for management of the species can be made. These include:

- Tanoak acorns should be gathered from beneath trees and sprout clumps as soon as possible after they fall. Many sound-appearing acorns are not viable after exposure to heat and cold.
- To insure higher and more rapid germination, propagators should place tanoak acorns point up. The gains from increased availability of soil moisture, because of an earlier start, outweigh the risk of damage from early spring frosts.
- Establishment of tanoak plantations from natural seedlings and from directly seeded acorns appears to be risky, at least for the inland environment. Even though seedlings channel the bulk of resources to developing root biomass at the expense of shoot elongation, they do not grow well or develop in a timely manner. Although some natural seedlings do release and grow rapidly, most do not. How to get adequate, consistent, and reliable shoot growth is not presently known.
- Because we cannot get tanoak seedlings to grow well in the shade and cannot get them to survive well in the sun, outplanting vigorous nursery stock could be one way to encourage rapid and reliable shoot growth. There is some evidence that this has worked with some species of true oaks (Quercus spp.) in the East. Planting could be at different spacings, and density and growth relationships learned. Such relationships could be much different than for stands that originate from root crown sprouts.
- If sprouting stumps are plentiful, establish tanoak stands by encouraging root crown sprouts in clearcuttings. Stumps should be lower than 20 cm (8 inches) to lessen the number of stool sprouts and the incidence of heart rot. Thinning of sprouts, at least before age 10, is not practical.
- For best growth, thin thrifty tanoak stands 20 years of age to a density of about 21 m^2/ha (90 ft^2/acre). For 60-year-old stands in the Sierra Nevada, thin to about 29 m^2/ha (125 ft^2/acre).
- To maximize yields or to meet personal objectives, manage tanoak stands for several products, including wood, wildlife, watershed, and pleasing scenery. Needed is a way to quantify, in dollars, the value of the yields other than wood.
- When tanoak occurs in mixed hardwood-conifer stands, harvest tanoak earlier in rotation for pulp chips and Douglas-fir later for sawtimber.
- Make a commitment to manage tanoak and designate a large area of land for its management, preferably land already stocked with good-quality trees. If this is not done, it is doubtful that a reliable supply of raw material will develop, and tanoak will have little chance of being more than a sporadically harvested, underutilized species.

REFERENCES

Anonymous. 1853. Alta California, San Francisco. October 21.
Anonymous. 1891. Pacific Coast Wood and Iron 15(5):213.
Atzet, Tom; Wheeler, David; Smith, Brad; Riegel, Greg; Franklin, Jerry. 1984. Tanoak series of the Siskiyou Region of Southwestern Oregon. FIR Rep. 6(3):6-7.
Atzet, Tom, Ecologist, Siskiyou National Forest, Forest Service, U.S. Department of Agriculture, Grants Pass, OR. Personal communication. November 1986.
Bolsinger, Charles L. 1987. (These proceedings).
Cole, Dana. 1984. Hardwood utilization experiments. Jackson Demonstration State Forest Newsletter 14. Fort Bragg, CA: Department of Forestry; 2 p. May.
Cooper, William S. 1922. The broad-sclerophyll vegetation of California. An ecological study of the chaparral and its related communities. Carnegie Institution of Washington Pub. No. 319; 119 p.
Davis, E.M. 1962. Machining and related characteristics of United States hardwoods. Tech. Bull. 1267. Washington DC: U.S. Department of Agriculture; 68 p.
Economic Development Administration. 1968. The Hoopa Valley Reservation hardwood study report. Washington DC: U.S. Department of Commerce; 154 p.
Griffin, James R.; Critchfield, William B. 1972. The distribution of forest trees in California. Res. Paper PSW-82. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; (Repr. with supplement 1976). 118 p.
Grinnell, Joseph. 1936. Up-hill planters. The Condor 38:80-82; March.
Hall, Guy H. President, Cal Oak Lumber Co. Personal communication. January 1982.
Mast, Fred R. 1968. Tanoak utilization story: new applications pay off. Forest Industries 95(9):31; August.
McDonald, Philip M. 1978. Silviculture-ecology of three native California hardwoods on high sites in north-central California. Corvallis: Oregon State Univ; 309 p. Dissertation.
McDonald, Philip M. 1980. Growth of thinned and unthinned hardwood stands in the northern Sierra Nevada . . . preliminary findings. In: Proceedings of the Symposium on the Ecology, Management, and Utilization of California Oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 119-127.
Perry, D.A. 1983. Generating electricity with wood and solid waste in southern Oregon. Forest Research Laboratory. Research Bulletin 40. Oregon State University. 87 p.
Pfieffer, J.R. 1957. Oregon hardwood plywood. Information Circular 10. Corvallis, OR: Forest Products Lab; 32 p.
Raphael, Martin G. 1987. (These proceedings).
Roy, D. F. 1957. Silvical characteristics of tanoak. Tech. Pap. 22. Berkeley, CA: California Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 21 p.
Sander, G.H. 1958. Oregon hardwoods: management, marketing, manufacture. Corvallis: Oregon State Univ. Ext. Bull. 775. 15 p.

Sawyer, John O., Jr. 1980. Douglas-fir--tanoak--Pacific madrone. In: Forest Cover Types of the United States and Canada. F.H. Eyre, ed. Washington, DC: Society of American Foresters; 111-112.

Sudworth, George B. 1967. Forest trees of the Pacific slope. New York: Dover Publications, Inc.; 321.

Tappeiner, John C., II; Harrington, Timothy B.; Walstad, John D. 1984. Predicting recovery of tanoak (Lithocarpus densiflorus) and Pacific madrone (Arbutus menziesii) after cutting or burning. Weed Sci. 32: 413-417; May.

Tappeiner, John C., II; McDonald, Philip M. 1984. Development of tanoak understories in conifer stands. Can. J. For. Res. 14: 271-277.

Tappeiner, John C., II; McDonald, Philip M.; Hughes, Thomas F. 1986. Survival of tanoak (Lithocarpus densiflorus) and Pacific madrone (Arbutus menziesii) seedlings in forests of southwestern Oregon. New Forests 1: 43-45.

Tappeiner, John C., II. Professor of Forestry, Oregon State Univ., Corvallis: Personal communication. October 1986.

Thornburgh, Dale O. Professor of Forestry, Humboldt State Univ. Arcata, CA: Personal communication. September 1986.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

The Ecological Setting for the Natural Regeneration of Engelmann Oak (*Quercus engelmannii* Greene) on the Santa Rosa Plateau, Riverside County, California[1]

F. Thomas Griggs[2]

Abstract: Natural regeneration of California's oak has been observed to be low to non-existent. On the Santa Rosa Plateau seedlings of Engelmann oak were searched out and the ecological setting in which they were growing was described. Engelmann oak seedlings were found growing under the canopy of 0.159 of the mature trees on the Vallecitos loam soil type, but with cattle present, 0.125 of the trees had one or more seedlings present. On Murrieta clay soil only 0.039 of the trees had seedlings under them. Saplings occurred under less than 0.01 of the trees on Vallecitos soil, but were found under 0.06 of the trees on the Murrieta clay.

The ecological setting in which the low elevation species of California's oaks grow has been significantly altered over the past two hundred years. Forces are currently operating on these California oaks which were not present throughout their evolution: exotic species of plants competing for available resources, grazing and browsing by livestock with different patterns of seasonal use than the native herbivores, different watershed hydrologic regimes, and humans whose huge numbers have impacted the native oaks for living space. These changes in ecology have resulted in an apparent reduction or elimination of natural regeneration (Griffin 1977). On the Santa Rosa Plateau in Riverside County, while sampling the Engelmann oak woodland, 1996 $1m^2$ randomly placed quadrats and 43 $100m^2$ plots turned up only 11 seedlings (Earl Lathrop, unpublished data). The purpose of this study was to systematically search out seedlings of Engelmann oak and describe some of the obvious ecological forces impacting them.

SITE DESCRIPTION:

The Santa Rosa Plateau is a topographic unit lying at the extreme southeast end of the Santa Ana Mountains in Riverside County, California. Lathrop and Thorne (1985) have described the plant communities and the flora of the Santa Rosa Plateau. The climate is Mediterranean and is moderated by sea breezes throughout the year. Ocean fog can blow in during any month, being most frequent in early summer. The oak woodland is representative of the southern oak woodland community type (Thorne 1976). It is dominated by Engelmann oak (Quercus engelmannii) with coast live oak (Quercus agrifolia Nee) present in lesser numbers. Snow (1972), Lathrop and Wong (1986), and Lathrop and Zuill (1984) have described the structure of the oak woodland on the Santa Rosa Plateau.

The Engelmann oaks in this study grow on two soil types found on the Santa Rosa Plateau Preserve: Murrieta stony clay loam occurs on the tops of olivine basalt capped mesas as a shallow soil averaging less than 20 cm thick (Knecht 1971). Where Engelmann oaks grow, the Murrieta clay occurs in deeper fractures in the basalt, with the basalt cropping out and covering between 25-50 percent of the surface. The other soil is the Vallecitos loam which is characterized by being well-drained and derived from metamorphosed fine grained sandstone and shale. Vallecitos loam is typically over one meter deep, with bed-rock rarely at the surface.

Cattle arrived on the Santa Rosa Plateau by 1846 when the plateau was part of a land grant given to Juan Moreno. Walter Vail purchased the plateau in 1904 as part of his much larger cattle operation. Shortly after 1930 the Santa Rosa Plateau was switched from a cow-calf operation to exclusively steers. This was an important change in management as the steers were removed every year when the range dried in the late spring. Other steers were returned to the plateau the

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources. November 12-14, 1986, California Polytechic State University, San Luis Obispo.

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following winter after the forage had greened, usually by January (Louie Roripaugh, Ranch foreman and cattle buyer for the Vail Co., personal communication). In 1964 the Santa Rosa Plateau was purchased by the Kaiser Development Company for the purpose of developing a residential community. Grazing was continued on an annual lease arrangement with a succession of leases. Cattle grazing between 1964 and 1981 varied between severe overgrazing and non-use by livestock. Since 1982 a cow-calf operation has been on the plateau at somewhat high stocking rates (supplimental feed is necessary between September and November). The California Nature Conservancy purchased 1,255 ha of the Santa Rosa Plateau in January 1984. The fence separating the preserve from the grazing land was completed six months later and the cattle were removed in early June 1984. Thus, only two growing seasons separate the grazing and non-grazing treatments in this study.

Wildfire burned across the plateau relatively frequently in the past: fires were intentionally started in the 1930's and the 1940's by the cowboys to expand the rangeland (type conversion). The most recent fire, which burned the study area, occurred in June 1981. Snow (1979) experimented with Engelmann and coast live oak seedling response to fire and found that Engelmann is less likely to be killed by fire.

SAMPLING METHODS:

Since all Engelmann oak seedlings had previously been observed to grow only under the canopy of mature trees, the individual Engelmann oak tree was used as the sampling unit. Sampling was carried out by walking under trees and examining the herbaceous vegetation for seedling oaks. When seedlings or saplings were found, the following data were recoreded:

Number of Engelmann oak seedlings present.

Number of Engelmann oak saplings present.

For this study seedlings are defined as being less than 0.5 m tall, while saplings range from 0.5 to 2 m tall and are less than 10 cm dbh.

The relative age of seedlings as determined by height.

First year seedlings are 5 cm tall or shorter, have a narrow stem, and the acorn is often still attached to the seedling. Older seedlings (two or more years old) were noticeably taller (10-20 cm), possess larger leaves, have a wider stem, have no evidence of an acorn, and often have evidence of resprouting caused by death or removal of an earlier stem.

Sunlight intensity falling on seedlings.

All seedlings were found to be growing under the canopy of mature trees. However, there is a noticeable decrease in vigor for seedlings growing in complete shade compared to those growing in partial shade, such as those seedlings growing at the edge of the canopy (dripline) of a mature tree. Interestingly, no seedlings were found growing where they could receive full sunlight through the entire day.

The presence of rocks or boulders adjacent to seedlings.

This observation was to determine if the presence of rocks benefitted the seedlings by any of the possible means: lessening the impact of fire and grazing by livestock and gophers, and by concentrating rainfall.

The presence of large branches closely over-hanging the seedlings.

The branches could be protecting the seedlings from grazing by cattle.

The presence of pocket gopher (*Thomomys bottae*) activity within two meters of any seedling.

Pocket gophers have been shown to be an important cause of mortality for valley oak seedlings (Griffin 1979).

The dominant associated species with the seedlings.

RESULTS AND DISCUSSION

Seedling/Sapling Frequencies.

The results are presented on tables 1 and 2, and are organized by soil type and grazing regime. One or more Engelmann oak seedlings were found under 0.159 of the mature Engelmann oak trees on the non-grazed Vallecitos loam, while on the grazed portion of the same soil type, 0.125 of the trees had seedlings under them. This difference is presumably due to the cattle, since the trees sampled were part of the same stand and separated by a fence. Figure 1 shows the different seedling population sizes found under the mature trees. The smaller population sizes occurred in greater frequency under the trees in the grazed pasture relative to those in the non-grazed pastures. The largest number of seedlings found under one tree in the grazed pasture was only 20 individuals, while in the non-grazed pasture several trees had well over 100 seedlings under each of them. This is probably due to the impacts of cattle grazing the seedlings or trampling them when seeking shade.

By contrast, on the Murrieta clay soil only 0.039 of the trees had seedlings under them even though this soil type was not grazed. However, the trees on the Murrieta clay had more saplings under them compared to the Vallecitos soil, by nearly an order of magnitude. Obviously, regeneration success has not been as great on the Murrieta clay in the recent past, as is seen by the drastically different seedling frequencies. Yet at some time in the more distant past, regeneration was relatively successful. The question of why the saplings are so much more abundant on the Murrieta clay inspires the speculation that these trees are a relatively greater distance from summer winter for cattle. The Murrieta clay occurs over half a mile from summer water while the trees on the Vallectios soil are within a quarter mile of several sources of summer water. Thus, the cattle would not spend as much time at the more distant Murrieta clay soils (resulting in less impact) relative to the Vallecitos soils.

First Year vs. Older Seedlings

Over half the seedling populations were composed of first year seedlings (table 2). The remainder were composed of mixtures of first year seedlings and older ones. In the grazed woodland, 0.84 of the occurrences were first year seedlings, presumably reflecting the negative impacts of the cattle in previous years on the older seedlings.

Full Shade vs. Half Shade

Over three-quarters of the seedling populations were growing in full shade (this varied from quite dense to light shade with numerous sun-flects). The remainder grew in half shade at, or just outside, the drip-line of the tree, receiving some amount of direct sunlight.

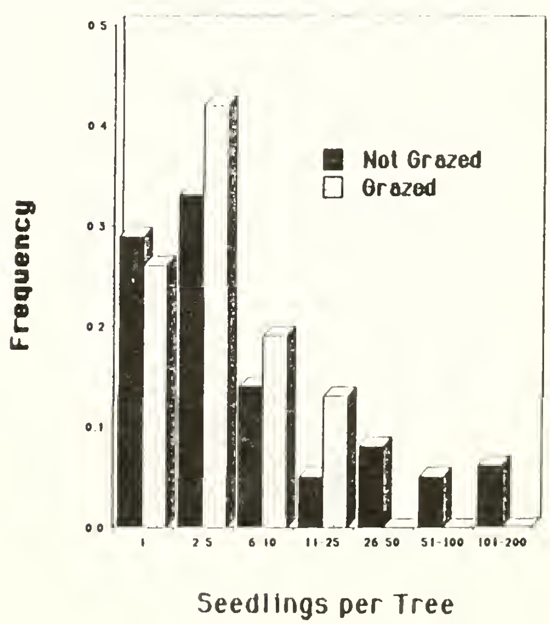
Table I. Frequencies of Engelmann Oak Seedling and Sapling Occurrences Under Mature Trees on the Santa Rosa Plateau.

Soil Type	Vallecitos	Vallecitos	Murrieta Clay
Grazing Regime	not grazed	grazed	not grazed
N	464 trees	344 trees	433 trees
Proportion w/ seedlings	.159	.125	.039
Proportion w/ saplings	.009	.006	.060

Table 2 Frequencies of Engelmann Oak Seedling Populations Experiencing the Listed Ecological Factor.

Soil Type	Vallecitos	Vallecitos	Murrieta Clay
Grazing Regime	not grazed	grazed	not grazed
N	74	43	17
Proportions with			
1st yr s eedlings	68	84	.53
Full Shade	.76	84	.76
Rocks in Soil	.18	26	.53
Branches	.07	.16	.24
Gophers Present	.69	.70	.29

Fig. 1 Frequency of Seedling Population Sizes Under Mature Engelmann Oaks



No Englemann oak seedlings were found more than one meter outside the dripline of a mature tree.

Presence of Rocks in the Soil

A quarter or less of the seedlings on the Vallecitos soils grew among rocks in the soil. Over half the seedlings growing on the Murrieta clay grew in association with rocks in the soil, which may be due to the stony characteristic of the Murrieta clay.

Overhanging Tree Branches

Engelmann oak seedlings showed little preference for the protection afforded by closely overhanging branches.

Pocket Gophers

Recent pocket gopher excavations were present within two meters of seedlings at essentially the same frequency - 0.69 and 0.70 - on the Vallecitos soils, regardless of grazing treatment. By contrast, pocket gophers were present near only 0.29 of the seedling populations on the Murrieta clay, a reflection of the lack of deep soils and the abundance of rock in the soil which minimizes pocket gopher habitat. Evidence of pocket gophers eating the roots of seedlings was rare and only obvious during the spring. However, a seedling must live for many years before its root system is large enough to withstand gopher browsing (Griffin 1979). Seedlings/saplings up to 40 cm tall are being killed by gophers, but this is currently rare.

Associated Species

Table 3 lists species found growing with the Engelmann oak seedlings and their frequency of occurence. The most frequent are species of exotic annual grasses. The several shrub species present reflects the proximity of Engelmann oak to both chaparral and coastal sage scrub communities.

Table 3. Frequencies of associated species of Engelmann Oak seedlings.

Avena barbata Brot.	.31
Hordeum leporinum Link.	.19
Bromus diandrus Roth.	.13
Toxicodendron radicans L. ssp. diversilobum (T&G) Thorne.	.13
Claytonia perfoliata D. Donn. ex Willd.	.08
Ribes indecorum Eastw.	.03
Erodium moschatum (L.) L'Her.	.02
Stipa pulchra Hitch.	.02
Solidago californica Nutt.	.02
Rhamnus ilicifolia Kell.	.02
Malosma laurina (Nutt. in T&G) Nutt. ex Abrams	.02
Opuntia phaeacantha Engelm.	.02
Vicia americana Muhl. ex Willd.	.01

CONCLUSIONS

The results of this study indicate that some of the critical components of regeneration are operating at the Santa Rosa Plateau, namely, viable acorns are being produced and germination requirements are being met, as seedlings are present in high densities under at least some of the trees. However, survival of seedlings to the sapling stage almost never occurs. Range cattle are the suspected agent in the mortality of the oak seedlings, as the frequency of seedlings is slightly less on the grazed pasture. However, only two growing seasons separate the grazed area from the non-grazed area. The other likely predator of oak seedlings, the pocket gopher, occurs at approximately the same density in both the grazed and ungrazed pastures on the same soil type, and is assumed to have equal impacts on both sides of the fence.

It would appear, then, that managing the cattle in the woodland would be the most obvious means of influencing the survival of oak seedlings. From casual observation, it appears that cattle eat the seedlings because they are mixed in the grass forage, rather than seeking them out because of higher palatability. Even during the warm summer months oak seedlings are not eaten as much as they are trampled by animals seeking shade. Thus, timing of grazing would be one way of affecting the survivorship of the oak seedlings. One interesting experiment would be to remove cattle when the Engelmann oak commences growth in April and return them after the first fall rains.

This would allow the cattle to utilize most of the forage while reducing the competition on the oak seedlings from other herbaceous species and the oaks would be ungrazed during their growing season. Methods in such an experiment must involve monitoring the survivorship of individually marked oak seedlings in order to accurately determine their fate.

References

Griffin, James R. Oak woodland. In: Barbour, Michael G. and Major, Jack, eds. Terrestrial vegetation of California. New York; Wiley-Interscience; 1977:338-415.

______. Animal damage to valley oak acorns and seedlings, Carmel Valley, California. In: Plumb, Timothy R. Tech. coord. Proceedings of the symposium on the ecology, management, and utilization of California oaks; June 26-28, 1979, Claremont, CA. Gen. Tech. Rep. PSW-44; Berkeley, CA; Pacific Southwest Forest and Range Experiment Station, US Department of Agriculture; 1980. 242 p.

Knecht, Arnold A. Soil survey of western Riverside area, California; USDA, Soil Conservation Service, 1971.

Lathrop, Earl W.; Thorne, Robert F. A flora of the Santa Rosa Plateau, southern California. Spec. Publ. No. 1, Southern California Botanists; 1985. 39 p.

______. Wong, Brian. Stand characteristics of southern oak woodland on the Santa Rosa Plateau, southern California. Crossosoma 12(4):1-7; 1986.

______. Zuill, Henry A. Southern oak woodlands of the Santa Rosa Plateau, Riverside County, California. Aliso 10(4):603-611; 1984.

Snow, Gerald Eldon. Some factors controlling the establishment and distribution of Quercus agrifolia and Quercus engelmannii in certain southern California oak woodlands. Corvalis, OR. Oregon State University; 1972; 105 p. Dissertation.

______. The fire resistence of engelmann and coast live oak seedlings. In: Plumb, Timothy R., Tech. Coord. Proceedings of the symposium on the ecology, management, and utilization of California oaks; June 26-28, 1979, Claremont, CA. Gen. Tech. Rep. PSW-44; Berkeley, CA, Pacific Southwest Forest and Range Experiment Station, US Department of Agriculture; 1980. 242 p.

Thorne, Robert F. The vascular plant communities of California. In: Latting, June, ed. Proceedings of the symposium on the plant communities of southern California. Spec. Publ. 2; Berkeley, CA; California Native Plant Society; 1976. pp. 1-32.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Yearly Variation of Blue Oak Seedling Emergence in Northern California[1]

Mitchel P. McClaran[2]

Abstract: Previous work in central California suggests that unsuccessful blue oak recruitment is more the result of mortality in the seedling and sapling stages rather than during germination and seedling emergence. Acorns were planted at two northern California sites to investigate the influence of yearly variation in rainfall, oak canopy and cold storage on seedling emergence. Emergence was not affected by cold storage. Emergence was greater with below average rainfall and under blue oak canopy. These results suggest that the reasons for unsuccessful blue oak recruitment varies within the distribution of the species.

A paucity of recent tree recruitment into blue oak stands (Quercus douglasii) has been noted in local and statewide surveys (see review in McClaran 1986, Muick and Bartolome 1986). The observance of seedlings but few saplings and the findings from a germination experiment in Monterey County (Griffin 1971) suggests that unsuccessful recruitment results from mortality in the seedling and sapling stages rather than during germination and seedling emergence. The objectives of this study were to determine the effect of rainfall amount, tree canopy and cold storage on blue oak seedling emergence in more northern and moist environs of its distribution (Griffin and Critchfield 1972).

METHODS

The field portion of the study was conducted at five separate but similar sites in the blue oak savanna at Hopland Field Station in Mendocino County. The controlled portion was done in 4 ft x 4 ft x 8 ft planter boxes with annual grassland species and rainfall as the water source on the University of California, Berkeley campus in Alameda County. A loam soil was present in the field (Gowans 1958) and planter boxes, although the two were not from the same soil series. Only full and intact acorns without visible insect damage, picked from trees in early September of each year from Hopland, were used in the study. All acorns were planted on their side at a 2-4 cm depth, with no treatment to the surrounding herbaceous vegetation.

Successful emergence was defined as the aboveground appearance of the shoot by June of the following year. Comparison of the emergence rates between treatments was done using the 95 percent confidence intervals calculated from the binomial distribution (Sokal and Rohlf 1969).

Acorns planted in 1982 and 1984 at Hopland and Berkeley made possible a comparison of emergence between heavy and below average rainfall amounts (table 1). At Hopland 500 acorns were planted in both years. In 1984 they were planted the same day as collected, and in 1982 they were kept at 1°C for two months before planting. At Berkeley 144 acorns were planted after two months of storage at 1° C in 1982 and 100 were planted in 1984. Fifty of these 100 acorns were planted one day after collection and 50 were kept at 1° C for two months to investigate the effect of cold storage on emergence. Acorns planted at Berkeley in 1982 that did not emerge by October 1983 were excavated to determine if mortality had occurred prior to germination.

To examine the effect of canopy on emergence, half of the acorns planted at Hopland in both years were planted under blue oak canopy and the other half in adjacent open grassland.

Table 1--Total rainfall at Hopland and Berkeley for July through June 1982-83, 1984-85 and the long-term average.

	Total Rainfall (cm)		
Location	1982-83	1984-85	Average[1]
Hopland	172	65	96
Berkeley	119	49	59

[1]Hopland average for 1953-86 from Field Station records, and Berkeley average for 1886-1985 from National Oceanic and Atmospheric Administration.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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RESULTS

There was no significant effect of cold storage on emergence of seedlings planted at Berkeley in 1984:

Treatment	Emergence Rate (pct)
Storage at 1°	52[a]
Planted immediately	40[a]

[1]Superscripts denote different values at $p < 0.05$.

Seedling emergence was significantly greater in 1984-85 than 1982-83 for acorns planted at Hopland and Berkeley:

	Emergence Rate (pct)	
Location	1982-83	1984-85
Hopland	3.4[a] [1]	9.6b
Berkeley	9.7[a]	52.0[b]

[1]Superscripts denote different values ($p < 0.05$) in each row.

A difference in emergence between the open grassland and under the canopy was only found in 1985:

	Emergence Rate (pct)	
Date	Canopy	Open grassland
1982-83	4.0[a] [1]	2.8[a]
1984-85	15.6[a]	3.6[b]

[1]Superscripts denote different values ($p < 0.05$) in each row.

Approximately 50 percent of the 132 acorns that did not emerge from the Berkeley planter boxes by October 1983 died after germination, apparently from damping-off fungus.

DISCUSSION

Storage at 1° C for two months did not change seedling emergence relative to immediate planting, and the trend was toward an increase in emergence. Although the cold storage treatment was not replicated in all phases of the study these results suggest that the absence of cold storage in 1984-85 did not cause the increase in emergence over that found in 1982-83. These findings are consistent with recommendations for storage between 1°-4° C to retard germination until sowing without decreasing seedling emergence (Korstian 1927, Harrington 1972).

The improved seedling emergence during drier years and under blue oak canopy found in this study are contrary to Griffin's (1971) findings at Hastings Natural History Reservation in Monterey County. He suggested that 170 percent of normal rainfall in 1968-69 (89 cm) was responsible for increasing emergence over that found in the dry year of 1967-68 (30 cm). Griffin also found greater emergence in the grassland (95 percent) compared with the woodland (85 percent). The *Quercus agrifolia* and *Q. lobata* canopy in his woodland treatment may account for this depressed emergence rate. The greater observance of seedlings under blue oak canopy in a statewide survey by Muick and Bartolome (1986) and Korstian's (1927) contention that germination is enhanced under a canopy because shade and leaf litter reduce acorn dessication, also contrast with Griffin's findings.

In general, the emergence rates in Hastings were several orders higher than at Hopland and Berkeley. The greater depth of planting (7 cm) at Hastings may account for this difference, as might greater care in collection and handling. Griffin's (1971) report of 100 percent germination which also exceeded a 72 percent rate found by Mirov and Kraebel (1937), supports that later explanation. An alternative interpretation enlists the location of the study sites in relation to the distribution of blue oak. Hastings is located nearer the center of blue oak distribution than Hopland and Berkeley which are at the wet fringes of its range (Griffin and Critchfield 1972). Greater emergence rates under drier than normal rainfall at Hopland and Berkeley, and damping-off mortality after germination but before emergence with above normal rainfall at Berkeley, suggest that too much rain can reduce seedling emergence at the wet fringes of blue oak distribution. If regional differences in seedling emergence response to rainfall and canopy do exist they should be recognized in the development of silvicultural guidelines.

CONCLUSIONS

Storage at 1° for two months did not change blue oak seedling emergence. Higher emergence was found under blue oak canopy than open grassland, and with below average rainfall than above average. These rainfall and canopy relationships do not agree with earlier findings in a more southern location. The disparity in these findings may reflect the geographic variation in the factors controlling recruitment.

Acknowledgments: Logistical and sampling assistance was provided by J. Bartolome, A. Dennis, M. Diemer, D. Hilyard, L. Huntsinger, T. Maranon and the staff at Hopland Field Station.

REFERENCES

Gowans, Kenneth D. Soil survey of Hopland Field Station. Berkeley, CA; Agric. Expt. Stn.; 1958. 34 p. + map.

Griffin, James R. Oak regeneration in the upper Carmel Valley, California. Ecology 52(5):862-868; 1971, late summer.

Griffin, James R.; Critchfield, William B. The distribution of forest trees in California. Res. Paper PSW-82. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1972. 114 p.

Harrington, James F. Seed storage and longevity. In: Kozlowski, T. T., ed. Seed biology, volume 3. New York: Academic Press; 1972. pp. 145-245.

Korstian, Clarence F. Factors controlling germination and early survival in oaks. Bull. Yale School of Forestry, no. 19; 1927. 115 p. + photo.

McClaran, Mitchel P. Age structure of Quercus douglasii in relation to livestock grazing and fire. University of California, Berkeley, CA; 1986. 119 p. Dissertation.

Mirov, N. T.; Kraebel, C. J. Collecting and propogating of the seeds of California wild plants Res. Note 18. Berkeley, CA: California Forest and Range Experiment Station, Forest Service, Department of Agriculture; 1937. 29 p.

Muick, Pamela C.; Bartolome, James W. Statewide oak regeneration survey. Report to Forest and Range Assessment Program, California Department of Forestry, Sacramento, CA; 1986. 100 p.

Sokal, Robert R.; Rohlf, F. James. Biometry: The principles and practice of statistics in biological research. San Francisco: W. H. Freeman and Company; 1969. 776 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Germination and Shoot Development of Seven California Oaks Planted at Different Elevations[1]

Kozue Matsuda and Joe R. McBride[2]

Abstract: Outdoor germination (radicle emergence) and shoot development patterns of California oaks were studied by planting acorns at three different elevations in Sierra Nevada and Santa Lucia Ranges in California. At all elevations, scrub oak (Querucs dumosa Nutt.) and blue oak (Q. douglasii Hook & Arn.) germinated soon after planting in late October-November. Valley oak (Quercus lobata Nee), canyon live oak (Q. chrysolepis Liebm), interior live oak (Q. wislizenii A. DC.) and coastal live oak (Q. agrifolia Nee) germinated in December at the lowest elevation and in January or February at the highest elevation. California black oak (Quercus kelloggii Newb.) germinated in February at all elevations. At the warmest plot, the species with fast germination developed shoots in December-January, a month earlier than those with slow germination. This time difference decreased as elevation increased or temperature decreased. Mortality before shoot establishment did not differ significantly with elevation, even where species were planted at higher or lower elevation than where they would occur naturally. The ecological significance of the fast and slow germination types was discussed.

Germination of some California oaks have been studied under controlled environments (Mirov & Kraebel, 1939; USDA 1974). In a regeneration study of California oaks, Griffin (1971) found that Quercus kelloggii Newb. and Q. agrifolia Nee, indoors germinated later than Q. douglasii Hook & Arn., Q. lobata Nee, and Q. turbinella Greene, and that Q. lobata sown outdoors germinated a little later than Q. douglasii in central California. However, information on germination of California oaks under natural environments is still insufficient.

The purpose of this study is to clarify outdoor germination process of California oaks and discuss its ecological significance. In this study, we examined germination and shoot development of seven California oaks at an elevation they naturally grow. Also, the same examinations were made at higher and lower elevations than they naturally grow. We hypothesized that elevational limitation in species distribution could be attributable to failure of seedling establishment, which might be caused by inappropriate timing of germination or shoot development.

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MATERIALS

Three species (Q. douglasii, Q. dumosa Nutt., and Q. lobata) of subgenus Quercus, three (Q. kelloggii, Q. agrifolia and Q. wislizenii) of subgenus Erythrobalanus and one (Q. chrysolepis Liebm) of subgenus Protobalanus were used. Actively falling acorns were collected from ten trees of each species in October and November, 1982. Locations of sampled trees were as follows: Q. douglasii, Mt. Diablo (500-700 m) and Hastings Reservations (600 m); Q. dumosa, Las Trampas Regional Wilderness (500 m); Q. kelloggii, Chews Ridge (1100-1200 m); Q. lobata, Pine Grove (760 m) and Hastings Reservation; Q. agrifolia, Las Trampas Regional Wilderness, Berkeley Hill (180-300 m) and Carmel Valley (100-300 m); Q. chrysolepis, Mt. Diablo (600-800 m); Q. wislizenii, Mt. Diablo (1000-1100 m).

In order to exclude any effect of cold storage, acorns were kept moist and placed outdoors in Berkeley until use. Buggy acorns were sorted out before planting.

METHODS

Three plots were located at different elevations in Santa Lucia and Sierra Nevada Ranges, respectively. The lowest plot in the Santa Lucia Range (SL-L, 23 m above sea level) was located near Point Lobos, Monterey Co. The middle one (SL-M, 560 m) was inside the Hastings Reservation in Carmel Valley, and the highest one (SL-H, 1360 m) in Chews Ridge, about 180 m below the summit. The lowest plot of the Sierra Nevada Range (SN-L, 98 m) was located near Camanche

Lake, Calaveras Co., the middle one (SN-M 725 m) inside Indian Grinding Rock State Park near Pine Grove, Amador Co., and the highest one (SN-H, 1260 m) within the Eldorado National Forests near Cook's Station, Eldorado Co.

Distribution of oaks was observed along the approaching roads (table 1). The elevational distribution range of the oaks was quite different between Santa Lucia and Sierra Nevada ranges, especially for Q. wislizenii. We did not find Q. dumosa in the area studied.

Each plot was located on a gentle slope facing NW to ENE, except the Point Lobos plot which was on a level site. The SL-L plot was in Pinus radiata D. Don and Q. agrifolia grove, SL-M plot in Q. agrifolia woodland, and SL-H plot in Q. chrysolepis, Q. lobata and Pinus coulteri D. Don forest. The SN-L plot was in Q. douglasii and Q. wislizenii woodland, SN-M plot in Calocedrus decurrens Torr. plantation, and SN-H plot in Pinus ponderosa Dougl. ex Laws. forest.

For protecting acorns from predators, acorns were sown in three germination boxes at respective plots. These boxes were 60 x 90 cm with 30 cm of height, one-third to half of which was buried into ground. The top and bottom of the

Table 1--Additional distribution range of oak species along approach roads to the study plots in Sierra Nevada and Santa Lucia Ranges in central California.

Species	Region	Range
Q. dumosa	Santa Lucia	[1]not found
	Sierra Nevada	[2]not found
Q. douglasii	Santa Lucia	150-700 m
	Sierra Nevada	40-400 m
Q. lobata	Santa Lucia	100-1500 m
	Sierra Nevada	0-750 m
Q. chrysolepis	Santa Lucia	500-1500 m
	Sierra Nevada	450-1000 m
Q. agrifolia	Santa Lucia	0-800 m
	Sierra Nevada	no distribution
Q. wislizenii	Santa Lucia	1200-1500 m
	Sierra Nevada	60-600 m
Q. kelloggii	Santa Lucia	700-1300 m
	Sierra Nevada	450-2000 m

[1]Sudworth (1908) reports the elevational range to be from 100 ft (303 m) to 4000 ft (1212 m) in the Santa Lucia Range.

[2]No information is available concerning the altitudinal distribution of this species in the vicinity of our Sierra Nevada transect.

boxes were covered with sheets of hardware cloth; the top sheet was removed at every observation. Acorns collected from each tree of each species were distributed evenly to each of the six plots. In some cases, the numbers of acorns from individual trees were so small that they could be distributed only to three plots in either region. Except for Q. kelloggii, about 150 acorns of respective species (14-16 acorns x 10-13 trees) were planted at respective plots in October and November 1982 within 2 weeks after collection. About 45 acorns (13-15 x 3 trees) of Q. kelloggii were available. Only the pointed part of acorns was buried into soils and acorns were covered with oak litter. Observation was made weekly in November, but every three or four weeks thereafter. Germination (radicle emergence) and shoot development were examined for individual acorns. Progress of shoot development was recorded by assigning each shoot to one of following stages: Stage S_1 - after epicotyls have grown over 2 cm; Stage S_2 - after the second leaf has appeared; Stage S_3 - after the last leaf from the primary bud has appeared.

Maximum and minimum thermometers were set on the soil surface of each plot. Records were taken at the periodical observations on phenology. Mean temperature and precipitation records at a nearest weather station of each plot were obtained from meteorological reports (NOAA 1982, 1983) Data at Hastings Reservation and Chews Ridge were from J. Griffin (pers. comm.).

RESULTS

Germination and Shoot Development

Temperature conditions measured at respective plots are shown in Figure 1. Mean temperature and precipitation records available near the study plots are shown in Table 2. In the winter of this study, the amount of precipitation at all locations was about 200 percent of average. Monthly mean temperature at the several locations in October, November, December, and April was up to 3.4°C lower than in the average year.

Time courses of germination and shoot development of acorns planted in the Santa Lucia plots are shown in Figure 2. Two different types of germination were observed. One is the fast germination type for Q. dumosa and Q. douglasii. This is characterized by germination within a month after sowing even at the highest plots--where most of acorns germinated in November. The other is the slow germination type for Q. lobata, and Q. chrysolepis. Their germination started later after sowing than the fast germination type and lasted for a long period of time. This expansion was mostly due to a variation of germination time within acorns from a same tree. The increase of elevation induced an apparent delay of germination. However, at the highest plot, germination occurred in January and February, while temperatures were still low (fig. 1). Quercus kelloggii showed delayed germination, though acorns germinated within a short period of time in February at all the elevations.

Shoot development of the fast germination species started in December at the lowest plot. At the higher elevations, the shoot development was delayed. The slow germination species flushed buds later than the others at SL-L and SL-M, though at SL-H leaf flush of the all germination type species occurred mostly at the same time.

In the Sierra Nevada plots, germination and shoot development patterns of the respective species were basically the same as in the Santa Lucia plots, though germination of the slow germination species and shoot development of all species at low and middle plots were later than those at the corresponding plots in Santa Lucia Range (fig. 3). At the high plots, germination and shoot development were synchronized in both regions (figs. 2 and 3). This may have been due to the fact that SL-L and SL-M had much warmer conditions than SN-L and SN-M respectively during the period from late October-early February, after which the differences became much less. Inversely, temperature at SL-H was little lower than that at SN-H (fig. 1).

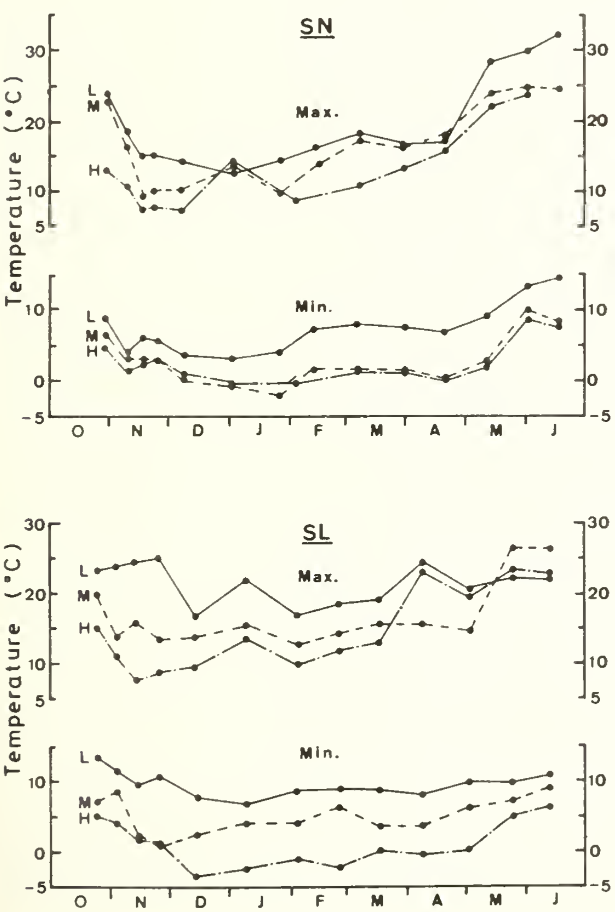

Figure 1--Maximum and minimum air temperatures at soil surface at low (solid line), middle (dashed line) and high (a point and dashed line) plots in Sierra Nevada (SN) and Santa Lucia (SL) ranges.

Mortality of Acorns and Germinated Seedlings

Mortalities of acorns and germinated seedlings before shoot establishment (stage S_3) at the Sierra Nevada plots were mostly less than 10 percent (table 3). Mortalities at the Santa Lucia plots varied considerably among the plots. A large mortality occurred after germination, but before shoot development (table 4). At SL-L, coarse and hard soils prevented roots from penetration into soils, resulting in desiccation of roots. At SL-M and SL-H, most of the mortality was associated with mold.

In the middle plot, many seedlings had the shoot apex killed (probably by low temperature), though they sprouted from axillary buds (table 4).

DISCUSSION

According to the difference in germination phenology, we classified the California oaks into two main groups: fast germination type (Quercus dumosa and Q. douglasii) and slow germination type (Quercus lobata, Q. chrysolepis, Q. agrifolia, Q. wislizenii and Q. kelloggii. When germinated at room temperature, Q. lobata had a large tree-to-tree difference in germination on time (Griffin, 1971). Some acorns germinated quicker than those of Q. agrifolia, with which the others overlapped. According to Matsuda & McBride (1986a), Q. lobata was intermediate between Q. douglasii and Q. agrifolia in germination timing outdoors in Berkeley. At the higher elevations of the present study, the tendency toward germination delay in Q. lobata was much more apparent than in the previous studies.

Black oaks (subgenus Erythrobalanus) in eastern America do not germinate until next spring (USDA 1974). Their dormancy seems to be working effectively to avoid cold periods in winter. Unstratified acorns of the black oaks successfully germinated at room temperature, even if they showed germination delay (Korstain, 1927; Aikman, 1934; USDA, 1974). Quercus agrifolia, Q. wislizenii and Q. chrysolepis also germinated without low temperature exposure (Matsuda & McBride, 1986b).

Acorns of the slow germination species germinated in the cold period of the study, whether in their natural elevation range or at higher elevations (figs. 2 and 3). This suggests that their germination delay ("dormancy") was not working perfectly as a mechanism of cold

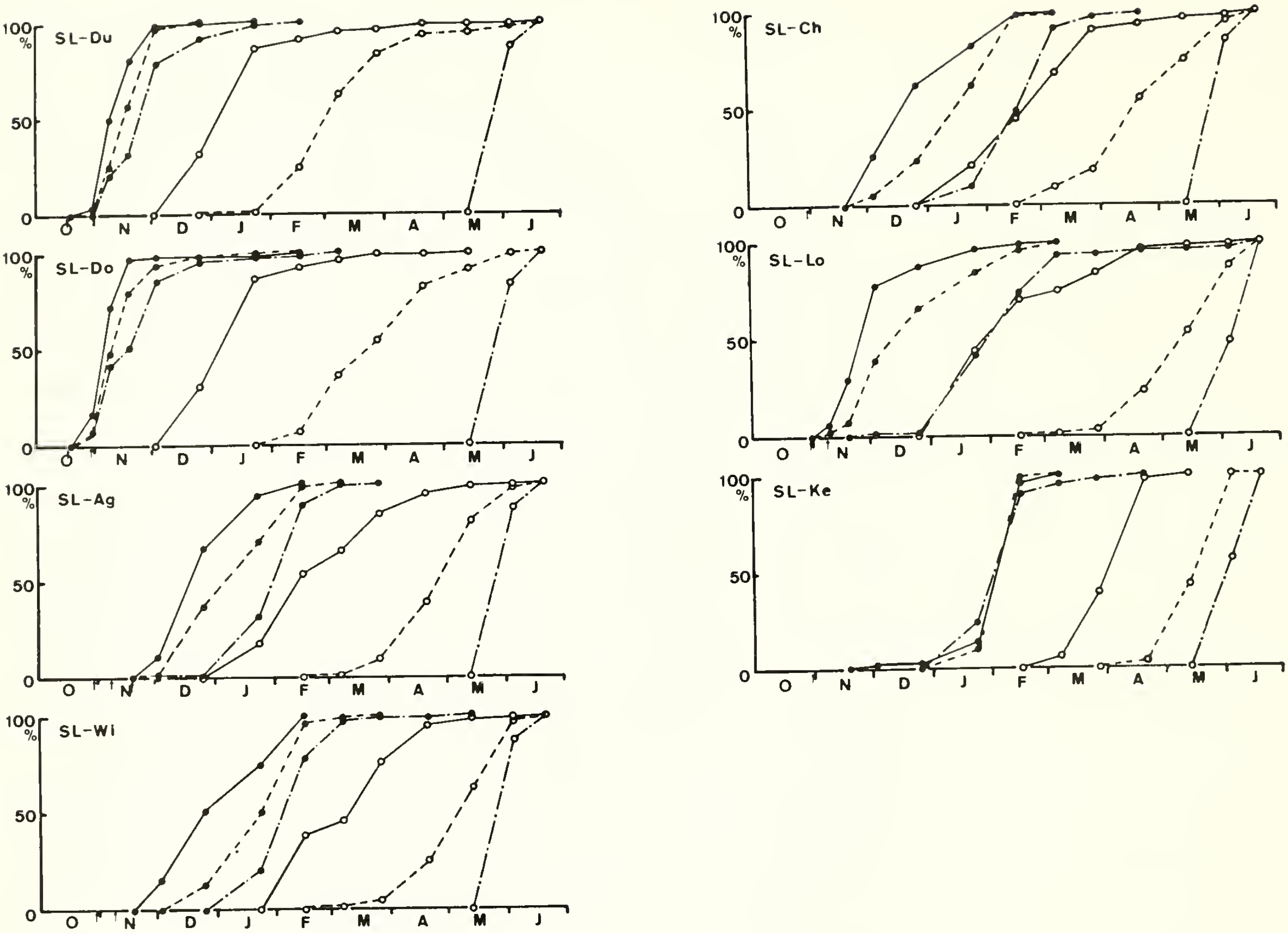

Figure 2--Time courses of germination (●) and shoot development (O) of California oaks planted at low (solid line), middle (dashed line) and high (a point and dashed line) elevations in Santa Lucia Ranges. (Du, Q. dumosa; Do, Q. douglasii; Ag, Q. agrifolia; Wi, Q. wislizenii; Ch, Q. chrysolepis; Lo, Q. lobata; Ke, Q. kelloggii. Shoot development was judged by the emergence of the second leaf. The results of individual tree lots are pooled. Arrows indicate the time of acorn planting. Due to difference in timing of acorn falling of individual trees, planting was made several times. However, acorns from a particular tree were planted simultaneously at all plots.)

avoidance. Although there were several periods of snowfall and minimum temperature reached below 0^{o} to $-3^{o}C$ at the high plots (fig. 1), mortality there was as low as that at the lower plots. The fast germination species rapidly germinated even at the high elevations, at which they are not naturally distributed. This indicates that low temperature at high elevation did not prevent autumn germination of their acorns. Inappropriate germination resulting in exposure of young roots to low temperature could be hypothesized as a direct cause for absence of the species there. Mortality data of Q. douglasii at the high plots, however, provide no evidence for this hypothesis. Relatively high mortalities of Q. dumosa and Q. douglasii at SL-H were caused by mold, which also induced very high mortality of Q. chrysolepis. Quercus chrysolepis naturally grows at this elevation. Thus, mortality by mold observed in this study may be related to microsite characteristics of the plot. Mold was abundant under the oak canopies due to the abnormally large amount of precipitation in the winter of our study (table 2).

The germination phenology and distribution pattern of the California oaks can be generalized as follows. The fast germination species are restricted to xeric sites at low elevation: Quercus dumosa is in chaparral (Hanes, 1977) and Q. douglasii is in foothill woodland and oak savanna (Griffin, 1977). The slow germination species are distributed up to higher elevation, except Q. agrifolia (table 1). At lower elevation, where both germination types grow together, the slow germination species (Q. agrifolia, Q. wislizenii and Q. lobata) are found at more mesic sites than the fast germination species (Q. douglasii and Q. dumosa). Morphology of young seedlings corresponds to moisture

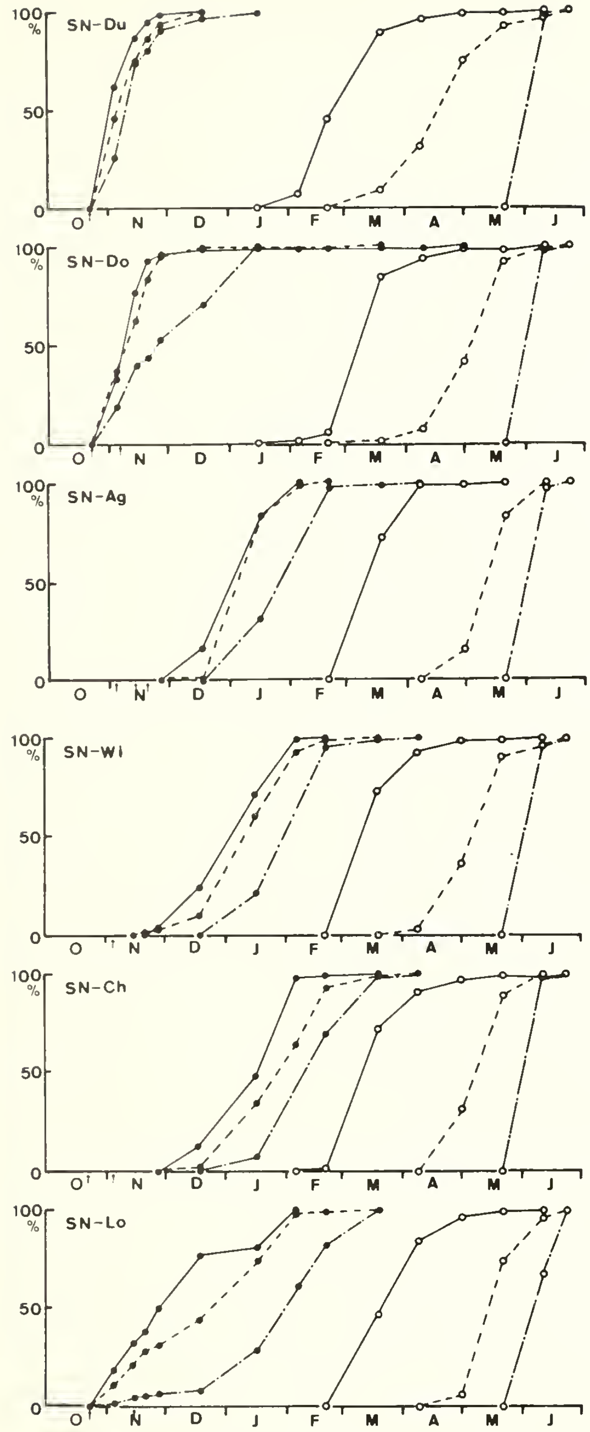

Figure 3--Time course of germination and shoot development of California oaks in Sierra Nevada Range. (See note of fig. 2.)

conditions of typical habitats. Quercus douglasii and Q. dumosa are known to have smaller shoot/root ratio than Q. lobata, Q. kelloggii and Q. agrifolia (Matsuda & McBride, 1986b).

The present results show that the fast germination species developed shoots earlier than the slow germination species at lower elevation (figs. 3 & 4). At xeric sites under Mediterranean climates, early shoot development is particularly important in order to capture soil water before soils dry up. As the elevation increased, however, time of shoot development of the fast germination species was delayed and finally became as late as that of the slow germination species. This means that the fast germination at the high elevation does not result in earlier photosynthesis. The advantage of large root system of the fast germination species might also be decreased under generally less xeric conditions at higher elevation. Restriction of the fast germination species to the low elevation makes sense in this context.

Germination delay at the high elevations possibly plays a positive role in shortening the period during which embryos are exposed to risk of damage from low temperature, mold and insect predators. Germination delay at the low elevation, in turn, could prevent shoots from developing too early. According to Matsuda & McBride (1986a), Q. lobata and Q. agrifolia began to develop shoots significantly sooner after germination than Q. douglasii grown under the same conditions. Therefore, shoots of the former could begin to grow in autumn without germination delay. Our results show that developing shoots were easily damaged by low temperature in the early spring (table 4). Relatively small root system of slow germination species might not be disadvantage in the mesic sites in which they are found. The larger shoot/root ratios would be of competitive advantage to these species.

The California black oaks examined in this study showed germination delay, while the California white oaks did not, except Q. lobata. A similar subgeneric difference also occurs in the eastern oaks in North America (Korstian, 1927; Aikman, 1934; USDA, 1974). Quercus lobata, which is distributed up to high elevation, showed a tendency of germination delay. This suggests an indispensable role of "dormancy" for growing at the high elevation.

In conclusion, variation in germination time found in the California oaks seems to have close relationships with temperature factors, moisture condition of habitats and adaptive seedling growth morphology.

ACKNOWLEDGMENTS

We owe thanks to Dr. James R. Griffin for arranging the study plots in Santa Lucia Range. We thank Jan Strahan, Pamela Muick, Jim Griffin and Ryoichi Matsuda for their help in field work work. We also thank Dr. M. Kimura, Dr. S. Barnhardt, and Dr. S. Conard for valuable comments on the manuscript.

Table 2--Temperature and precipitation records [1982-83 (NOAA)] at three different locations in Sierra Nevada and Santa Lucia Ranges. Figures in parentheses are difference from the average year.

Location (elevation, m)	Mean temperature (°C) Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Precip.(m) (Oct-Jun)
Sierra Nevada Range										
Camp Pardee (201)	(17.5) (-0.6)	10.3 (-2.1)	7.9 (-0.2)	6.1 (-1.3)	10.9 (+1.2)	11.7 (+0.4)	13.4 (-0.7)	18.6 (+0.5)	22.3 (+0.1)	424 (+250)
Tiger Creek (718)	13.8 (-1.9)	7.5 -2.4)	5.0 (-1.0)	6.3 (+0.6)	8.2 (+0.3)	8.1 (-0.8)	9.1 (-2.4)	15.3 (0)	18.6 (-0.9)	769 (+314)
Calaveras Big Tree (1431)	8.9 (-2.6)	3.1 (-3.4)	1.4 (-2.2)	3.6 (+1.1)	2.4 (-1.0)	3.2 (-0.9)	4.2 (-2.4)	12.2 (+1.4)	15.5 (+0.2)	976 (+441)
Santa Lucia Range										
Monterey (117)	16.1 (-0.2)	12.7 (-0.9)	10.8 (-0.5)	11.9 (+1.2)	12.3 (+0.7)	12.5 (+0.8)	12.6 (+0.4)	13.8 (+0.6)	14.8 (+0.2)	390 (+212)
Hastings Reservation (549)	14.9 (-1.0)	9.9 (-2.0)	7.9 (-1.5)	9.3 (+0.9)	9.3 (+0.3)	9.4 (-0.2)	8.8 (-2.2)	13.4 (-0.1)	15.2 (-1.6)	1080 (+539)
Chews Ridge (1427)	- - - - - - - - - - - - - - - no available data - - - - - - - - - - - - - - -									2318

Table 3--Mortalities before shoot establishment (Stage S_3) at different elevations.

Species	[1]Mortality (pct) Santa Lucia Low	Santa Lucia Middle	Santa Lucia High	Sierra Nevada Low	Sierra Nevada Middle	Sierra Nevada High
Q. dumosa	14[b]	10[b]	42[a]	4[b]	12[a]	10[ab]
Q. douglasii	8[b]	<u>7</u>[b]	26[a]	<u>10</u>[a]	9[a]	10[a]
Q. lobata	4[a]	<u>7</u>[a]	<u>12</u>[a]	2[a]	<u>5</u>[a]	3[a]
Q. chrysolepis	25[b]	27[b]	<u>77</u>[a]	3[a]	<u>8</u>[a]	5[ab]
Q. agrifolia	<u>9</u>[a]	<u>20</u>[a]	17[a]	2[a]	1[a]	5[a]
Q. wislizenii	16[a]	27[a]	<u>18</u>[a]	<u>2</u>[a]	<u>6</u>[a]	<u>5</u>[a]
Q. kelloggii	19[ab]	<u>12</u>[b]	37[a]			

[1]Mortality indicates percentage of killed individuals in planted acorns. Mortalities observed for individual tree lots (14-16 acorns per lot, 10-13 lots) are averaged except *Q. kelloggii* (13-15 acorns per lot, 3 lots). Within respective regions, mortalities marked by different superscripts significant differ from each other (p=0.05). Mortalities inside distribution range are shown with bars.

Table 4--Mortality at specific developmental stage of oaks planted at different elevations in Santa Lucia Range.

Species	Plot	[1]Mortality (pct)				[2]Sprout (pct)	[3]No.
		UG	G	S_1	S_2		
Q. dumosa	Low	0	11	1	2	5	179
	Middle	4	5	0	1	28	178
	High	2	39	0	1	5	180
Q. douglasii	Low	2	6	0	0	1	150
	Middle	2	4	1	1	16	195
	High	2	24	0	0	2	150
Q. lobata	Low	1	3	0	0	2	150
	Middle	1	5	1	1	15	164
	High	1	10	1	0	3	150
Q. chrysolepis	Low	1	20	1	3	12	151
	Middle	1	23	1	1	19	149
	High	1	76	0	1	0	150
Q. agrifolia	Low	0	4	3	3	24	150
	Middle	0	37	3	1	24	150
	High	0	17	0	0	2	150
Q. wislizenii	Low	1	9	2	4	13	165
	Middle	1	30	4	2	13	163
	High	1	16	0	0	2	165
Q. kelloggii	Low	5	9	0	5	3	44
	Middle	2	9	0	0	3	43
	High	2	35	0	0	0	43

[1]UG, before germination; G, after germination but prior to development of 1 cm epicotyls; S_1, prior to emergence of second leaf; S_2, prior to emergence of last leaf.

[2]Sprout shows a percentage of seedlings sprouting after damage of shoot apex in final survivors.

[3]No. indicates number of acorns planted.

REFERENCES

Aikman, J.M. The effect of low temperature on the germination and survival of native oaks. Iowa Acad. Sci. Proc. 41:89-93. 1934 January.

Griffin, J.R. Oak regeneration in upper Carmel valley, California. Ecology 52:862-868. 1971 March.

Griffin, J.R. Oak woodland. In: M.G. Barbour & J. Major (eds) Terrestrial Vegetation of California. New York: J. Wiley and Sons; 1977. pp. 383-415.

Hanes, T.L. Chaparral. In: M.G. Barbour & J. Major (eds) Terrestrial Vegetation of California. New York: J. Wiley and Sons; 1977. pp. 417-470.

Korstian, C.F. Factors controlling germination and early survival in oaks. Yale Univ. Sch. Forestry Bull. 19:1-115. 1927 January.

Matsuda, K. and J.R. McBride. Difference in seedling growth morphology as a factor in the distribution of three oaks in central California. Madrono 33:207-216. 1986a July.

Matsuda, K. and J.R. McBride. Comparison of young seedling morphology in oaks. (unpublished data) 1986b.

Mirov, N.T. and C.J. Kraebel. Collecting and handling seeds of wild plants. Forestry Publication No. 5. Washington, D.C.: USDA Civilian Conservation Corps. 42 p.

NOAA. Climatological Data: California. Ashville, NC: Environmental Data and Information Service. 1982, 1983.

Sudworth, G.B. Forest Trees of the Pacific Slope. New York: Dover Pub. Inc.; 1908. 318 p.

USDA. Seeds of woody plants in the United States. Washington, D.C.: USDA Forest Service; 1974. 714 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Factors Associated with Oak Regeneration in California[1]

Pamela C. Muick and James W. Bartolome[2]

Abstract: Eighty-four randomly located plots, in 25 counties, were sampled in 1984 and 1985 as part of the first systematic investigation of oak regeneration on private range lands in California. The twofold purpose of this study was to assess the status of regeneration for the eight major oak species in the state, and to identify any environmental or management characteristics associated with presence or absence of oak regeneration. Tree, sapling and seedling-sized individuals of the 8 major oak tree species were located. Sapling to tree ratios (S:T) of all 8 species were calculated and ranked across 5 regions of the state. Overall, S:T ratios were higher for evergreen and black oaks and lower for deciduous white oaks, interpreted to mean that white oaks as a group are less likely to maintain their current stand area. Observations of environmental, vegetation and management characteristics and wildlife signs on plots with and without blue oak saplings were evaluated. Generally, regeneration as indicated by the presence of sapling-sized oaks, was site specific and few statewide generalizations about factors related to regeneration were possible. A comparison of the positions of seedling and sapling blue oaks and interior live oaks, relative to tree and shrub canopy, indicated the possible relevance of canopy position to successful regeneration.

Where is the next generation of oaks? In their preliminary report to the State Board of Forestry, the Hardwood Task Force (1984) noted that "In certain parts of the State, blue oak, valley oak and Engelmann oak are not regenerating well. Failure to regenerate widely means that in certain areas of the State these species currently cannot be managed as a renewable hardwood resource."

What conditions allow oaks to regenerate naturally? The published references cover only a few oak species on a few sites. An evaluation of the existing literature and scientific opinion reveals several often contradictory hypotheses identifying causes for failure of regeneration. These causes have included grazing and browsing by large and small vertebrates, changes in fire regimes and groundwater levels. climatic shifts, and human impacts. To understand conditions necessary for production of the next generation of oaks, one must first determine A) the status of regeneration for the major oak species on a statewide basis, and B) any identifiable environmental factors and management practices associated with regeneration.

What is successful oak regeneration? Regeneration is the process by which trees lost through mortality are replaced. The presence of small established trees in a stand indicates probable recruitment. This study used the presence of sapling-sized oaks (larger than 1 cm at the ground and smaller than 10 cm (4 inches dbh) as an indicator of successful oak regeneration. The evaluation of successful regeneration was based on a ratio between the numbers of sapling-sized oaks and the number of tree-sized oaks, referred to subsequently as the S:T ratio. The S:T ratio was used to compare and to evaluate levels of regeneration by species and by region. Saplings, rather than seedlings, were chosen because of well-documented studies of high seedling mortality rates, ephemeral qualities of naturally occurring seedling populations (Griffin 1971 and 1976, Knudsen 1984), and the assumed higher survival rate of saplings.

This paper presents an overview of the S:T ratio of survey plots for all species and a more detailed analysis for blue oak, describing the key factors of site, vegetation, mangement and wildlife and their relationship to the presence or absence of saplings. The survey provides

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, Nov. 12-14, 1986, California Polytechnic State University, San Luis Obispo, CA.

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information useful for development of management guidelines and for research. The objectives of the study were twofold: first, to assess the status of regeneration for the eight major oak species in the state; second, to identify any environmental or management characteristics associated with presence or absence of oak regeneration.

METHODS

Species

Eight species were surveyed: blue oak (*Quercus douglasii* H. and A.), valley oak (*Q. lobata* Nee.), Engelmann oak (*Q. engelmannii* Greene.), Oregon oak (*Q. garryana* Dougl.), black oak (*Q. kelloggii* Newb.), coast live oak (*Q. agrifolia* Nee.), interior live oak (*Q. wislizenii* A. DC.) and canyon live oak (*Q. chrysolepis* Liebm.). The eight species were separated into two taxonomic groups, (1) black and evergreen oaks, and (2) white oaks. The black and evergreen group includes black, coast live, interior live, and canyon live oaks. The white oak group includes blue, valley, Engelmann, and Oregon oaks.

Plot selection

The field work for this study took place during the 1984 and 1985 field seasons. Plot locations were chosen to include all major hardwood range species on as many sites as could be inventoried within the constraints of time and money allocations. Two types of plots were established: Survey plots and Regeneration plots, and a total of 120 plots were sampled (Figure 1). The 84 Survey plots were selected from a larger set of hardwood inventory ground truth points established for the US Forest Service Forest inventory assessment (US-FIA) by the Pacific Northwest Forest and Range Experiment Station for the California assessment (Bolsinger 1986). These US-FIA plots are randomly located, concentrated in the northern half of the state and include few sites with valley oak and Engelmann oak. Random plots were selected for field sampling following three criteria: 1) plot data sheet was obtained from USFS-PNW; 2) plot located in an area targeted for survey; 3) landowner gave permission for field survey.

Additional plots, termed Regeneration plots, were established to collect information on naturally occurring regeneration observed in the field and to enlarge the information base for valley oak and Engelmann oak. Plot configuration and data collected on the Regeneration plots followed the format used on the Survey plots. The results of the 36 Regeneration plots are not presented in this paper and are available in a report distributed by the funding agency, California Department of Forestry, Forest and Rangeland Resource Assessment Program (CDF-FRRAP), "An assessment of natural regeneration of oaks in California".

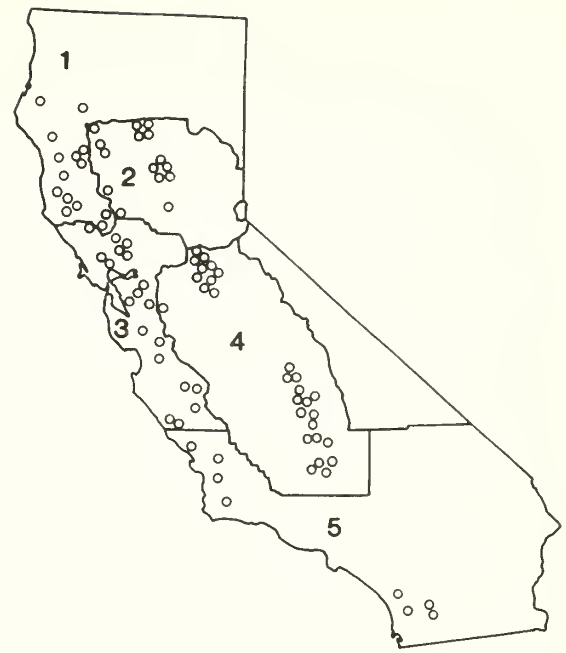

Figure 1: Map of California showing the 84 randomly located plots surveyed in the oak regeneration study by region.

The randomly located survey plots were sampled in 25 counties and the elevations ranged from 80 meters to 1800 meters (260 to 5900 feet) above sea level. The plots were located from within view of the Pacific Ocean to mid-elevations of the Sierra Nevada, from 78 kilometers (30 miles) north of the Mexican border to Redding, at the upper end of the Sacramento Valley.

Survey plot layout

The US-FIA plots usually contained 5 sites (Figure 2) and covered an area of approximately 2 ha (5 acres). The center points of each site were identical to those established for US-FIA plots. A 5.6 m (18 ft) radius plot was delineated from the center point of each site (Figure 2) for an area of 100 m^2 per site, (300 to 500 m^2 per plot).

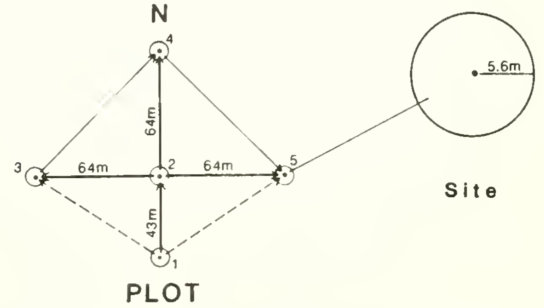

Figure 2: Plot layout, adapted from USFS-Forest Inventory Analysis system.

Size Classes of Oaks

The most feasible method to evaluate regeneration over a wide area in a short time translates size classes into probable stand-age characteristics. The presence of small trees and saplings suggests probable prior regeneration. Although size and age are weakly correlated, small oaks are likely to be younger than large oaks (Knudsen 1984, White 1966). For the purposes of this study three size classes of oaks were defined: tree, sapling and seedling:

SIZE CLASS	DEFINITION
Tree	> 10 cm (4") at diameter breast height
Sapling	< 10 cm (4") and > 1 cm at the ground (<.5") (basal diameter)
Seedling	< 1 cm at the ground (basal diameter)

Tree, sapling and seedling variables

Within each site every oak was measured and environmental characteristics were noted. The height and diameter at breast height (dbh) of every tree-sized oak was recorded. The height, dbh and/or diameter at the ground (bd) of every sapling-sized individual was recorded. Additionally, the number of stems of saplings were counted and categorical data about presence or absence of browsing noted. The sapling's position relative to tree canopy, or shrub overstory, was divided into three overstory categories: under the canopy, on the canopy's edge, and in the open. Each of the seedlings were placed into a height class category (<10 cm, 10-20 cm, or >20 cm), and an overstory category (identical to sapling overstory categories, which includes both tree and shrub canopies.

Plot variables

Plot location information, vegetation, land use information and microsite factors were measured or described. At each plot, vegetation type and management characteristics including livestock grazing, signs of fire, wood cutting and wildlife were noted. At each of the 3 to 5 sites, cover of trees, shrubs, grasses, litter and bare ground was visually estimated. Presence or absence of signs of the following wildlife species were noted: gophers, ground squirrels, deer, bear, badger, voles, pigs, and rabbits.

Regions

From a management perspective a regional analysis was more useful than the statewide summary. Therefore, the state was divided into five regions by combining the 10 planning regions established by the California Department of Forestry - FRRAP (Figure 1).

Region 1- North Coast and the Cascades combines FRRAP regions 1 and 2;

Region 2- North Sierra corresponds to FRRAP region 3;

Region 3- Delta and Central Coast combines FRRAP regions 4 and 5;

Region 4- South Sierra corresponds to FRRAP region 6;

Region 5- South Coast, Southern California and Desert combines FRRAP regions 8, 9, and 10 respectively.

Data analysis

Summary statistics were calculated using the Statistical Analysis System (SAS) on the mainframe computer at U.C. Berkeley and sub-routines SORT, FREQ, SUM and CORR. Selected variables were analyzed using Student's t-test.

Sapling to tree ratio

The S:T ratio was used an a indicator of recruitment into stands and probability of successful regeneration. These ratios are summarized into four categories, (1) very low, (2) low, (3) medium and (4) high:

	Category	Sapling to Tree Ratio (S:T)
1	Very Low	S:T ratio greater than or equal to 1:10
2	Low	S:T ratio > 1:10 and < 1:2
3	Medium	S:T ratio < 1:1 or = 1:2
4	High	S:T ratio less than or equal to 1:1

RESULTS AND DISCUSSION

A total of 1036 tree-class, 785 sapling-class, and 3753 seedling-sized oaks were counted and measured on 84 survey plots. Table 1 summarizes the ratios for each species by region. In the black and evergreen oak group, canyon live oak has the highest S:T ratio of all species and interior live oak S:T ratios are similar. Black oak S:T ratios are lower in the Coast Ranges than in the Sierra Nevada. Coast live oak is found in only in two of the five regions and, where found, low S:T ratios were calculated.

Of the white oaks, Engelmann oak grows only in Region 5, Southern California. In contrast to the findings of Griggs and Lathrop (pers. comm.) the two survey plots sampled have a medium S:T ratio. Blue oak, the species with the highest sample size in the study (41 plots), had a variable pattern of S:T ratios. Blue oak

Table 1: Summary of sapling to tree ratios (S:T) for survey plots by region.

Oak Species	N of Plots	REGION 1	REGION 2	REGION 3	REGION 4	REGION 5
Canyon live	20	****	****	****	****	***
Interior live	13	****	****	***	***	N/A
Black	18	*	****	**	***	*
Coast live	10	N/A	N/A	**	N/A	**
Engelmann	3	N/A	N/A	N/A	N/A	***
Blue	41	*	***	**	***	**
Valley	6	*	*	*	**	---
Oregon	13	*	*	*	N/A	N/A

Key to symbols:
- **** High — S:T ratio less than or equal to 1:1
- *** Medium — S:T ratio between 1:1 and 1:2
- ** Low — S:T ratio between 1:2 and 1:10
- * Very Low — S:T ratio greater than or equal to 1:10
- N/A — Region outside of the distribution of the species
- --- — Species occurs in this region, no plots sampled

resembled black oak in that Coast Range plots had lower ratios than those in the Sierra Nevada. Valley oak was not sampled in every region where it is known to occur, however all six plots sampled in four regions had low or very low S:T ratios. Oregon oak was sampled in the three regions in which it grows and all ratios were very low.

Factors associated with blue oak regeneration

Blue oaks made up 44 percent of all trees sampled on survey plots, and almost half, 41 of the plots, contained blue oaks. Sixty-one percent of the blue oak stands contained only blue oak trees, suggesting at least two different types of blue oak habitats, single species and mixed species stands. Four hundred and one blue oaks were counted and measured and the average density of trees in all stands containing blue oak was 151 stems per ha (61 per acre). Basal area of blue oak stands ranged from a low of 1 square foot per acre to a high of 91 square feet per acre, with an average of about 23 square feet per acre. Tree cover ranged from 31 percent in Region 3, to 50 percent in Region 5, averaging 36 percent statewide.

Two hundred and forty-six blue oak saplings were counted on 29 plots. Eighty-four percent of the 246 saplings were located either on the edge of the canopy or in the open. The average blue oak sapling was 6.5 m (21 ft) from the nearest tree sized blue oak. Most blue oak saplings appeared to have grown from seed, since 72 percent were of seed origin. Regionally, more blue oak saplings were found in Region 4, South Sierra, than in any other region. The low values in Region 5, Southern California, reflect the range limits of blue oak.

Environmental factors, were grouped into four categories (site, vegetation, management, wildlife) and were analyzed by region. Plots with and without blue oak saplings were compared over four of the five regions. Region 5 was not included since it is largely outside the distribution of blue oak. The paired values for each variable were evaluated for significance, at the .05 level, using Students' t-test.

None of the site factors was significant statewide, however, two factors were significant within regions (Table 2). In Region 2, North Sierra, slope was a significant factor suggesting that plots on steeper slopes were more likely to have saplings. In Region 3, Delta and Central Coast, aspect was a significant factor, and plots on more mesic, east and northeast aspects were more likely to contain saplings.

Vegetation factors of tree, shrub and herbaceous cover were generally not statistically significant except for shrub cover in Region 4, South Sierra (Table 2), where the sparser shrub cover was significantly associated with the presence of saplings. However, the pattern of sparse cover and presence of saplings varies throughout the other regions.

Management factors are often identified as reasons for lack of oak regeneration (Table 3). Livestock grazing was noted on all plots with and without saplings in every region except Region 1, North Coast. No significant pattern related to livestock grazing emerged. More detailed information regarding season and intensity of grazing should be measured in future studies. Evidence of fire was observed on most plots and woodcutting was variable throughout the regions, with no patterns revealed, although the inability of large

Table 2: Comparison of site factors and vegetation factors between blue oak survey plots with and without blue oak saplings by region.

Variables:	REGION 1 SAPLINGS Pres.	REGION 1 SAPLINGS Abs.	REGION 2 SAPLINGS Pres.	REGION 2 SAPLINGS Abs.	REGION 3 SAPLINGS Pres.	REGION 3 SAPLINGS Abs.	REGION 4 SAPLINGS Pres.	REGION 4 SAPLINGS Abs.
N Plots	1	1	8	4	4	2	14	6
Site Factors:								
x̄ elevation in meters	1800	1640	1056	995	2225	640	2123	2680
x̄ aspect in degrees	256	280	173	180	108 *	163	180	127
x̄ slope in pct	11	21	13 *	17	15	18	16	16
Vegetation Factors:								
x̄ tree cover pct	29	23	23	27	30	21	31	30
x̄ shrub cover pct	6	23	16	0	6	1	5 *	12
x̄ herbaceous cover pct	73	45	56	69	60	38	56	53

* Indicates a significant difference at .05% using Student's t test.

Table 3: Comparison of management factors and wildlife sign between blue oak survey plots with and without blue oak saplings by region.

Pct of plots containing signs of:	REGION 1 SAPLINGS Pres.	REGION 1 SAPLINGS Abs.	REGION 2 SAPLINGS Pres.	REGION 2 SAPLINGS Abs.	REGION 3 SAPLINGS Pres.	REGION 3 SAPLINGS Abs.	REGION 4 SAPLINGS Pres.	REGION 4 SAPLINGS Abs.
Management Factors:								
Cattle grazing	0	0	80	100	100	100	90	100
Fires	100	100	30	100	50	100	50	70
Woodcutting	0	0	30	50	30	0	60	60
Wildlife:								
Gophers	100	0	50	80	80	0	100	100
Badgers	0	100	0	0	30	0	10	10
Voles	0	0	0	0	0	0	0	0
Ground squirrels	0	100	0	50	30	0	50	90
Pigs	0	0	30	0	50	0	0	10
Deer	100	100	80	50	100	0	60	90
Rabbits	0	0	0	30	0	0	30	30

diameter blue oak trees to stump sprout after cutting has been documented (Longhurst, 1956). Wildlife, particularly rodents and deer, are often named as culprits in the lack of blue oak regeneration. The data show gopher and deer sign on most plots with saplings (Table 3). No other patterns regarding signs of other wildlife species emerged.

Overstory relationships

George Sudworth (1908) and Willis Jepson (1910) described varying degrees of shade tolerance for oak species based on field observations. And, an interesting pattern did emerge regarding the position of seedlings and saplings in relation to the canopy of trees and shrubs. In Table 4, blue oak, a deciduous white oak, and interior live oak, an evergreen black oak, two commonly co-occurring species found in northern and central California, are compared by size class and canopy position. More than 60 percent of blue oak seedlings were found under the canopy, about a third were found on the edge and only a few, 7 percent, were found in the open position. However, blue oak saplings are found much less frequently under the canopy, and most are found on the edge or in the open positions. In comparison, 95 percent of interior live oak seedlings are found under the canopy, and only a few on the edge and in the open positions. Sapling interior live oaks, in contrast with blue oak saplings, are more likely to be found under the canopy, and fewer on the edge and in the open positions.

Table 4: Comparison between positions of seedlings and saplings of blue oak and interior live oak, in relation to tree or shrub overstory category.

Species	Size Class	Pct of seedlings or saplings under each overstory category: Canopy	Edge	Open	Total number of individuals	N. of plots
Blue oak	Seedling	62	31	7	353	22
	Sapling	16	42	42	246	29
Interior live oak	Seedling	95	4	1	1037	19
	Sapling	67	20	13	138	17

SUMMARY

Oak regeneration is found throughout California, though it is highly variable in occurrence by species and place. Seedlings and saplings of every major oak species were found on at least one survey plot. Adequacy of existing sapling populations to replace trees lost through mortality was ranked by S:T ratio. Both canyon live oak and interior live oak have 1:1 or better S:T ratios. Black oak and blue oak have lower S:T ratios in plots in the Coast Ranges than on plots in the Sierra Nevada. Low or very low ratios were calculated for coast live oak, black and blue oak in the Coast Ranges, and Oregon white oak. The few Engelmann oak plots had a medium S:T ratio. More plots of valley, Engelmann and Oregon white oak should be sampled for more conclusive evidence.

Blue oak regeneration is highly site specific. Plots with numerous saplings were found adjacent to similar areas with no saplings. Blue oak saplings were found on 70 percent of plots with blue oak trees. Saplings averaged 6.5 m (21 ft) from the nearest tree. The most blue oak saplings were found in Region 4, Southern Sierra. Environmental factors for blue oak plots were grouped into four categories, and plots with and without saplings were contrasted. Slope was a significant site factor in the northern Sierra Nevada where steeper slopes were more likely to have saplings. This may be related to sprouting after fire. In Region 3, Delta and Central Coast, aspect was a significant factor and plots on more mesic aspects were more likely to have saplings. Vegetation factors related to cover were significant only in one case, shrub cover in Region 4, the South Sierra, where a low percent shrub cover was related to presence of saplings. The almost ubiquitous presence of livestock grazing on plots with and without saplings does not support the prevailing belief that livestock grazing precludes oak regeneration. However, this survey did not distinguish season or intensity of grazing, factors likely to be important for successful oak regeneration. Fire scars were noted on almost every plot. Two wildlife factors were notable, gopher and deer signs were found on

almost every blue oak plot with and without saplings, whereas vole sign was contrastingly absent.

Position of seedling or sapling relative to canopy was identified as an important factor and strong statewide trends for species emerged. Seedlings of all species were commonly found underneath tree and shrub canopies, however, locations of sapling sized oaks relative to tree and shrub canopy appeared to vary by species. Blue oak saplings were more often found on edges of the canopy and in the open, whereas interior live oak saplings were most usually found under the canopy. This leads to the hypothesis that densely stocked stands of blue oak may not support regeneration regardless of other factors. Therefore, the relative position of seedling and sapling oaks to tree or shrub canopy may be an important factor in establishment of oak seedlings and survival of oak saplings.

Since oak regeneration is highly site specific, it follows that successful management of oaks must also be site specific. The development of management guidelines, retention standards and regulations for oak harvesting operations will require additional information. The ecology of each species, the existing mix of species at a site, stand and age structure, and the pattern of species distribution over the land, all affect and effect the next generation of oaks and the renewability of the hardwood resource.

Acknowledgements Assistance with the study was provided by: Nan Ober; Ann Dennis; David Amme; Dr. Jim Griffin, Hastings Reservation; Chuck Bolsinger, USFS, PNW; and UC Cooperative Extension forestry, livestock and farm advisers. This study was supported by the California Department of Forestry, Forest and Rangeland Resources Assessment Program.

REFERENCES

Bolsinger, C.L. The hardwoods of California timberlands, woodlands, and savannahs: PNW, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Research Station. U.S. Department of Agriculture; 1986. In press.

California Board of Forestry. California's hardwood resource: the preliminary report of the Hardwood Task Force. California Department of Forestry: Forest and Rangeland Resource Assessment Program; 1983. 67 p.

Griffin, J.R. Oak regeneration in the upper Carmel Valley, California. Ecology 52(5):862-868; 1971.

Griffin, J.R. Regeneration in Quercus lobata savannas, Santa Lucia Mountains, California. Amer. Mid. Nat. 95(2):422-435; 1976.

Griggs, Thomas, Preserve Manager, The Nature Conservancy, Santa Rosa Plateau, Riverside County. Personal communication. 1986.

Jepson, W.L. The silva of California. University of California Memoirs, 2:1-480. Berkeley, CA. The University Press; 1910.

Knudsen, M.D. Life history aspects of Quercus lobata Nee in a riparian community, Bobelaine Audubon Sanctuary, Sutter County, California. Sacramento, CA: Sacramento State University; 1984. 135 p. M.S. Thesis.

Lathrop, Earl, Professor of Biology, Loma Linda University, Riverside, CA. (Telephone communication). 1986.

Longhurst, W.M. Stump sprouting in response to seasonal cutting. J. Range Manage. 9(4):194-196; 1956.

Muick, P.C. and J.W. Bartolome. Statewide oak regeneration survey. U.C. Berkeley, Department of Forestry and Resource Management. CDF-FRRAP; 1986. 100 p.

Sudworth, G.B. Forest trees of the Pacific slope. Washington, DC., Forest Service, U.S. Department of Agriculture; 1908. p. 441

White, K.L. Structure and composition of foothill woodland in central coastal California. Ecology 47(2):229-237; 1966.

Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Coast Live Oak Thinning Study in the Central Coast of California[1]

Norman H. Pillsbury, Michael J. DeLasaux, and Timothy R. Plumb[2]

Abstract: A long-term thinning study was established in ten stands of coast live oak (*Quercus agrifolia* Née) in the Central Coast of California. Information about diameter, basal area, and volume growth and yield is being obtained from unthinned control plots and from plots thinned to 50 and 100 square feet of basal area per acre. Descriptive information was also collected about the overstory, understory, and the site. Remeasurement at 5-year intervals will provide valuable data about the effects of thinning in coast live oak stands.

During the past decade there has been increasing interest in the potential of wood for supplying energy. California's oak woodland is one source receiving increasing pressure for harvesting. These woodlands are mostly an unmanaged and underutilized resource that could provide a continuous source of wood fiber for energy and wood products, given proper management.

Coast live oak (*Quercus agrifolia* Née) was selected for this study because of its extensive range in California, from San Diego to Mendocino County covering about 750,000 acres (Bolsinger, personal communication). The species has been utilized for fuelwood and charcoal production. To our knowledge it has not been conscientiously managed for fiber or wood production. Coast live oak's relatively rapid growth rate, especially when compared to blue oak (*Quercus douglasii* Hook and Arn.) or other deciduous oaks found on non-conifer soils, will allow for a more rapid return on an investment for stand improvement. Coast live oak commonly grows in dense, relatively even-age stands and appears to be amenable to thinning.

Based on four studies (Pillsbury 1978,1985; Pillsbury and De Lasaux 1985; and De Lasaux 1980) involving inventory of coast live oak stands (Figure 1) they are typically dense, ranging from 100 to over 700 trees per acre (averages for these studies varies from 300-350) and basal area ranges from about 75 to 250 square feet per acre (averages for these studies is 150-160). Tree spacing ranged from about 7 to 20 feet (average of 12-13) while average tree diameter for the stands varied from about 5 to 17 inches (averages of 10-11). Coast live oak stands are largely between 40 and 110 years of age although stands have been measured as young as 28 years and as old as 131 years. Typically they average 60-80 years in age. Site index values varied from a low of 32 feet to a high of 84 feet at 50 years.

We are aware of no coast live oak studies that show the effects of thinning on the growth of the residual stand. Thinnings are normally conducted to stimulate the growth of the trees that remain

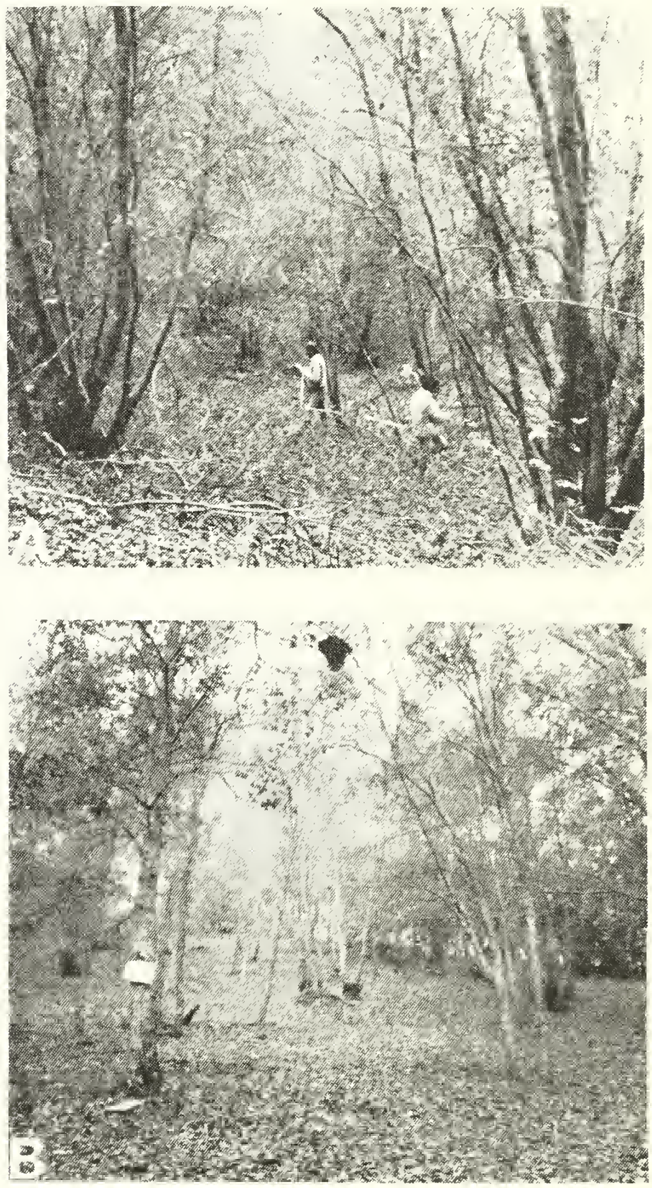

Figure 1. Unthinned (A) and thinned (B), 42 year old Coast live oak stand.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 13-15, 1986, San Luis Obispo, California.

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and to increase the total yield of useful fiber from the stand. The basic objectives of thinning are: a) to redistribute the growth potential of the stand into fewer but larger trees, and b) to utilize all the merchantable material produced by the stand prior to harvest (Smith 1962). A long-term thinning project might consist of a series of cuttings to temporarily reduce the stand density (usually measured in basal area or volume). Artificial changes in stand density do not affect total volume production unless the stand becomes exceedingly dense or open (Smith 1962). The faster diameter growth induced by thinning, however, increases the proportion of stem wood that is large enough for profitable use. Thus, thinning can be used to increase the economic yield of a stand in spite of evidence that, in the biological sense, gross production of wood or of total dry matter is not subject to much alteration.

Normally a thinning or series of thinnings should be done early in the life of the stand, and after the first harvest it is recommended that a more frequent thinning prescription be followed for the next generation of trees. However, given the current stand densities and ages of coast live oak stands found in the central coast region, it is possible that a moderate to heavy thinning would still accelerate diameter increment to the benefit of the landowner.

The age that the final harvest would occur (rotation) for coast live oak was examined in a preliminary site, growth and yield study on the Central Coast (Pillsbury and De Lasaux 1985). Based on the growth rate and stand condition, a biological rotation of a stand could be as early as 50 years, although a harvest at age 75 or 80 would be feasible especially for stands on lower sites.

Currently, little is known about site productivity, regeneration, tree growth and the potential effects of harvesting on oak woodlands. Little information is available on different management practices and their effects. Growth and yield information is mostly unavailable for western hardwoods. By developing a number of permanent plots, growth can be documented over time. This data will prove valuable to foresters and landowners who wish to maximize fiber production in existing stands or want to compare the potential for different management strategies.

The primary long-term objective of this study is:

1. Establish a series of permanent plots to develop long-term diameter, basal area and volume growth and yield information for thinned and unthinned stands of coast live oak in Monterey, San Luis Obispo, and Santa Clara counties.

Other objectives of this study include:

1. Evaluate the changes in understory vegetation following thinning.
2. Evaluate the regeneration of coast live oak (stump sprouts and seedlings) following thinning.
3. Evaluate disturbance of soils during the thinning process and the effects of such disturbance.

Many of the stands measured in previous studies are near rotation age, whether they could benefit from thinning is important to know. This study may help to determine if a thinning of older stands will yield increased fiber while allowing for immediate income from the removed trees.

METHODS

Plot Selection

Ten sites were selected for this study and were distributed as follows: Monterey County - 4 sites, San Luis Obispo County - 5 sites, and Santa Clara County - 1 site. Three plots were established at each site consisting of one control plot and two plots that were thinned to 50 and 100 square feet per acre respectively. Plots were established in stands approximately 40 to 85 years old.

Several factors were considered to determine which plot should be thinned to either 50 or 100 square feet per acre. If the three plots were approximately equal in basal area normally the center plot was selected as the control or unthinned plot because it would most likely represent the average field condition. For other sites, normally the plot having the lowest basal area stocking level was selected for thinning to 50 square feet per acre, the plot having the highest level of basal area stocking was selected for thinning to 100 square feet per acre, and the plot having the middle stocking level became the control.

This approach alters the stand structure in a similar manner for both of the thinned plots. The percent basal area cut method was not used to determine where the treatments should be applied. Reducing the basal area level by some percentage would not allow for differences in initial stocking levels, stand table distribution, or the complexity of crown classes and tree vigor levels that are commonly found throughout the sites.

Each plot is one-fifth acre in size and is surrounded by a two-fifths acre buffer zone for a total area of three-fifths acre. Plots were established by compass and tape; metal rebar was used to monument plot corners.

Data Collection

Trees were divided into two categories: "cut trees" and "tag trees". For purposes of this study, "cut trees" are those trees that were small (normally less than 6 inches dbh), defective, and should automatically be removed. Only dbh and total height were recorded for "cut trees". All other trees were defined as "tag trees" and were marked with an aluminum tree tag. The information recorded from "tag trees" was used in the analysis to determine which trees were to be left (make up the residual stand) and which were to be removed (thinned as part of the treatment). The following information was obtained for each tree: tree number, species, dbh, total height, merchantability indicator code, vigor code, azimuth from plot center, horizontal distance from plot center, crown class, and a code that indicated if the tree should be removed and if the tree forked below breast height. The same data was collected for trees in the control plot.

The DBH measurement location was marked by a nail. Occasionally the reference nail for the DBH measurement had to be located 1 to 2 feet above or below DBH level (4.5 feet) due to abnormalities such as tree forking,and swelling. Determination of tree heights was difficult especially when the tree had excessive lean, up to 70 degrees from vertical in a few cases. Tree lengths were used as tree heights for all leaning trees.

DATA ANALYSIS

Development of Stand, Basal Area and Stock Tables

Basic mensurational data were compiled for each plot before and after thinning and extrapolated to a per acre stand basis. A stand table consisting of the number of trees of a given species per diameter class per acre was developed. Trees were put into 2-inch diameter classes (e.g., the 8-inch class includes trees 7.00 through 8.99 inches). Basal area tables were also developed by species and diameter class on a per acre basis. Stock tables, the cubic foot volume of trees of a given species per diameter class per acre, were developed.

Tree volumes for hardwoods were computed according to three utilization standards, total volume, wood volume, and sawlog volume based on equations by Pillsbury and Kirkley (1984). Total volume is the total outside bark volume including the stump. Wood volume is inside bark volume from stump height (1 foot) to a 4 inch top (inside bark) for all stems. Sawlog volume is the inside bark volume found in trees having an 11-inch or greater DBH and have straight, sound segments 8 feet or greater in length, from stump height to a 9 inch top diameter inside bark. Only total volumes were computed for non-hardwood species. Tree volume equations used in the study the following form:

$$\text{Volume (cu.ft.)} = b_0(\text{DBH})^{b_1} (\text{Ht})^{b_2} (\text{Sawlog Ind.})^{b_3}$$

where: DBH is diameter at breast-height in inches,
Height is total height in feet,
Volume is in cubic feet based on one of the three utilization standards discussed above,
Sawlog Ind. is a code of "1" or "10". A value of "10" means the tree meets the sawlog criteria discussed above, and a value of "1" means that it does not meet sawlog standards. If the tree is not of sawlog quality and size, the last term can be dropped from the equation, and
b_0, b_1, b_2, b_3 are regression coefficients.

The total tree volume was calculated from a local volume equation developed from data by Pillsbury and Stephens (1978) and Pillsbury and Kirkley (1984). This was done to obtain a more precise estimate of volume growth following successive inventories because height, a less precise variable to measure, is not used in the equation. To determine the effect of eliminating height from the calculation of total volume, volumes for the three plots at site number 1 were compared using both local and standard volume equations to determine the actual difference. The difference, 1.3%, is not considered significant. All wood and sawlog volumes are from standard volume equations developed by Pillsbury and Kirkley (1984). A comparison of the proportion of volume measured as total, wood and sawlog volume is shown in Figure 2.

Thinning Prescription

The strategy used for cutting was a combination improvement cut and low thinning. Two plots at each site were thinned to 50 and 100 square feet basal area respectively, while the third, control plot, was not thinned. Trees designated as "cut trees" during initial field measurements were

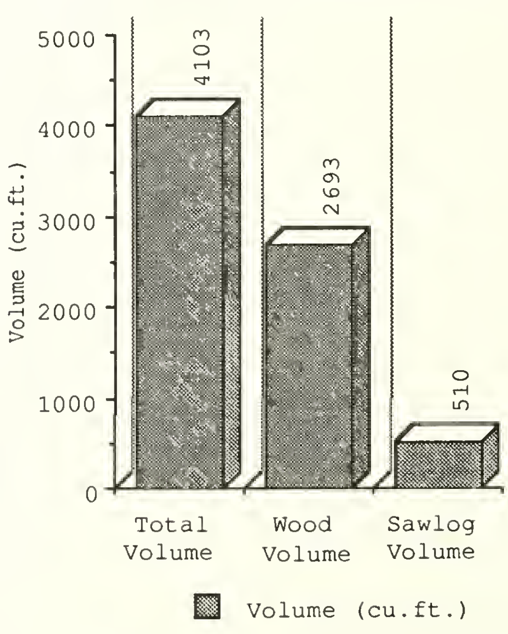

Figure 2. Proportion of total volume, wood volume, and sawlog volume in the coast live oak thinning study stands in Monterey, San Luis Obispo, and Santa Clara counties.

Table 1. Summary of coast live oak stand characteristics for central coast counties prior to thinning.

Site No.	Average Age (years)	Site Index (feet)	Crown Cover (%)	Average Spacing (feet)	Average Diameter (inches)	Number Trees (#/ac)	Basal Area (sf/ac)	Volume: Total[1] (cubic feet per acre)	Volume: Wood[2] (cubic feet per acre)	Volume: Sawlog[3] (cubic feet per acre)
1	52	52	97	9.6	7.7	478	153	3558	2059	135
2	57	36	96	10.8	10.4	372	219	5391	3022	0
3	28	84	84	7.8	5.7	723	125	2470	1611	101
4	63	60	93	13.7	12.4	255	202	5867	4572	2259
5	77	48	87	19.4	16.1	133	163	5060	3690	649
6	41	47	92	9.9	7.4	447	135	3013	1727	35
7	81	33	77	12.7	8.7	272	111	2594	1379	23
8	73	53	90	13.0	10.5	262	157	4052	3026	1216
9	85	39	87	19.8	16.7	115	170	5111	3391	539
10	61	42	90	11.7	9.8	335	157	3947	2478	145
Average	62	50	89	12.8	10.5	339	159	4106	2696	510

[1] Total volume includes all stem and branch wood plus stump and bark; excludes roots and foliage.
[2] Wood volume is computed from stump height (1 foot) to a 4 inch top outside bark; excludes roots, bark and foliage.
[3] Saw-log volume is computed for trees 11 inch d.b.h. and larger; from stump height to 9 inch top outside bark for straight sections 8 feet long; excludes roots, bark, and foliage.

automatically removed from the stand. These were mostly small diameter trees (less than 6 inches) of poor vigor and were either in the suppressed or intermediate crown class. The decision to cut a"tagged" tree was based on the following criterion. Trees were removed if they:

a) were not coast live oak,
b) were damaged or defective,
c) were less than 6 inches dbh,
d) were one stem of a forked tree,
e) were of suppressed or intermediate crown class, or
f) were of poor vigor.

In most cases further basal area reduction was needed to obtain either 50 or 100 sq. ft. basal area for the plot. Additional trees were removed if they:

g) were obviously from a previous stand,
h) were not sawlog quality or size, or
i) were too closely spaced to an adjacent tree.

Also, some changes in tree selection were made during the tree removal process. Trees that had excessive lean and whose crown adversely crowded adjacent crowns were removed. If the felling of a large tree would likely break or damage other trees, then either the large tree was not cut or the trees that would be damaged were also included on the removal list. The actual changes in the composition and structure of the stand resulting from thinning are illustrated in Figure 3-8. The bar graphs show the average change calculated from data for the 10 sites in Monterey, San Luis Obispo, and Santa Clara counties.

RESULTS

Stand, basal area and stock tables were developed for each plot and will be used to compare the changes due to stand growth every five years.

Initial stand characteristics for the ten stands measured in this study are shown in Table 1. Values shown for each stand are averaged from three one-fifth acre plots prior to thinning.

Figures 3 through 7 illustrate the change in the number of stems per acre, basal area per acre, total volume per acre, wood volume per acre and sawlog volume per acre as an average for the 10 sites for each treatment.

FUTURE ANALYSIS AND NEEDS

It is anticipated that the thinning study sites will be remeasured in successive five-year periods. Trees remaining on the treatment plots and all trees on the control plot will be inventoried for species, dbh, total height, sawlog indicator, tree vigor, and crown class. Also each plot should be measured for percent crown cover. New stand, basal area, and stock tables will be developed to show the relative change in distribution. Differences in basal area and volume will be converted to annual growth and analyzed to determine the level of increase obtained by thinnings.

More information is needed about the regeneration of coast live oak stands. We know that coast live oak is usually a vigorous stump sprouter after harvesting, but little specific information is known about how sprouting of this species is affected by stump size, age, site conditions, and the degree of exposure resulting from thinning. Although some of this information will be obtained from this study, the study was not designed to get the detailed information needed to accurately evaluate the effect of thinning levels on the spouting potential of coast live oak. More intense work is needed to obtain the information needed to develop effective management practices for the species.

Advanced reproduction (seedlings and small trees) are frequently present in coast live oak stands. How it will respond to thinning and how thinning will affect the establishment of new seedlings must also be determined. Guaranteeing satisfactory stocking is a basic requirement of stand improvement.

Finally, this study is only a beginning of the work needed to determine the overall role of thinning in the management of coast live oak in terms of total wood fiber production, increase growth of the residual trees, site effects, and economic consequences.

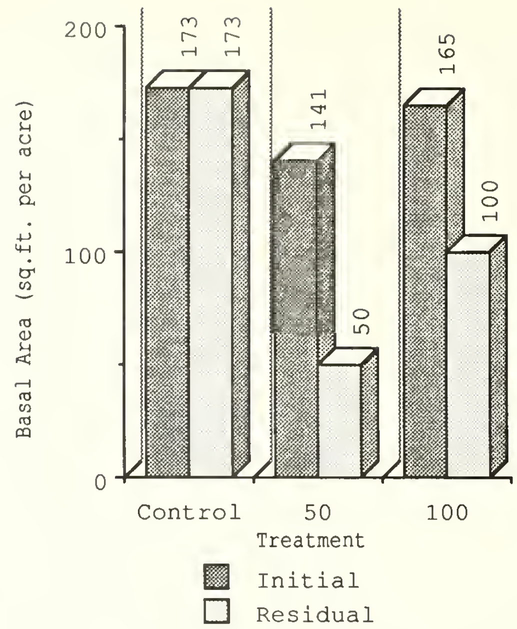

Figure 4. Comparative stand information for basal area per acre by treatment for the 10 coast live oak study sites in Monterey, San Luis Obispo, and Santa Clara counties.

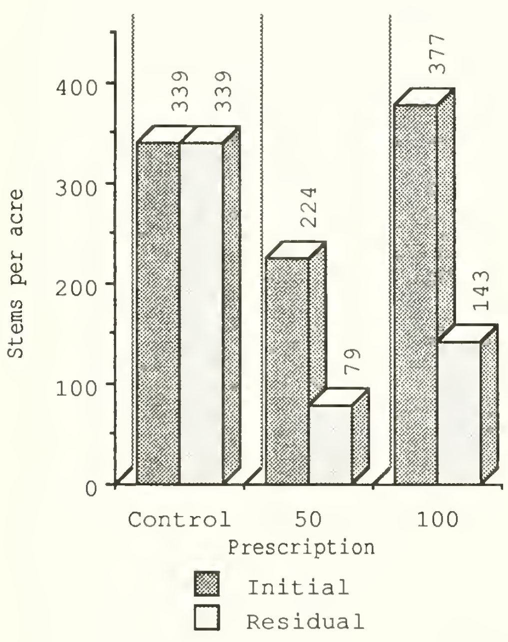

Figure 3. Comparative stand information for number of stems per acre by treatment for the 10 coast live oak study sites in Monterey, San Luis Obispo, and Santa Clara counties.

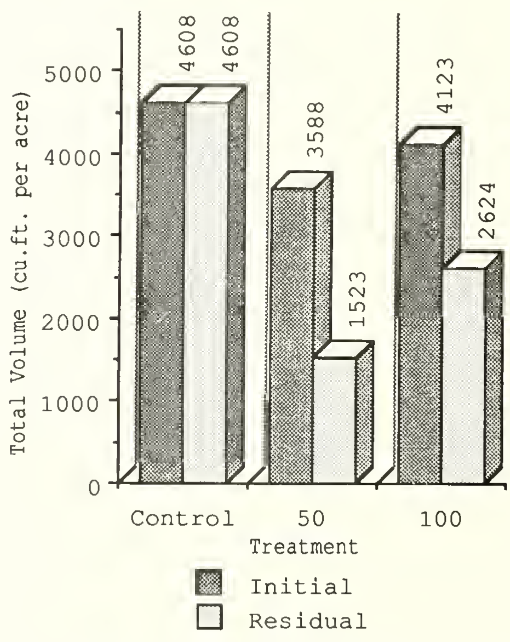

Figure 5. Comparative stand information for total volume per acre by treatment for the 10 coast live oak study sites in Monterey, San Luis Obispo, and Santa Clara counties.

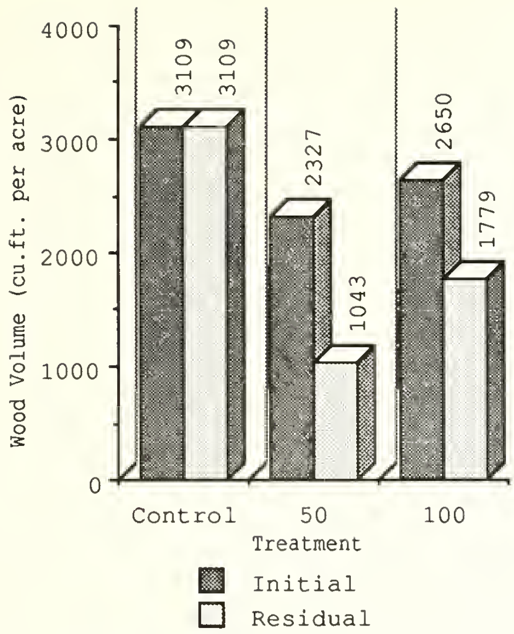

Figure 6. Comparative stand information for wood volume per acre by treatment for the 10 coast live oak study sites in Monterey, San Luis Obispo, and Santa Clara counties.

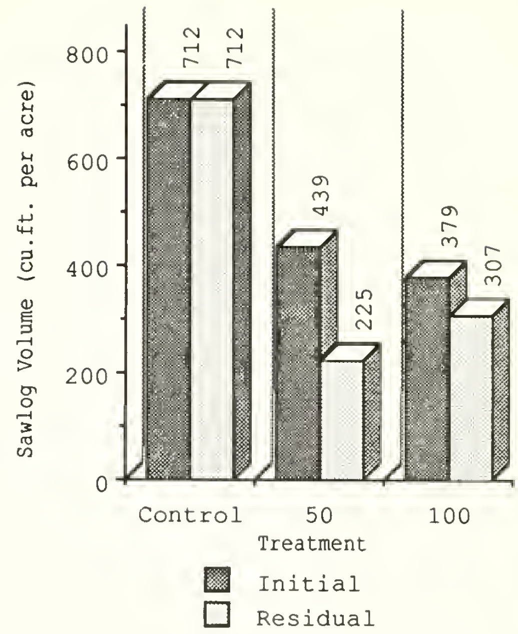

Figure 7. Comparative stand information for sawlog volume per acre by treatment for the 10 coast live oak study sites in Monterey, San Luis Obispo, and Santa Clara counties.

REFERENCES

Bolsinger, Charles. March 1986. Personal communication.

Daniel, Theodore W.; Helms, John A.; Baker, Frederick S. 1979. Principles of Silviculture. McGraw-Hill Book Company, New York. 500 p.

DeLasaux, Michael J. 1980. Inventory of Coast Live Oak Resource for Dry Creek Ranch, Buellton, California. Senior Project. California Polytechnic State University, San Luis Obispo. 73 p.

DeLasaux, Michael J. 1986. Personal communication.

Pillsbury, N.H. 1978. Stand Density Characteristics for Hardwoods in the Central Coast Counties of California. Central Coast Resource Conservation and Development Area, Salinas. 32 p.

Pillsbury, N.H. 1985. Coast Live Oak Thinning Study in the Central Coast of California. Report to: California Department of Forestry, Sacramento. Natural Resources Management Department, California Polytechnic State University, San Luis Obispo. 310 p.

Pillsbury, N.H.; De Lasaux, M.J. 1985. Site Index, Height, and Yield Prediction Equations for Blue Oak and Coast Live Oak in Monterey and San Luis Obispo Counties, California. Report to: USDA Forest Service, San Francisco, California. Natural Resources Management Department, California Polytechnic State University, San Luis Obispo. 125 p.

Pillsbury, N.H.; Kirkley,M.L. 1984. Equations for Total, Wood, and Saw-Log Volume for Thirteen California Hardwoods. Research Note PNW-414. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 52 p.

Pillsbury, N.H.; Stephens, J.A. 1978. Hardwood Volume and Weight Tables for California's Central Coast. California Department of Forestry, Sacramento. 54 p.

Smith, David Martin. 1962. The Practice of Silviculture. John Wiley & Sons, New York. 578 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Survey of Soil Nitrogen Availability Beneath Evergreen and Deciduous Species of *Quercus*[1]

V. Thomas Parker and Christine R. Billow[2]

Abstract: Inorganic nitrogen was measured in the soil beneath 3 evergreen and 3 deciduous species of *Quercus*. Available ammonium or nitrate varied from 0.5-46 ug/g soil. Nitrate concentrations decreased with elevation while ammonium remained constant. No consistent differences between evergreen and deciduous species were found. These results agree with a detailed 2 year study of available nitrogen and N-mineralization rates of *Q. agrifolia* and *Q. lobata*. These results contrast with studies of evergreen and deciduous species in the eastern U. S. and suggest that the mediterranean climate of California has more influence on soil nitrogen dynamics than does lifeform.

Comparisons between evergreen and deciduous species have produced a number of hypotheses on the relative advantages of leaf life span (Chabot and Hicks 1982). Among the most prevalent, are the suggestions that evergreenness confers a physiological advantage under otherwise unfavorable moisture or temperature conditions; for example, evergreen leaves can respond quickly to either temporary or seasonal removal of stress (Perry 1971, Bell and Bliss 1977), or can maintain some level of activity under stress (Mooney 1969, Mooney and Dunn 1970). Additionally, evergreenness should confer advantage under nutrient-poor conditions due to increased nutrient use efficiency, or tolerance of nutrient poor soils by tighter, more conservative nutrient cycles (Monk 1966, Small 1972, Schlesinger and Chabot 1977). Indeed, there appears to be a marked distributional pattern in parts of North America where evergreen species dominate on nutrient poor soils while deciduous species dominate more fertile areas (Goldberg 1982, Chabot and Hicks 1982).

Both climatic stress and nutrient stress are possible hypotheses explaining distributional patterns of species in the mediterranean climate of California. The climate imposes a seasonal drought on most tree species while the soils are nitrogen poor (Helmers et al. 1955, Holland 1973, Parker and Muller 1982, Jackson et al. 1985). The seasonal flux in soil moisture limits not only the physiological activity of trees but also microbial mineralization of organic matter (Alexander 1977). Because of mild temperatures and winter rains perhaps synchronization occurs between decomposition and vegetation uptake and growth (Gray 1983, Schlesinger 1985). Hollinger (1984) found, for example, that both the evergreen *Quercus agrifolia* Nee and the deciduous *Q. lobata* Nee are capable of nitrogen uptake during winter months, the same time we have estimated net mineralization of nitrogen to peak (Billow 1987).

Evergreen and deciduous hardwood species co-dominate on the same soils in California; within-habitat differences in distribution appear related more to moisture availability than soil fertility (Griffin 1971, 1973). How does the difference in leaf type, then, under the influence of a mediterranean climate, affect the cycling and availablity of the limiting nutrient nitrogen?

As in other evergreen-deciduous comparisons, the content of the limiting sets of minerals in the leaf litter of the deciduous species is considerably greater than that of the evergreen (Chabot and Hicks 1982, Gray 1983). In the case of California oaks, deciduous species have about twice as much nitrogen (pct dry wt) as evergreen species (Wheeler 1975, Hollinger 1984). Because *Q. agrifolia*, annually drops roughly twice the leaf biomass of *Q. lobata*, it produces a similar input of nitrogen to the surface litter (Hollinger 1984). An earlier study during the 1976-77 drought year found an order of magnitude greater concentrations of soil nitrate-N beneath the evergreen *Q. agrifolia* than in soils beneath *Q. lobata* (Parker and Muller 1982, Parker unpublished). But we have followed available nitrogen pools and mineralization rates beneath these two species for the past two years and have found similar nitrogen availability. Levels of nitrate-N were significantly higher beneath the evergreen during the winter and early

[1]Presented at the Symposium on Multiple-use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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spring of 1984-85 but were similar during 1985-86 (Billow 1987). Potential field N-mineralization rates (using in situ polyethylene bag technique, Eno 1960) also were similar. Further, seasonal patterns of inorganic N pools and N-mineralization rates paralled each other. Net N-mineralization was reflected by net nitrification which was highest during winter and early spring for both species.

A similar nitrogen fertility pattern beneath both Q. lobata and Q. agrifolia contrasts other temperate situations where lower N-availability is found associated with evergreen species. We evaluated site available nitrogen beneath several pairs of co-occurring deciduous and evergreen oak species. Because we had already found similar rates of N-mineralization beneath Q. lobata and Q. agrifolia and a winter peak in both inorganic pools and mineralization rates, we decided a survey of available soil nitrogen at one point in time could prove useful as a preliminary step in analyzing nitrogen dynamics of California oaks. The limitations of the measurement of instantaneous nitrogen pools are fully acknowledged. Our objective in this study is to identify obvious patterns to generate questions for future more detailed work. The general consensus is that a great divergence in nutrient dynamics exists between evergreen species (usually on poor soils) and deciduous species (usually on more fertile soils) (Chabot and Hicks 1982). Our long-term objective is to determine if these general hypotheses concerning soil fertility and evergreen-deciduous distribution patterns are applicable to species occupying the same soils in a mediterranean climate.

We have limited our study to central California species of Quercus. The congeneric comparison removes some potential sources of variablity (although not all) such as extreme differences in secondary compounds found in the litter that may also influence mineralization rates (Haynes 1986a, 1986b). The species sampled beneath were the evergreens Quercus agrifolia Nee, Q. wislizenii A. DC., and Q. chrysolepis Liebm., and the deciduous species Q. lobata Nee, Q. douglasii H. & A., and Q. kelloggii Newb.

METHODS

We sampled the same species at several sites (see table 1 for species locations). Our sites were above the north fork of the Yuba River in the Tahoe National Forest (900 m on HWY 49, 29 September 1985), the Stanford University Jasper Ridge Biological Preserve (180 m, 30 November 1985), Henry Coe State Park (670 m, 15 January 1986), the University of California's Hopland Reserve (670 m, 21 January 1986), the University of California's Hastings Natural History Reservation (600 m, 24 January 1986), and the Los Padres National Forest along Chews Ridge in Monterey County (1525 m, 24 January 1986). In general, we sampled beneath individuals isolated from one another in annual grasslands as much as possible. This worked for all the species except Q. kelloggii and Q. chrysolepis, which were sampled in adjacent pure forest stands. At Henry Coe, Q. douglasii was also sampled under forest conditions and Q. kelloggii at this site was in a mixed hardwood-conifer forest including Pinus ponderosa, Arbutus menziesii, Q. douglasii, P. sabiniana, and Arctostaphylos glauca as other important species. In each case, three 0-10 cm soil samples were collected from beneath 6 canopies of each species. Samples were stored overnight at 4 C, sieved through a 2 mm screen, and extracted using standard techniques (10 g fresh soil in 100 ml 2N KCl; 24 hr at 20 C). Percent moisture was determined by loss in weight in 50 g of sample soil after 48 hr at 80 C. Soil extracts were analyzed for ammonium-N and nitrate-N using a Technicon autoanalyzer II (Technicon 1973, 1977). Statistical analyses used ANOVA and Student's "t" to compare species within a site (Zar 1974, Statistix 1985). Variance heterogeneity required the use of log-transformations or Mann-Whitney-U tests in some instances (Zar 1974). Simple correlation analysis was used to identify patterns of inorganic nitrogen and elevation (Zar 1974, Statistix 1985).

RESULTS

The concentrations of ammonium-N and nitrate-N in the soil beneath both evergreen and deciduous species of Quercus ranged from 5.7-23.9 and 0.2-46.7 ug/g soil, respectively (Table 1). These values are similar to those found in our earlier study (5.7-27.0, 2.0-46.7, respectively, Billow 1987). Inorganic nitrogen concentrations in the soil beneath Q. agrifolia and Q. lobata were statistically similar at Hastings Preserve and Jasper Ridge but differed significantly ($p<0.05$) in nitrate-N at Henry Coe State Park; soil beneath Q. agrifolia had greater concentrations than that beneath Q. lobata. Comparison of Q. kelloggii and Q. chrysolepis at Chews Ridge and Yuba River sites also showed significant differences in nitrate-N concentrations, however, at these sites the concentrations beneath the deciduous species, Q. kelloggii, were significantly ($p<0.01$) greater than those

Table 1--Available NH_4-N and NO_3-N in the soil beneath various *Quercus* species. Values expressed are x ± S.E. in ug/g dry wt of soil. An * or difference in superscript letters following values represents significant differences within a site. At the Henry Coe site, the "s" and "w" following *Quercus douglasii* refer to savanna and woodland sites, respectively.

SITE/SPECIES	NH4-N	NO3-N
Yuba River		
Quercus kelloggii	15.8(2.9)	5.5(1.0)*
Q. chrysolepis	23.9(5.0)	1.8(0.3)
Chews Ridge		
Q. kelloggii	6.9(1.1)	2.1(0.6)*
Q. chrysolepis	8.4(1.0)	0.5(0.1)
Hastings		
Q. lobata	11.3(0.1)	2.1(0.3)
Q. agrifolia	12.1(1.5)	1.6(0.2)
Jasper Ridge		
Q. lobata	7.4(1.2)	21.0(6.5)
Q. agrifolia	9.4(1.9)	40.3(3.4)*
Henry Coe SP		
Q. douglasii(s)	13.7(0.9)[b]	0.6(0.1)[a]
Q. douglasii(w)	16.6(1.3)[b]	0.5(0.1)[a]
Q. kelloggii	10.6(0.8)[a]	0.5(0.1)[a]
Q. lobata	14.0(0.9)[b]	1.4(0.3)[b]
Q. agrifolia	15.6(1.0)[b]	2.6(0.9)[c]
Hopland		
Q. douglasii	14.5(2.3)[b]	0.6(0.2)[a]
Q. kelloggii	1.3(0.2)[a]	0.2(0.1)[a]
Q. lobata	16.2(2.0)[b]	1.7(0.5)[b]
Q. wislizenii	13.9(2.8)[b]	1.0(0.3)[b]

in the soil below evergreen *Q. chrysolepis*. Soil beneath *Q. chrysolepis* in these cases had twice the concentration of ammonium-N found for *Q. kelloggii* but was not statistically significant due to variance. *Quercus douglasii* appears to hold an intermediate position between the other two deciduous species, having greater ammonium-N concentrations than *Q. kelloggii* but less nitrate-N concentrations than *Q. lobata* at both sites where all three occurred. Soil nitrogen concentrations beneath *Q. wislizenii* were only measured at one site (Hopland Field Station) and were in the range of values generally found for *Q. agrifolia* and *Q. lobata* at all sites.

Elevation and soil nitrate-N concentrations were negatively correlated (fig. 1); nitrate-N concentrations increased with decreased elevation. Ammonium-N concentrations were not related

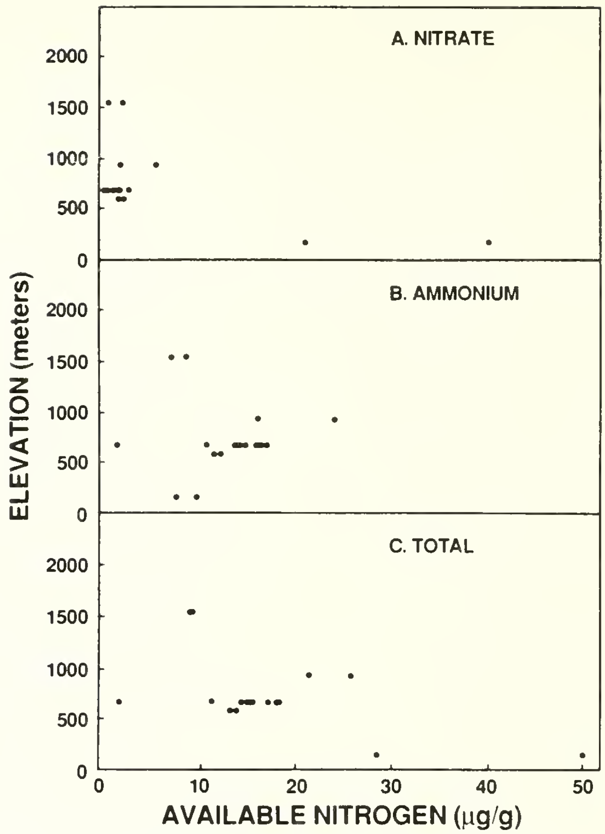

Figure 1--Patterns of soil available inorganic nitrogen beneath a variety of oak species and elevation (m). Nitrate-N (ug/g) is illustrated in "A", ammonium-N in "B", and total inorganic nitrogen (NH_4-N + NO_3-N) in "C". Both nitrate and total available inorganic nitrogen were negatively correlated with elevation (correlation coefficient -0.540 and -0.543, respectively, both $p<0.05$).

to elevation, but combined ammonium- and nitrate-N (total) were also negatively correlated with elevation.

DISCUSSION

The findings of this study agree with our previous findings which suggest California evergreen and deciduous oaks do not differ significantly in soil nitrogen availability (Table 1, Parker unpublished, Parker and Muller 1982, Billow 1987). In some cases, comparisons between a deciduous-evergreen species pair found higher concentrations of nitrogen beneath the evergreen, in other cases beneath the deciduous species. Soil nitrogen availability can be greater beneath *Q. agrifolia* than *Q. lobata* in some years during mid-winter months when soil inorganic nitrogen concentrations and N-mineralization are peaking, but is usually similar (Parker and Muller 1982, Billow 1987). This survey suggests that the mid-winter evergreen-deciduous nitrogen peak may not hold in all cases. Due to the use of a single soil sampling period per species per site, we may have simply missed the peak periods for many of these species because nitrogen availability and precipitation patterns shifted during the 1985-86 season (Billow 1987).

Seasonal decomposition and mineralization processes in the California oak savannas and woodlands are limited by water availability rather than cold winter temperatures. Mineralization processes are sensitive to moisture and temperature, particularly to the combination of drying with warm temperatures (Schlesinger and Hasey 1981, Schlesinger 1985, Haynes 1986a). Similar levels of inorganic nitrogen found under California oaks (table 1), plus similar potential mineralization rates (Billow 1987), suggests that soil N-mineralization processes beneath deciduous and evergreen species reach comparable functional equilibrium under the influence of the mediterranean climate.

These results contrast with patterns in other temperate areas, especially mesic eastern U. S. forests, where evergreen and deciduous species are often found in habitats that differ greatly in fertility (e.g. see Chabot and Hicks 1982). In such studies, rates of N-mineralization, and thus nitrogen availability, are lower beneath the evergreen species (e.g., Nadelhoffer et al. 1983); sclerophylly (evergreenness) has been hypothesized as an adaptation to nutrient poor soils (Monk 1966, Chabot and Hicks 1982).

Another pattern found was the significant negative correlation between elevation with both total available inorganic nitrogen and nitrate-N (fig. 1). At lower elevations, greater concentrations of nitrate-N were found while ammonium-N had no particular pattern. We interpret these results as a reflection of site rainfall and temperature more than differences in species or leaf characteristics. The implication is, however, that those species with a generally higher elevational distribution pattern would likely show lower seasonal rates of N-mineralization and levels of nitrogen availability because the rainfall limits decomposition and mineralization to comparably colder conditions. Thus, their overall nitrogen budgets may be lower.

Similarities in available inorganic nitrogen pool sizes and potential N-mineralization rates among evergreen and deciduous California oaks seem clear to us, but our confidence in other interpretations is limited by our methods both in this study and our previous work and the gaps in our knowledge. More detailed work is needed to gain an understanding of relationships between evergreenness and soil fertility in the California oak savannas and woodlands. In depth investigation of seasonal patterns of inorganic nitrogen availability and net mineral N production in the soil and litter of Quercus agrifolia, Q. lobata (Billow 1987), and Q. douglasii (Jackson et al. 1985) is only a first step. Description of seasonal patterns of microbial and standing crop nitrogen should be one focus of future study since microbes and plants are large sinks of inorganic nitrogen in natural ecosystems. To our knowledge, only one study provides an attempt at this type of information in oak communities (Jackson et al. 1985). Information on litter decomposition beneath species of Quercus is completely lacking and is essential to understanding the influence of a mediterranean rainfall regime on the leaves of species which may vary in lifespan, degree of sclerophylly, nutrient, and other characteristics. Finally, research is needed on the temporal pattern of inputs (stemflow and throughfall), outputs (leaching) and storage (clay fixation and CEC) in this system.

Acknowledgements: We wish to thank Mike Williams, Vicky Kelly, Joan Leong, and Robert Patterson for help with field collections. In addition, Jim Griffin at Hastings Natural History Reservation and Al Murphy at Hopkins Field Station provided invaluable help. We thank the California Department of Parks and Recreation for permission to sample in Henry Coe State Park, and Stanford University for permission to use sites at Jasper Ridge. In particular we wish to thank Peter Vitousek and Doug Turner at Stanford University for the use of facilities and help during the analysis phase.

LITERATURE CITED

Alexander, M. Introduction to soil microbiology. 2nd ed. New York: John Wiley and Sons; 1977. 467 p.
Bell, K. L.; Bliss, L. C. Overwinter phenology of plants in a polar semidesert. Arctic 30:118-21; 1977.
Billow, C. R. Nitrogen dynamics beneath a deciduous (Quercus lobata Nee) and an evergreen (Q. agrifolia Nee) oak in California. San Francisco: San Francisco State Univ.; 58 p. Thesis.
Chabot, B. F.; Hicks, D. J. The ecology of leaf life spans. Ann. Rev. Ecol. Sys. 13:229-59; 1982.
Eno, C. F. Nitrate production in the field by incubation of the soil in

polyethylene bags. Soil Sci. Soc. Amer. Proc. 24:277-279; 1960.
Goldberg, D. E. The distribution of evergreen and deciduous oaks relative to soil type: an example from the Sierra Madre, Mexico and a general model. Ecology 63:942-951; 1982.
Gray, J. T. Nutrient use by evergreen and deciduous shrubs in southern California. I. Community nutrient cycling and nutrient-use efficiency. J. Ecol. 71:21-41; 1983.
Griffin, J. Oak regeneration in the upper Carmel Valley, California. Ecology 52:862-868; 1971.
Griffin, J. Xylem sap tension in three woodland oaks of central California. Ecology 54:152-159; 1973.
Haynes, R. J. The decomposition process: mineralization, immobilization, humus formation, and degredation. In: Haynes, R. J., ed. Mineral Nitrogen in the plant-soil system. Orlando, Fl: Academic Press; 1986a:52-126.
Haynes, R. J. Nitrification. In: Haynes, R. J., ed. Mineral Nitrogen in the plant-soil system, pp. 127-165. Orlando, Fl: Academic Press; 1986b:127-165.
Hellmers, H.; Bonner, J. F.; and Kelleher, J. M. Soil fertility: a watershed management problem in the San Gabriel Mountains of southern California. Soil Science 80:189-197; 1955.
Holland, V. L. A study of soil and vegetation under Quercus douglasii compared to open grassland. Berkeley, CA: Univ. of California; 1973. 359 p. Dissertation.
Holland, V. L. Effect of blue oak on rangeland forage production in central California. In: Proceedings of the Symposium on the Ecology, Management, and Utilization of California Oaks, USDA For. Serv. Gen. Tech. Rep. PSW-44; 1980; 314-318.
Hollinger, D. Y. Photosynthesis, water relations, and herbivory in co-occurring deciduous and evergreen California oaks. Stanford, CA: Stanford Univ. 1984. 173 p. Dissertation.
Jackson, L. E.; Strauss, R. B.; Firestone, M. K.; and Bartolome, J. W. The effect of plant growth patterns on seasonal dynamics of nitrogen in a California oak savannah. Bull. Ecol. Soc. Am. 66:199-200; 1985.
Monk, C. D. An ecological significance of evergreenness. Ecology 47:504-505; 1966.
Mooney, H. A. Dark respiration of related evergreen and deciduous mediterranean plants during induced drought. Bull. Torrey Bot. Club 96:550-55; 1969.
Mooney, H. A.; Dunn, E. L. Convergent evolution of mediterranean-climate evergreen sclerophyll shrubs. Evolution 24:292-303; 1970.
Nadelhoffer, K. J.; Aber, J. D.; and Mellilo, J. M. Litter production and soil organic matter dynamics along a nitrogen-availability gradient in southern Wisconsin (U. S. A.). Can. J. For. Res. 13:12-21; 1983.
Parker, V. T. Dominance relationships of tree associated herbs in some California annual grasslands. Santa Barbara, CA: Univ. of California; 1977. 149 p. Dissertation.
Parker, V. T.; Muller, C. H. Vegetational and environmental changes beneath isolated live oak trees (Quercus agrifolia) in a California annual grassland. Amer. Midl. Nat. 107:69-81; 1982.
Perry, T. O. Winter-season photosynthesis and respiration by twigs and seedlings of deciduous and evergreen trees. For. Sci. 17:41-43; 1971.
Schlesinger, W. H. Decomposition of chaparral shrub foliage. Ecology 66:1353-1359; 1985.
Schlesinger, W. H.; Chabot, B. F. The use of water and minerals by evergreen and deciduous shrubs in Okeefenokee Swamp. Bot. Gaz. 138:490-97; 1977.
Schlesinger, W. H.; Hasey, M. M. Decomposition of chaparral shrub foliage: losses of organic and inorganic constituents from deciduous and evergreen leaves. Ecology 62:762-774; 1981.
Small, E. Photosynthetic rates in relation to nitrogen recycling as an adaptation to nutrient deficiency in peat bog plants. Can. J. Bot. 50:2227-33; 1972.
STATISTIX [Computer program]. Version 1.0. NH Analytical Software. 801 W. Iowa Ave. St. Paul, MN, USA; 1985.
Technicon Instruments. Nitrate and nitrite in water and wastewater. Industrial method number 100-70W. Technicon Instruments Corporation, Terrytown, New York, USA; 1973.
Technicon Instruments. Individual/simultaneous determinations of nitrogen and/or phosphorus in BD acid digests. Industrial method number 329-70W. Technicon Instruments Corporation, Terrytown, New York, USA; 1977.
Wheeler, N. C. Foliar nutrient reabsorption efficiency in five species of California oaks. San Diego, CA: San Diego State University; 1975. 107 p. Thesis.
Zar, J. H. Biostatistical analysis. Englewood Cliffs, NJ.: Prentice-Hall, Inc.; 1974. 620 p.

Protection and Damage Factors

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Protection and Damage Factors[1]

Robert E. Martin[2]

The growth and well being of hardwoods, as with any other organism, are dependent on the total environment. Many of the factors affecting the hardwoods are considered normal elements in their environment, contributing to their productivity. Other factors are generally considered to be damaging to hardwoods. These agents would usually include diseases, insects, and fire.

The specific term used tends to indicate the role the agent has. When we use the term disease or pathogen, the indication is that there is damage being done to the plant. Since disease may be any condition of the plant not considered normal and the pathogen as the causative agent, both these terms imply something harmful to the plant. Unfortunately, there is not a general term which might include all the agents which will affect the hardwood, at one level being beneficial, or at least not harmful, but at some other level causing injury to the plant. The pathogens may be, at some level of occurrence, microorganisms, nutrients, weather, or many kinds of macroorganisms.

Arthropods include the insects, which are often considered to be injurious to hardwoods. While it is true that some arthropods may be harmful, most contribute to the well-being of hardwoods, even to the extent of controlling damaging arthropods.

Fire is another agent often looked upon as being damaging to hardwoods. True, fire may kill or damage hardwoods and may make trees more susceptible to arthropods or pathogens. Fire may also be important in providing the conditions for regeneration and growth of hardwoods. Thus fire, as with other agents, may be either harmful or beneficial, depending on the timing and nature of its occurrence.

The papers in this section cover the effects of diseases, insects, and fire on hardwoods. Most of these do not cover more than the effects of a single agent, as most of our research is funded and conducted in this manner. We should keep in mind, however, that there is often interaction among the agents which affect hardwood well-being. In the future, hopefully there will be more research which deals with the interaction of two or more agents as they affect hardwoods.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, San Luis Obispo, CA, November 12-14, 1986.

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Natural Agent Interaction[1]

Robert E. Martin[2]

Abstract: Natural agents affect the abundance, distribution, and stature of California's hardwoods, as well as that of almost any biological species. In addition to affecting the vascular plants, the agents interact with each other, either enhancing or mitigating the influence on the overall biotic community. The agents may be biotic, such as insects, diseases, or herbivores, or abiotic, such as various components of the weather, the physical elements of the site, or fire. The purpose of this paper is to look at some of the possible interrelationships among the agents and the sum of their effects on hardwoods.

When talking of a hardwood, we generally talk of it in a holistic sense, as though it is an amalgamated mass of protoplasm, all having the same characteristics. Yet we know that the plant has many different organs, may be in various physiological aor phenological states, and may be at various stages of growth. Thus, talking about the effects of agents on a hardwood, we must be specific about the plant as well as the agent affecting it.

Interaction among agents which affect hardwoods, as well as other plants and animals often influence the total effect of the complex. The total effect can be enhanced in a synergistic way or reduced by the antagonistic interaction among agents.

We can look at the way in which the interaction proceeds when one agent is considered as the intiating agent, and consider various paths which might develop from the action. What readily becomes obvious is that we have little information on the progress of the interactions. It is also difficult to sort out the "normal" elements of the plant habitat or environment from those which are causing a problem for the plant.

Throughout most of the paper, I'll discuss some potentials for interaction among agents affecting hardwoods. Where feasible, specific agents and interactions will be mentioned. We must realize, however, that many of the situations are hypothetical. The main purpose of this paper is thus to be sure, as we proceed through the meeting that you are considering the possible interactions that might be occurring. Also, you should be considering that we can depict here only a small number of the interactions that are possible or plausible.

THE HARDWOOD IN ITS ENVIRONMENT

First, let's look at the plant and the many agents which can affect it's well being. Considering the plant at the center, since we are centering our attention on it, we can place it at the center and surround it with the various agents (fig. 1). Ordinarily, we might not consider the need to protect the plant from some of these, but any can be injurious or fatal to the plant.

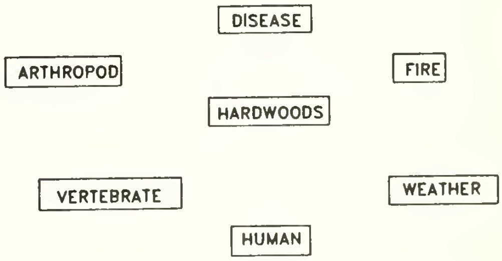

Figure 1--Each hardwood can be considered at the center of the various groups of agents which might cause damage.

Any organism exists in an environment which we tend to consider its normal environs (fig. 2). We seldom know how much of that environment is needed and necessary for the plant's well-being, and how much is deleterious to its health and growth. Many of the agents discussed below are part of that environment we consider to be normal and we don't separate out those effects. In the following paragraphs, we will consider the agents when they seem to have an effect outside the normal environment of the hardwood.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, San Luis Obispo, CA, November 12-14, 1986.

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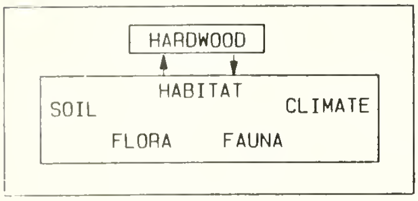

Figure 2--Each plant exists in an environment where elements may be consicered normal at some level of occurrence.

Insects are usually considered to be a major souce of potential injury. Here, I've used the broader Arthropoda, which include the Insecta but also the Arachnida (spiders and mites) and the centipedes and millipedes. Although many arthropods are important to the proper growth and well-being of the plant, others may cause considerable damage.

Pathogens are ordinarily considered to be the fungi and bacteria which detract form the normal health of the plant. The protection specialist may lump some of the arthropod damage into the disease category, so the separation of arthropod and pathogen damage is sometimes unclear even to the specialist. Indeed, the two groups of agents often work in conjunction, producing a synergistic effect where the sum of the damage is more than the individual effects of either of the two.

Fire is an important agent affecting hardwoods. Often it is considered only in the light of damaging or killing hardwoods. We must look at it also in its importance in providing the conditions for regeneration and growth of various species. The variety of fire regimes and their differences in effects on hardwoods must be considered just as we consider the differences among arthropods and pathogens.

Weather has great influences on the health of hardwoods. In contrast to climate, the average of the weather over long periods of time, weather varies considerably from the norm over various periods of time. Temperature, precipitation, and wind in different conbinations can have disastrous effects on most species, and can work in consort with the arthropods, pathogens, and fire to make the effects worse. As with the three groups of agents above, proper culture of hardwoods is the best protection from weather elements.

Vertebrates have important roles in the distribution and health of hardwoods, as anyone who has cultured a garden or forest is well aware. The role may be from the transport and scarification of seeds to the local annihilation of a particular species.

Humans, though only one of perhaps hundreds of vertebrate species which affect hardwoods, play a key role among the agents affecting hardwoods because of our ability to transport the plant itself, many agents affecting the hardwood, and tools and energy with which to modify the plant and its environment. Biologically we are only a subgroup of the vertebrates, but our special abilities warrant separate consideration.

The Hardwood

The hardwood cannot be considered itself as a homogeneous unit. After considering the wide range of species and habitats, we must consider the various organs, stages, and conditions in which the plants exist (fig. 3).

HARDWOOD

CONDITION	STAGE	ORGAN
HEALTHY	SEED	SEED
WEAK	SEEDLING	FRUIT
SENESCENT	SAPLING	FLOWER
DORMANT	MATURE	BUD
VERDANT	OVERMATURE	FOLIAGE
STRESSED		BRANCH
		BOLE
		ROOT

Figure 3--Agents affecting hardwoods may attack one or more plant organs, stages, or conditions.

First, let's consider the various organs of hardwoods. Different agents will have different effects on different organs. Some agents will affect only one organ at a given stage of development under a certain range of conditions. Examples would be various arthropods and pathogens. Other agents, such as fire or weather, might affect the entire plant or many organs at the same time.

The stage of development of a hardwood is another consideration in looking at the effects of agents. Fire and ungulates might keep seedlings or sprouts of hardwoods at a limited size by repeated killing back to ground level, or might result in the loss of seedlings which have no ability to sprout. Combinations of fire, insects and pathogens might cause the loss of old growth. On the other side, birds, small mammals, and weather may be responsible for the transport and planting of seeds for the establishment of new seedlings at some distance from the source.

The condition of hardwoods is also important in the effects agents will have. Fire, pathogens, or weather may weaken a hardwood for insects to kill it later, or the phenological state of a plant may make it more or less susceptible to an agent. The site on which the hardwood is growing will affect its general susceptibility to agents; the more ideal the site, generally the less susceptible.

Another consideration in looking at agents and their effects on hardwoods is the "normal" environment in which the plant exists (fig. 3). Each plant grows in a specific location where the factors are unique. The characteristics of that looation, as well as the genetic makeup of the plant, will influence what will happen. The rate of growth, form, and susceptibility to agents will all be influenced. Further, we generally oan't define accurately the elements of this normal situation.

Effects of Agents

Eaoh group of agents will be considered in turn. The direot effects of the agent will be oonsidered, as well as the indirect effects as the agent works through other agents to affect the hardwood.

Arthropods

Inseots are generally considered to be the most damaging among the arthropods, perhaps beoause of their abundance but also maybe because their damage is so visible. Injury from arthropods may be direct or indirect (fig. 4).

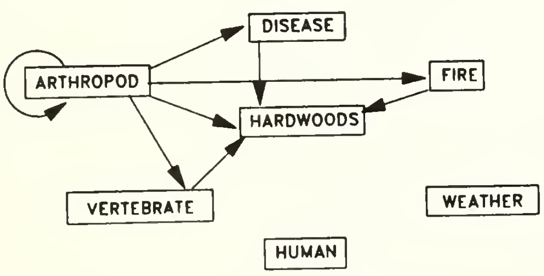

Figure 4--Arthropods may attack hardwoods directly or in conjunction with other agents.

Direct injury from arthropods may be defoliation, such as that of the Califronia oakworm (Phryganidia californica). It is one of several species of worms that feed on oaks, but is perhaps the best known and most studied. Its range extends from SanDiego into central Oregon (Wickman 1985). Several papers on this species appear in this symposium. Examples of the interaotion among agents are the insect parasites which attack the oakworm (Young 1977).

New insect pests of plants appear oocasionally, introduced from abroad or other localities. Eucalyptus species (Eucalyptus spp.) have enjoyed freedom from many of their natural insect enemies, but the recent appearance of the longhorned Eucalyptus borer may pose a serious threat to some Eucalyptus species, particularly Eucalyptus globulus (Acorn 1986). As a newly introduced pest, it may spread more rampantly because it is temporarily from its enemies.

Arthropods may also influence other agents affecting hardwoods. The potential for insects to carry diseases has been an important factor in the loss of hardwoods elsewhere, most recently in the loss of so many elms in Eastern United States. Insects may also influence the fire regime, such as the intensity, extent, and return interval of fires. This could occur through changing species composition or overstory cover.

Diseases

Diseases may affect the hardwoods directly or indirectly through their influence on other agents, and in turn may be affected by other agents (fig. 5). Hect-Poinar et al in this symposium discuss the protection of California oaks from several insects and diseases, and Tidwell (1986) has indexed diseases of California oaks. Diseases may affect the susceptibility to other agents. The interactive cycle with fire, where a tree may be scarred by fire forming an infection court, which in turn may make the tree more susceptible to future fire, insect attack, or wind and snow breakage, might be cited as an important example.

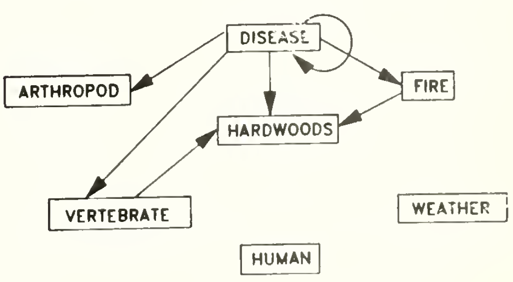

Figure 5--Diseases may act directly to injure hardwoods or in consort with other agents.

Fire

Fire may be a very important and direct influence on the prevalence of any plant species (fig. 6). It can temporarily remove a species from a site and do much to help another become established - common observations we have all made. Less understood, and often not even considered are fire's role in changing site characteristics and the habitat of arthropods, diseases, and vertebrates in such ways that may greatly favor the establishment and growth of one species of hardwood over another.

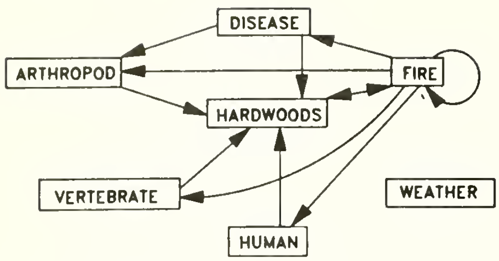

Figure 6--Fire may act directly to reduce or increase a hardwood on a site, or may act synergistically with other agents.

Martin et al (1976), Mitchell and Martin (1980), and Martin and Mitchell (1980) have considered many of the interactions that might occur among fire, insects, and diseases. Although their papers considered mostly interactions in connection with conifers, in principle the ideas are applicable to hardwoods.

Weather

Weather is an agent we all recognize as having a great influence on any plant species, yet one which is not often influenced immediately by other damaging agents. The long-term influence of other agents, particularly humans, may modify the weather and climate.

Weather and climate influence all the other agents and have their direct influence on hardwoods (fig. 7). They influence the species that grow on a site, and, to look back a little further, influence the site itself. As weather changes, the phenological and physiological condition of plants change, making them more or less susceptible to other agents.

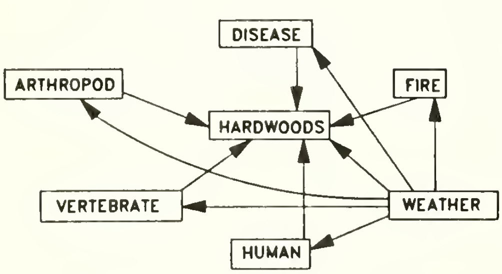

Figure 7--Weather, through temporary fluctations from the normal, may make hardwoods more susceptible to other agents, or may damage harwoods directly.

Drought is often a cause for injury or death of plants. Dieback of the crown or complete loss of plants may occur during and following drought. Drought may also make plants susceptible to insects and diseases. Often it is difficult to determine whether the insects and diseases or the drought are responsible for the decline or death of the plant, or whether it is the combination that is deadly.

Weather which is wetter than normal may also result in injury to hardwoods and other plants. A direct effect may result from the inundation of root systems or flooding which physically disrupts the plant. Wet weather may increase theinfluence other agents, such as root or leaf diseases which flourish under the wetter conditions. It may be that the Phytophthora fungus attacked the root systems of some shrub and hardwood species during the recent wet winters in California, resulting in plant dieback.

Weather and climate affect the activities of humans, all the way from choices of living sites to daily or hourly activities. The cumulative effects have had and will continue to have a great influence on hardwoods.

Vertebrates

Vertebrates may affect the well-being of hardwoods in positive or negative ways, often depending on the population of any given species or group of species. Humans, although they technically belong with the other vertebrates, are discussed separately because of their unique nature and capabilities.

Vertebrates may affect hardwoods at any stage of development. Perhaps the most obvious are at the seed or sapling stage. Vertebrates may also affect the potential for fires, insects, or diseases to affect hardwoods (fig. 8).

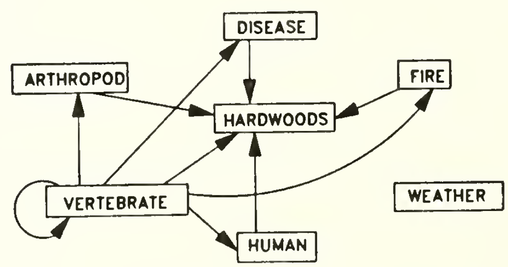

Figure 8. - Vertebrates may affect hardwoods in many ways, and also indirectly through modifying the effects of other agents.

Vertebrates may contribute to the distribution, planting, or destruction of seeds. If rodents or birds, in particular, are low in number, the distribution of seeds may be inhibited in those species with relatively heavy seeds. In addition to dispersal, rodents may bury seeds in caches, often leaving unused seeds well-planted for germination. When the population becomes too high, however, most seeds may be used and very few are available to produce seedlings. The swing in population will probably return to the low end in time, thus allowing hardwoods to produce an abundance of seeds which will be available for germination.

Large vertebrates affect hardwoods by eating seeds, trampling or browsing seedlings, debarkingtrees of various sizes. Trampling may also provide micro relief and the planting of seeds, or can result in compaction of soils, thus reducing establishment or growth potential. The grazing or browsing may favor the establishment or growth of other plants, in some cases hardwoods, by reducing the competition. Browsing or debarking of trees often provides means for insects to attack hardwoods, which will in turn further weaken or kill the tree.

Humans

Humans, because of our unique abilities, can affect not only the hardwoods themselves, but almost all the other agents which may damage hardwoods (fig. 9). Our influence goes even to influencing the weather in the short term if we consider the nature of the rain which falls. The extent to which we influence long-term weather and climate may be more debatable. Since humans are so versatile in the ways they influence hardwoods, from planting and nurturing them on the one hand to cutting and bulldozing them on the other, I'll let the reader ponder the various ways we might influence all the factors.

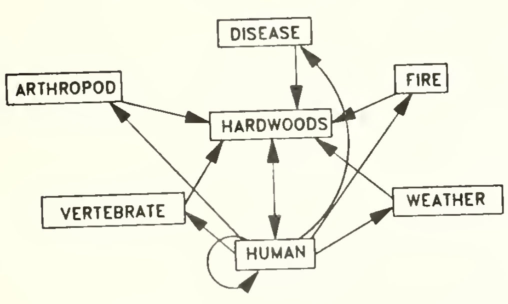

Figure 9--Humans, through their ability to affect so many factors, may have a wide range of effects on hardwoods.

Summary

Many agents influence the well-being of hardwoods at many stages or conditions of growth. An agent at one population level may enhance conditions for hardwood growth, while at another may severely hinder growth or result in hardwood mortality. There is much interaction among agents (fig. 10), and the overall picture would be confusing. Because of all the interactions and the means in which we approach problems, most research on protection of vegetation deals with only a few factors. This approach is both necessary and limiting, and understanding of the entire sphere of influences on hardwoods will continue to be constrained.

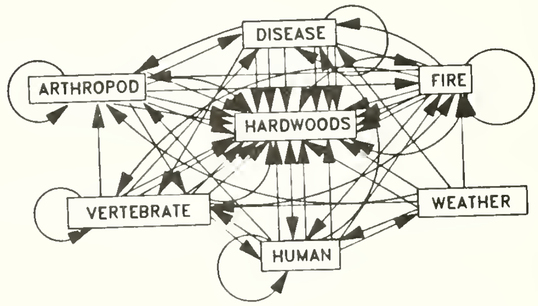

Figure 10--The interactions of all agents are so complex that a study of several agents at once would be difficult and expensive, and the study of only one agent at a time may be too simplistic.

References

Acorn. Long-horned borer:newcomer from 'down under'. Acorn, Natural Resources Management Department, Calif. Polyt.State Univ., San Luis Obispo, CA. Symposium Edition, Nov, 1986:10.

Martin, Robert E., Dan D. Robinson, and Walter H. Schaeffer. Fire in the Pacific Northwest: perspectives and problems.Proc 15th Annu.Tall Timbers Fire Ecol. Conf. Tall Timbers Res. Stn., Tallahasee, FL:1-23.

Martin, Robert E., and Russel G. Mitchell. Possible, potential, probable, and proven fire-insect interactions. Land-Use Allocation: Processes, People, Politics, Professionals. Proceedings, 1980 convention of The Society of American Foresters. Spokane, WA.:138-144.

Mitchell, Russel G., and Robert E. Martin. Fire and insects in pine culture of the Pacific Northwest. Proceedings Sixth Conference on Fire and Forest Meteorology. Seattle, WA. Society of Amer. For.:182-190.

Tidwell, T.E. Index of diseases and microorganisms associated with California oak trees. Calif. Dept. of Food and Agric., Sacramento, CA:103 p.

Wickman, Boyd E. California oakworm. Forest Insect and Disease Leaflet, #72, revised. USDA Forest Service. Washington, DC. 1985, 4p.

Young, L.C. Pupal parasites of the California oak moth, Phryganidia californica Packard: A biological and ecological study. Berkeley, CA: Univ. of California; 1977. 126 p. Dissertation.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Protection of California Oak Stands from Diseases and Insects[1]

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Abstract: Diseases and insect pests of oaks are widespread and serious in at least 14 counties of California, and mortality has been reported from eight coast range counties. Since 1977 two diseases in particular have become a problem: a large-branch dieback caused by *Diplodia quercina*, which is more severe when trees are stressed by drought, and a twigblight caused by *Cryptocline cinerescens* and *Discula quercina* which has become severe following some very wet seasons. An association between pit scale infestation and twig blight severity was established, although the nature of this interaction is not clear. Experiments to control the two diseases showed promising results with Banner, Rubigan and especially with pruning and Benomyl.

In the management of oak stands, disease and insect problems are of considerable importance. Some diseases and insects have been known for some time, such as root rot caused by *Armillaria mellea* (Vahl ex Fr.) Kummer, crown rot caused by *Phytophthora* spp., pit scales (*Asterolecanium minus*, Lindinger) tussock moths (*Orgyia vetusta* (Boisduval)), orange tortrix (*Argyrotaenia citrana* (Fernald)) and oak moths (*Phryganidia californica*, Packard). Other pathogens and pests have only recently been recognized and apparently fluctuate markedly in response to environmental vicissitudes.

The Index of Diseases and Microorganisms associated with California Oak trees (Tidwell, 1986) lists *A. mellea* on 10 oak species. This fungus is found frequently on root systems where, under natural conditions, it may cause little damage. However, when oaks are watered near the root crown in the summer or otherwise stressed, they may succumb to this root rot rather rapidly. There is no known effective chemical treatment for a tree with this disease, but if the disease has not progressed too far, cutting out the infected tissue and exposing the affected area to air has been suggested to prolong the life of the tree (Brown et al., 1963).

Phytophthora crown rot is mainly a problem in nurseries or in urban plantings and also is associated with over watering in the summer. Other pathogens of oaks include *Spaerotheca lanestris* causing powdery mildew and witches' brooming and *Erwinia quercina*, a bacterium, causing a drippy acorn disease (Brown et al., 1963) just to mention a few. Tidwell (1986) listed 418 spp. of organisms on 37 oak species (native and imported) in California.

There are 50 insect pests listed on *Quercus* spp. of which the pit scale often is serious on *Q. lobata* and *Q. agrifolia*. Applications of an oil-carbaryl mixture during the period of early crawler emergence (late April through early June) gives effective control of this insect (Koehler et al., 1968).

During the last 8 years, dieback (Hecht-Poinar, 1986) and twig blight (Hecht-Poinar, 1981) have become of concern to ranch owners, landscape architects and urbanites in California. This report mainly concerns these diseases.

DISTRIBUTION

Dieback and twigblight are common and sometimes severe in all of the coast range counties where observations have been made. Tree mortality has been reported in Marin, San Luis Obispo, Santa Clara, Contra Costa, San Mateo, Napa, Solano, and Monterey counties (fig. 1).

Figure 1--Distribution of Dieback and Twigblight on *Quercus agrifolia* (1982-1984).

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[1] Presented at the Symposium on Multiple Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Areas where systematic surveys were conducted, the disease occurred on a variety of sites, topographies and exposures. Trees varied widely in susceptibility to twig blight. Unaffected trees frequently were found growing next to trees with severe symptoms (fig. 2).

Figure 2—Slope with mostly Q. agrifolia in Contra Costa County showing infected and uninfected trees growing side by side.

DIEBACK

A dieback of large branches (fig. 3) of Q. agrifolia Nee, Q. lobata Nee, and Q. kellogii Newb. is caused by Diplodia quercina West. This disease appeared after the severe drought of 1976-1977 in California (Hecht-Poinar et al., 1981). A similar association was found in Belgium by Roland (1945) who reported devastating losses due to Diplodia in red oak forests in the Ardennes following a period of severe drought in the 1940s. During the early eighties, when California experienced several wet winters, this dieback became less severe; it increased again in 1985-1986 following a relatively dry early spring period.

Inoculations made with hyphae which had been grown in culture in a laboratory confirmed that infection could occur through wounds, pruning cuts, leaf scars and occasionally petioles. The regular presence of the fungus in buds suggests that petiole infection might occur in nature. However, the failure of the fungus to spread from sporulating infections to nearby healthy branches suggests that direct infections without wounds are not common. The fungus rarely grows from one branch fork to another or down a branch to the main stem. While black staining in the wood may extend for 60 cm from the point of infection, the fungus rarely can be isolated more than a few cm from the point of entry. A large number of inoculations were made on mature Q. agrifolia with different isolates of Diplodia

Figure 3--Q. agrifolia in Palo Alto, Calif. showing severe symptoms of Diplodia dieback.

quercina. With each isolate, five branches were used on each of two trees. During the winter months no dieback developed, even though the fungus became established. Following early spring and late summer inoculations, most branches were girdled and killed within 2-4 weeks. Asexual fruiting bodies of the fungus formed above and below the point of inoculation within 1 month and once, in July 1983, within 2 weeks. These structures produced viable spores for about 2 years. Spores germinated within 24 hours in a moist environment. (Hecht-Poinar et al., unpublished).

Experiments with different concentrations of Benlate (Benomyl-Methyl 1-(butyl carbamoyl)-2-benzimidazolecarbamate) 50% (DuPont) on 64 large oaks in three different locations, showed: 1) the recommended dosage of 1 lb/100 gal Benlate was not as effective against subsequent inoculations with Diplodia as were dosages of 4, 7, and 10 lbs/100 gal.; 2) Benlate could be recovered from the branches up to 15 months after spray application with all concentrations and 3) protection lasted for at least 12 months when the trees were sprayed in May; however 4) when trees which were already infected and showed active fungus were sprayed with the fungicide, no effect on germination of the spores was observed (Hecht-Poinar et al., unpublished).

TWIGBLIGHT

The twigblight (fig. 4) of Q. agrifolia Nee, Q. lobata Nee, and Q. wislizenii A. DC., which has become a serious problem since the early eighties, is caused by at least two organisms: Cryptocline cinerescens (Bul.) von Arx (Morgan-Jones, 1973) and Discula quercina (West) von Arx. (von Arx, 1957; Hecht-Poinar, 1986). Pathogenicity was established for both fungi on oak seedlings in the greenhouse (fig. 5).

Inoculations of mature trees and stump shoots were unsuccessful on 10 successive attempts between December 1982 and March of 1984. Results of greenhouse researches suggest that these 2 fungi infect in nature during periods when oaks are producing succulent new shoots in early spring during cool weather. In the greenhouse, mature spores are produced in about 2 months, whereas in the field, mature asexual fruiting structures apparently are not produced following current year infections until late fall or winter, a lapse of at least 8 months. Mature fruiting structures produced large numbers of viable spores after only 6 hours of moisture.

In infected trees, twigblight may vary from just a few twigs to nearly complete involvement of the crown. Sometimes twigblight is more pronounced on one side of the crown or on lower branches, and observations suggest that repeated heavy infection may lead to death of some trees. Buds may harbor the fungus but acorns have not been found to do so.

Figure 4--Q. agrifolia with severe symptoms of Cryptocline cinerescens.

Figure 5--Q. agrifolia inoculated with Cryptocline in greenhouse. Symptoms visible after 2-6 weeks.

An explanation for the sudden epidemic of twig blight is wanting. Anthracnose diseases are often unpredictable and similar outbreaks of leaf and twig diseases have been observed at different times on bay trees, madrones, Chinese elms and other tree species in this area. Some anthracnoses, notably those on Modesto ash and California sycamore, commonly occur at high levels, others such as those on bay rarely produce epidemics. However, observations carried out in cooperation with C. S. Koehler (Hecht-Poinar et al., unpublished) showed that the amount of twig dieback may be correlated with the amount of pit scale (fig. 6). The basis of this relationship has not been determined. It was found that fruiting structures are often produced in a ring around individual scale insects (fig. 7). Crawlers, therefore, might pick up spores as they emerge and disperse, but emergence generally occurs in May, when sporulation is unlikely. A similar interaction between pit scales and Dothiorella (Boyce and Speers, 1959) and Botryodiplodia (Schmidt and Fergus, 1965) on Q. prinus was observed. Attempted isolations from 50 surface-sterilized scale insects failed to yield either twig infecting fungus. Isolations from brown

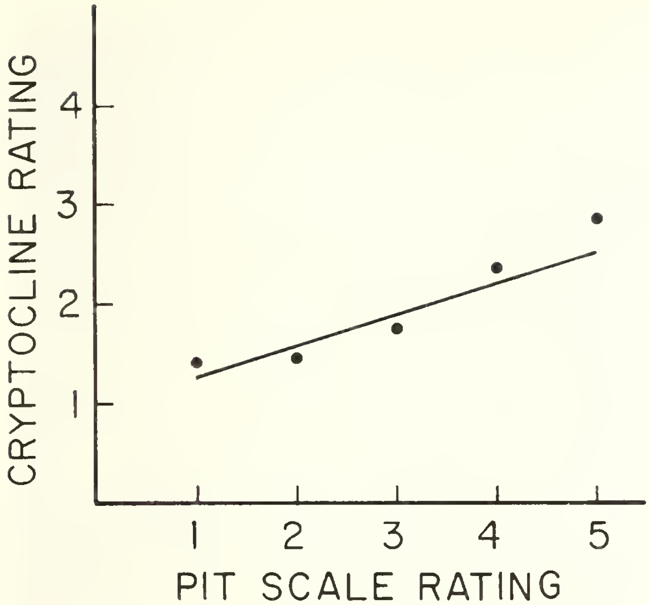

Figure 6--Correlation between pit scale infestation and Cryptocline severity on Q. agrifolia. The point representing a scale rating of 5 is farther from the regression line than others. This is because that point is represented by only 7 trees. All other points had many more trees representing them. A total of 112 trees was rated in Napa and San Mateo counties.

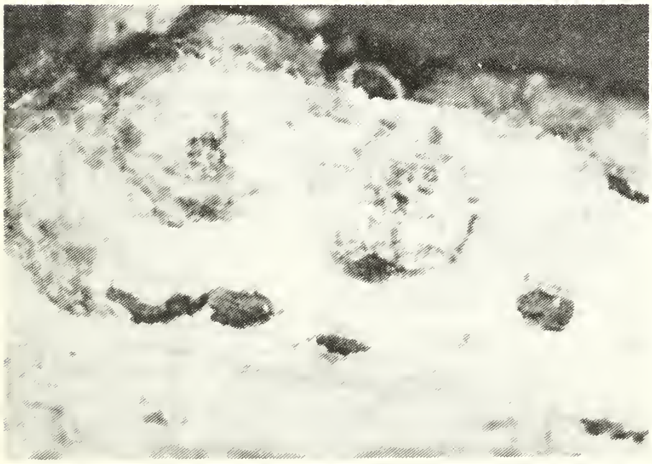

Figure 7--Oak pit scale surrounded by acervuli of C. cinerescens on twig of Q. agrifolia.

spots under a similar number of scales on undiseased twigs also failed to yield either fungus.

Control experiments against twig blight have been carried out in the greenhouse and in the field with a number of fungicides which had shown promise against the fungi in culture media in the laboratory. Of the 6 fungicides tested Banner (Ectaconazole), Rubigan (EL-222) and Benlate (Benomyl) so far show the most promise in the control of twigblight although data are incomplete at this time.

ACKNOWLEDGMENTS: This study was funded by a grant from the Elvenia J. Slosson Endowment Fund for Ornamental Horticulture from 1982-1985 and the International Society of Arboriculture in 1984. We thank Dr. A. H. McCain, Extension Plant Pathologist, UC Berkeley, for his valuable suggestions. We would also like to thank John Britton Tree Service, St. Helena, Calif.; Black Oak Tree Service, Napa, Calif., Silverado, Girard and Stag Leap Wineries and the Stanford University Grounds Department for their cooperation.

REFERENCES

von Arx, I. A. Revision der zu Gloesporium gestellten Pilze. Verh. K. Ned. Akad. Wet. Afd. Natuurk. 51:1-153. 1957.

Boyce, J. S., Jr. and Speers, C. F. Oak dieback in Virginia in 1959. Pl. Dis. Reptr. 44:(5)351; 1960.

Brown, L. R., Butterfield, H. M., Davis, C. S., Koehler, C. S., McCain, A. H. and Raabe, R. D. Oaks on home grounds. Div. Agr. Sci. Univ. Cal. Pub. AXT-89; 1963.

Hecht-Poinar, E., Britton, J. C. and Parmeter, J. R., Jr. Dieback of oaks in California. Plant Disease 65:281; 1981.

Hecht-Poinar, E. and J. R. Parmeter, Jr. Cryptocline cinerescens and Discula quercina causing twig blight of oaks in California. Plant Disease 70:(8) 800. 1986.

Koehler, C. S., Campbell, R. L. and Davis, C. S. Control of pit scales on oak. Weeds, Trees and Turf; March, 1968.

Morgan-Jones, G. Genera Coelomycetarum. VII. Cryptocline Petrak. Can J. Botany 51:309-325; 1973.

Roland, G. Etude faite sur une tracheomycose du Chene occasionee par un Diplodia. Parasitica 1:11-36; 1945.

Schmidt, R. A. and Fergus, C. L. Branch canker and dieback of Quercus prinus L. caused by a species of Botryodiplodia. Can. J. Bot. 43:731-737; 1965.

Tidwell, T. E. Index of diseases and microorganisms associated with California Oak trees. Cal. Dept. Food and Agr. Div. Plant Industry, Sacramento, Calif. 95814; 1986.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Nonchemical Control of Evergreen Hardwood Competition in New Conifer Plantations[1]

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Abstract: Evergreen hardwoods represent a significant source of competition for conifers. This effect can be particularly severe in new plantations where these species cause substantial growth losses and frequently increase seedling mortality. Although herbicides provide a proven, cost-effective method for control of evergreen hardwood competition, increased restrictions on their use have shown that existing alternative vegetation management treatments and strategies need refinement and that new approaches should be developed. Existing nonchemical treatments for controlling evergreen hardwoods are reviewed and a framework for using existing technology presented.

The need to control evergreen hardwood[3] competition in coniferous plantations on Pacific Coast sites (California, Oregon, and Washington) has been clearly established (Cleary 1978, Newton 1981 and 1984, Strothmann and Roy 1984, Tappeiner et al. 1986a, Walstad et al. 1986). In young plantations competition results in reduced conifer growth and in many cases, increased seedling mortality. This effect has been well-documented (Zavitkovski et al. 1969, Gratkowski and Lauterback 1974, Radosevich et al. 1976, and others) and has been shown to cause regeneration delays which can produce substantial losses in both timber value and volume yield (Brodie and Tedder 1982).

For the last several decades perhaps the single most versatile and cost-effective vegetation management tool available to foresters has been herbicides. Yet the controversy surrounding the use of these chemicals in the forest environment has significantly increased in recent years which has resulted in additional restrictions. Despite the fact that many foresters view these restrictions as transitory, it is very likely that opposition to the use of herbicides in forestry will persist and that increasing regulatory limitations will preclude realization of their full potential as a vegetation management tool (Hobbs 1986).

The purpose of this paper is to present a strategy and framework for dealing with evergreen hardwood competition in new conifer plantations without the benefit of herbicides using nonchemical treatments based on existing knowledge. Geographically, the paper is limited to those areas with a Mediterranean-like climate, principally southwest Oregon, northern California, and those portions of the Sierra Nevada which support the development of mixed conifer and evergreen hardwood forests. Our discussion is predicated on the assumption that policies conducive to intensive forest management (e.g., artificial regeneration) will be continued through the 1990s. Because the control of competing vegetation is vital to successful reforestation in water limited environments, the focus of this paper will be restricted to vegetation management treatments associated with stand establishment. Although a discussion of nonchemical treatment costs are beyond the scope of this paper, their importance in management decisions should not be overlooked.

HARDWOOD ADAPTATIONS

Evergreen hardwoods have evolved adaptations which make them particularly well-suited to forest environments characterized by a Mediterranean-like climate (i.e., hot, dry summers and wet, cool winters). Such adaptations afford these species a competitive advantage over conifers until the latter are large enough to limit hardwood growth or cause other concomitant changes in the understory environment which may limit evergreen hardwood regeneration (Tappeiner et al. 1986b). Despite the fact that in many cases conifers eventually become dominant, prolonged competition from well adapted evergreen hardwoods results in lost conifer growth, extended rotations and in some instances, understocked or nonstocked stands.

Morphological characteristics such as sclerophyllous leaves with thick cuticles and sunken stomata help to minimize transpirational water loss during summer drought. For some species such as canyon live oak (*Quercus chrysolepis* Liebm.), deep root systems are able to tap sources of soil water unavailable to conifer seedlings (Hobbs and Wearstler 1985). Other evergreen hardwood species which lack this ability have extensive lateral root systems capable of quickly extracting water from a large

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, Cal Poly, San Luis Obispo, California.

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[3]The term "hardwood" refers to all woody angiosperms exhibiting either the shrub or tree growth form.

soil volume. Physiologically these plants are also capable of reduced respiration and transpiration during periods of high moisture stress and even though photosynthesis may be reduced, net photosynthesis may still occur up to approximately 15 bars of moisture stress (Hanes 1977). Based on work done by Harrison et al. (1971, cited in McDonald 1982), it is reasonable to suggest that some evergreen hardwood species in southwest Oregon and northern California may be capable of net photosynthesis throughout the year. This has also been suggested as possible for conifers in southwest Oregon (Emmingham and Waring 1973).

Reproductive adaptations enable evergreen hardwoods to rapidly reoccupy forest sites following disturbance. For example, many species such as mountain whitethorn (*Ceanothus cordulatus* Kell.) can produce thousands of viable seed per hectare. These may remain dormant in the soil duff layer until disturbed by fire after which rapid germination may result when conditions are favorable (Gratkowski 1974). Many evergreen hardwood species are also capable of producing numerous sprouts following either fire or mechanical damage to the above ground portions of the plant. For example, Hobbs and Wearstler (1985) reported 861,513 sprouts per hectare of canyon live oak and greenleaf manzanita (*Arctostaphylos patula* Green) during the first year following slashing with chain saws. This adaptation is particularly difficult to control because plants may sprout repeatedly unless meristematic tissues in burls and roots are killed. The ability of evergreen hardwoods to quickly occupy sites following disturbance, whether by seed or sprout, enables them to remain the dominant form of vegetation for many years thus limiting conifer establishment and prolonging the transition to a conifer dominated forest.

We have not attempted to describe in detail the numerous adaptations this group of plants have evolved, but have mentioned the more obvious characteristics. For a more thorough account of evergreen hardwood adaptations the reader is referred to McDonald (1982).

THE EFFECT OF COMPETITION

Among the reasons seedlings fail to survive or grow following planting is their proximity to associated vegetation. Competition is not the only reason that trees fail to respond as expected following planting, however, but they rarely perform well if subjected to significant levels of it. Competition from associated vegetation can account for very large declines in coniferous tree productivity. Data from various locations in North America suggest that from 2- to 10-fold decreases in forest productivity can be caused from competing vegetation (Stewart et al. 1984). In addition, the presence of hardwood tree species in new plantations can markedly affect the species composition of the stand, and thus, its overall value.

An important fact about forest vegetation management is that thresholds of competition exist. In other words, there is a level of vegetation control which must be obtained for effective, economical tree responses to occur. These threshold values vary according to the density of trees, proportion of the species involved, and distance to competitors.

McDonald (1980) reported an experiment in which a constant density of seedling ponderosa pine (0.1 tree/m^2 = 1,000 trees/ha) was subjected to various hardwood shrub densities (0 to 3.5 shrubs/m^2). Canopy cover of the shrubs at the sixteenth year ranged from 0 to 4,100 m^2/ha. A strong relationship was found between ponderosa pine growth (tree diameter and height) and the degree of shrub density and cover. During the sixteen years of this study, the increase in tree productivity in the shrub-free vs. the heavy shrub stand was 9.5 cm in diameter and 3.2 m in height.

A similar study was conducted by Oliver (1979) on a more productive site. In this study, various spacings of ponderosa pine were subjected to either a constant level of hardwood shrubs (14,000 m^3/ha canopy) or to no shrubs. After twelve years, the absence of shrubs significantly increased stem diameter, height, and live crown ratio of the ponderosa pine relative to trees growing in shrubs. The effects of shrub association were most pronounced at wide tree spacings. Similar observations have been made in other experiments with other species (e.g., Gratkowski and Lauterback 1974, Radosevich et al. 1976, Allan et al. 1978, Balmer et al. 1978, Nelson et al. 1981, Conard and Radosevich 1982). Generally, trees will not respond to vegetation manipulation in the geographical area addressed by this paper until at least 70 to 80 percent of the competitors have been suppressed. Success of a species will depend on the resource requirements of that species, the availability of resources during periods of demand, and adaptations to partitioning of resources in time and space relative to other species in the community. A generalized relationship between the survival and growth and competition intensity is depicted in figure 1.

Lanini and Radosevich (1986) measured the microenvironmental changes and hardwood shrub responses that resulted from three methods of site preparation (rotary chopper, brushrake, or controlled burn) and subsequent shrub suppression by herbicide application. The relative value of vegetative manipulation also was examined by evaluating conifer growth in relation to site resource status. After four years 2,000 m^3/ha and 7200 m^3/ha of shrub canopy volume were observed on the brushraked and rotary chopped plots, respectively. The controlled burn was intermediate in response (5000 m^3/ha). However, herbicide application after any method of site preparation maintained shrub canopy volumes below 1000 m^3/ha for the four-year study period.

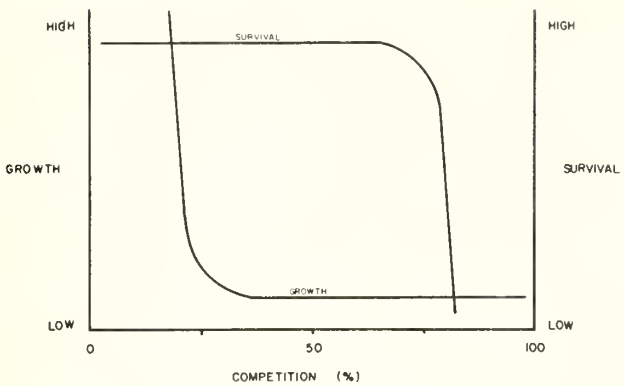

Figure 1--A generalized relationship between competition levels and seedling survival and growth.

Resource availability varied with the level of shrub suppression. Both soil moisture and light were most plentiful when shrub canopy volumes were lowest. However, water abundance was the resource most improved by the absence of shrubs.

Ponderosa pine growth responded favorably to increases in both light and soil moisture. These factors interacted significantly to increase growth of ponderosa pine when shrub canopy volumes were low. Increases in soil moisture were more beneficial for sugar pine and white fir height and canopy volume growth than was increased light. However, an increase in white fir stem growth resulting from an increase in soil moisture at low shrub canopy volumes was offset by increased light abundance which had a negative influence. Studies similar to that of Lanini and Radosevich (1986) have been conducted by others (e.g., Zedaker 1981), Preest (1975) and Ross et al. (1986)). In essence, these studies have found a quantitative linkage between the availability of resources, physiological processes, and subsequent morphological development of trees. Gains in growth rate of conifers have generally been greatest when the competing vegetation has been well controlled and when the operations were performed very early in the life of the conifers.

THE NONCHEMICAL APPROACH

A Potential Strategy

We suggest that without herbicides, the most critical period for the application of nonchemical treatments is during the plantation establishment phase and that all treatments should focus on promoting rapid, early growth. After site preparation plants will begin to reinhabit the site. The time to manipulate vegetation for greatest success is during this period because the vegetation is usually less prevalent and is often more susceptible to control. Most successful vegetation management occurs within the first five years of a plantation's life. Occasionally competing vegetation becomes so tenacious after planting that some form of suppression must occur to maintain the plantation. It is rare that such treatments ever kill all the competing vegetation. Rather, the goal is to suppress it sufficiently to allow conifers to gain dominance. These treatments must usually occur within a few years of planting in order to be successful.

Unfortunately there is no single nonchemical treatment as effective as an appropriately prescribed herbicide for the control of competing evergreen hardwoods. There are, however, a number of alternatives which may offer potentially useful treatments. Although under certain conditions such treatments may be effective when applied on an individual basis (i.e., a single treatment used during site preparation), a more realistic scenario for many sites is likely to be the utilization of at least two of these treatments during plantation establishment. Regardless of which nonchemical treatments are used, the suggested strategy for the nonchemical management of evergreen hardwood competition should be based on a system of three performance criteria: carefully analyze site conditions; reduce competition quickly and use supplemental treatments if necessary; and strive for operational perfection.

Prior to the controversy about chemical use in the forest, reforestation prescription errors which resulted in rapid site occupancy by evergreen hardwoods, could frequently be remedied with a herbicide application. Currently, such operational flexibility has been severely limited. Although reforestation prescriptions should be based on a thorough evaluation of site conditions likely to exist during the stand establishment phase, such attention to detail is not often the case. Only through a careful on-the-ground inspection of the site prior to harvest can potential vegetation management problems be evaluated. For example, dormant seed buried in the duff layer could not be detected by an arm chair survey, the result of which might be the emergence of thousands of evergreen hardwood germinants following the use of prescribed fire. In the absence of herbicides such an oversight is likely to result in additional treatment expense or the failure to meet minimum stocking standards. Similarly, the sprouting potential of evergreen hardwoods in the understory of mature conifer stands could not be assessed without an on-site inspection. This would indeed be unfortunate because for some species such as tanoak (*Lithocarpus densiflorus* (Hook. and Arn.) Rehd.) and Pacific madrone (*Arbutus menziesii* Pursh) prediction equations have been developed which are capable of estimating the sprouting response to cutting and fire (Tappeiner et al. 1984). The most crucial aspect of the preharvest site evaluation is to be able to anticipate what environmental conditions are likely to exist at planting as the result of prescribed treatments and how they will affect seedling performance. It is also important to consider how quickly and to what extent these conditions may change due to the encroachment of competing vegetation.

Previously we suggested that for conifer seedlings the most critical period during which competition from evergreen hardwoods or other types of vegetation should be minimized is during the establishment phase. The exact length of this period will vary among sites depending upon individual circumstances. The concept of a critical period during which weed competition will have a profound effect on crop yield is not new, however. Although this hypothesis is drawn from agricultural studies of annual crops (Zamdahl 1980, cited in Radosevich and Holt 1984) we believe it has applicability to forestry as well. It has been our experience that seedlings grown in environments maintained in a relatively weed-free condition for several years following planting will rapidly increase growth thus dramatically improving the probability of successful establishment. During this period it is the rate of site occupancy by evergreen hardwoods relative to that of planted seedlings that is of primary concern. Treatments which enhance this relationship in favor of conifers should be used judiciously to achieve the desired effect. The long-term objective is to attain rapid crown closure of conifers. We hypothesize that in the absence of herbicides actions taken during the establishment phase will probably affect achieving this objective more than at any other time during the rotation.

Historically, herbicides have provided the forester with numerous options that add stability and reliability to timber management plans because of their proven effectiveness in temporarily controlling unwanted evergreen hardwoods. However, without this tool or with increased limitations on its use, the forester will lose some of the flexibility to respond effectively to unanticipated vegetation management problems. Under such circumstances the margin for error in reforestation operations will decrease. Mistakes made throughout the reforestation process, from preparing the prescription and growing seedlings in the nursery to post-planting vegetation or animal damage control treatments, are likely to be compounded in terms of seedling performance. Because many nonchemical treatments as currently practices are not as effective as herbicides, increased attention to detail is essential. For example, inadequate planning, sloppy contract administration, and infrequent visits to newly planted areas to assess changes will probably result in decreased stocking. The appropriate utilization of existing technology in a timely manner with an extra helping of common sense and some ingenuity are prominent ingredients for implementing the nonchemical strategy.

Treatments

We have identified 12 nonchemical treatments for which some information is available (table 1). The extent of this information varies widely among treatments, however. For example, information on the use of prescribed burning for site preparation is voluminous and yet that related to the effect of preharvest burning on potential post-harvest competitors is confined to relatively few publications. Most of these nonchemical treatments effect seedling performance by reducing the transpirational leaf surface area of evergreen hardwoods thus improving soil water conditions. Other treatments, although not designed to reduce the size or extent of the competitor, are intended to increase seedling survival or growth thus improving the ability to compete. These we refer to as supplemental treatments (i.e., animal damage control, artificial shade, slow release fertilizers, genetically improved planting stock).

Prescribed burning has been used for years to prepare sites for planting and considerable information is available (Loucks et al. 1986). One of the beneficial aspects of this treatment is that it temporarily delays the recovery of sprouting evergreen hardwoods by approximately a year. This has been shown to result in increased soil water (Gaweda 1983). However, such treatments may stimulate the germination of dormant evergreen hardwood seed (Gratkowski 1974) or create conditions favorable for rapid site domination by herbaceous species; particularly grasses. For many sites, post-planting follow-up treatments are likely to be necessary because of sprout emergence or occupancy by herbaceous vegetation. This is particularly true for areas burned after conditions associated with the winter/spring planting season have become unfavorable thus allowing vegetation a complete growing season to recover before the next favorable planting period. This situation should be avoided, particularly on south exposures where moisture demand will be highest.

Foresters have much less experience with preharvest underburning but some early results are encouraging (Martin 1982, Kauffman and Martin 1985a and b). Kauffman and Martin (1985b) found that burning while sprouting shrubs were actively growing increased mortality regardless of how much duff was consumed. They also found seed supplies may be dramatically reduced by several preharvest burns and increased duff consumption (Kauffman and Martin 1985a). On soils where duff conservation is a major concern, a single light to moderate burn followed by another type of treatment (e.g., slashing, grubbing, hand-pulling) may be effective although as far as we know this combination has not been tested. Despite the fact that the long-term effects of preharvest burning on competing vegetation are unknown for northern California and southwest Oregon, the treatment may have potential and is in keeping with the suggestion that preharvest

Table 1--Nonchemical treatments for which information is available.

- Prescribed burning, as used traditionally for site preparation. (May require another type of follow-up treatment such as paper mulching, slashing, etc.)	- Brush slashing. (Can be done either before and/or after prescribed burning or machine site preparation treatments. May require several applications. Herbaceous vegetation may replace brush on some sites.)	- Animal damage control. (Depending upon the animal pest, control treatments vary in effectiveness and may require annual maintenance or retreatment. Used as a supplemental treatment.)
- Preharvest underburning in mature conifer stands. (This may require two or more burns conducted over a period of several years.)	- Scalping. (Useful primarily for the temporary control of herbaceous vegetation, but is not particularly effective unless scalps are large and repeated several times.)	- Artificial shade. (Improves seedling survival on south aspects. Used as a supplemental treatment.)
- Machine site preparation. (Largely confined to sites with slopes of less than 35 percent. May require another type of follow-up treatment depending upon site conditions.)	- Grazing. (May have some benefit, but the number of sites where this may be useful is probably limited.)	- Slow release fertilizers. (Initial results show significantly greater seedling growth on one study site. Used as a supplemental treatment.)
- Grubbing and hand-pulling brush germinants and seedlings. (May be used alone or in combination with prescribed burning or machine site preparation treatments. Several applications may be necessary.)	- Paper mulching. (May be effective in controlling herbaceous vegetation, but difficult to maintain in steep terrain. May require replacement.)	- Genetically-improved planting stock. (This option is a number of years off, but will undoubtedly come into widespread use as suitable seed becomes available. Used as a supplemental treatment.)

treatment of evergreen hardwoods may be an effective method of controlling their recovery following disturbance (Martin 1982, Tappeiner et al. 1986b).

Machine site preparation treatments have been used for many years to control various types of competing vegetation, including evergreen hardwoods. These treatments are, however, usually restricted to slopes of 35 percent or less because of machine limitations. Generally with increasing treatment severity (e.g., soil displacement), the more effective the control of competing vegetation. Concern over the maintenance of long-term site productivity by the retention of surface soil is an important consideration, however, and may preclude the use of some machine treatments on many sites. With less severe treatments such as root-raking without soil displacement or discing, the need for a follow-up post-planting treatment may exist. For more detailed discussions of machine site preparation the reader is referred to Roby and Green (1976), Gutzwiler (1976), Stewart (1978), and Ross and Walstad (1986).

Removal of young plants that have developed from seed is possible by grubbing with hand tools or may even be pulled by hand. Little information is available on these techniques probably because they have never been seen as realistic options. They are labor intensive and impractical for the control of sprouts developed from previously well-established plants. This type of treatment may have some utility, however, after prescribed fire or machine site preparation treatments which stimulate evergreen hardwood seed germination.

Brush slashing has received sporadic attention during the last 30 years but has never been viewed as a serious option for the control of evergreen hardwoods. In addition to being labor intensive, brush slashing stimulates vigorous sprouting in many evergreen hardwood species. Little is known, however, about the effect of different intensities, frequency or timing of slashing treatments relative to the species ecophysiology. What little information is available has been recently summarized by Hobbs (1986). This treatment option may have potential when used in conjunction with either pre- or post-harvest prescribed burning or machine site preparation. It is important to recognize the fact that on some sites, slashing may result in rapid site occupancy by herbaceous vegetation. We have observed this to occur in southwest Oregon, particularly on those sites without appreciable amounts of scree or ravel (a mantle of unstable rock fragments or gravel over the mineral soil; usually in steep terrain). On those sites where scree is prominent, the establishment of herbaceous vegetation is often slow and in such cases slashing may offer temporary control of competition. We caution, however, that the haphazard use of slashing may result in a significant first-year sprout response and that more than a single slashing treatment may be necessary on some sites.

Scalping has traditionally been done with hand tools (e.g., the planting hoe) at the time of planting to remove vegetation, duff, and scree from the planting spot and to expose the mineral soil. As currently practiced this treatment is not an effective means of controlling either herbaceous or evergreen hardwood competition. This is largely because of the cost associated with creating scalps larger than a square meter around each seedling, and the probable necessity for a follow-up treatment. In addition, evergreen hardwoods larger than a centimeter in diameter are difficult to remove by scalping.

Grazing domestic livestock in new conifer plantations to control evergreen hardwoods has received relatively little research attention although a number of publications are available (Green and Newell 1982, Knipe 1983, Kosco and Bartolome 1983, Leininger 1983, Monfore 1983). Many foresters generally consider this as an unworkable vegetation management treatment because it results in livestock either browsing or trampling conifer seedlings. We feel that although grazing and reforestation have historically been considered incompatible, there may be some potential for this treatment alternative with additional research. Its applicability is likely to be limited to very specific types of site conditions, however.

Paper mulches are used successfully to control grasses and other types of herbaceous vegetation in the immediate vicinity of conifer seedlings. Mulches may require annual maintenance or replacement, however, depending upon individual site conditions. They may be of use in suppressing seed germination, or in killing germinants or very young evergreen hardwoods but are impractical for use with sprouts. Discussions of this treatment can be found in Schubert (1976) and Greaves and Hermann (1978).

In addition to the preceding treatments we have identified, there are four other treatments we have previously referred to as supplemental which deserve brief mention. These treatments, although not designed to have a direct and immediate impact on evergreen hardwood competition, may influence the rate at which conifer seedlings become established and hence eventually dominate the site. In this respect they may play an important, although largely unquantified, role in vegetation dynamics. We refer to animal damage control treatments, the use of artificial shade and slow-release fertilizers, and the planting of genetically improved stock.

Discussions of animal damage control can be found in Greaves et al. (1978), Strothmann and Roy (1984), Campbell and Evans (1984), and Schaap and DeYoe (1986). Artificial shade has been shown to increase conifer seedling survival on south aspects. Strothmann and Roy (1984) correctly point out, however, that shade may not be necessary to successfully regenerate Douglas-fir, for example, on south slopes if all other facets of the reforestation process are favorable. Other summaries of artificial shade can be found in Greaves and Hermann (1978) and Helgerson and Bunker (1985). Recent reports have indicated that fertilizers applied to seedlings at the time of planting have a positive effect on growth (Strothmann 1980, Carlson and Preisig 1981). Preliminary results of a trial in southwest Oregon have shown that fertilized seedlings had almost double the first-year height growth of that measured for the untreated controls (O.T. Helgerson, pers. comm. 1986). Gains to be made in seedling growth from existing tree improvement programs are as yet unclear, but all indications are that they will be substantial. This impact will not influence timber management programs until large quantities of improved seed become available for large scale operational use.

FUTURE RESEARCH NEEDS

The level of research devoted to the development of nonchemical treatments and strategies for the control of evergreen hardwoods is inadequate to meet future needs. This lack of information extends beyond evergreen hardwoods to most types of vegetation which compete with potential crop trees for limited resources. For many of the evergreen hardwood species we seek to manipulate, there is a significant void in our understanding of their ecophysiology and how they respond to various types of treatments. Only by developing a better understanding of these species can we hope to advance the science of vegetation management into such high-tech realms as biological control and genetic engineering. For the time being, however, a more realistic approach to the problem is to seek ways of using existing information to develop workable strategies and treatments tailored to specific site conditions. A good example of this is the perspective McDonald (1986) provides on the pros and cons of grass competition in young conifer plantations.

CONCLUSIONS

It has been shown that the control of evergreen hardwoods in young conifer plantations improves seedling growth and in some cases survival. Increasing restrictions on the use of herbicides have, however, made the management of these species more difficult and narrowed the margin for error in the reforestation process. Given our current level of knowledge, most nonchemical treatments are not as effective as herbicides.

They do, however, offer foresters with alternatives that show some potential. These treatments should be refined and integrated into a vegetation management strategy which enhances seedling performance and improves the probability of establishment. Only by expanding our understanding of the evergreen hardwood species we seek to manipulate can we hope to develop acceptable and cost-effective nonchemical treatments.

REFERENCES

Allan, G.G., J.W. Beer, and M.J. Cousin. Growth enhancement of a juvenile conifer forest six years after application of a controlled release herbicide. Int. Pest Control 20(2):6-13; 1978.

Balmer, W.E., K.E. Utz, and O.G. Langdon. Financial returns from cultural work in natural loblolly pine stands. South. J. Appl. Forestry 2:111-117, 1978.

Brodie, J.E., and P.L. Tedder. Regeneration delay: Economic cost and harvest loss. J. For. 80(1):26-28, 1982.

Campbell, D.L., and J. Evans. Wildlife-reforestation problems and seedling protection in western Oregon: Review and current knowledge. USDI Bureau of Land Management Tech. Note OR-4, Oregon State Office, Portland. 46 p. 1984.

Carlson, W.C., and C.L. Preisig. Effects of controlled-release fertilizers on the shoot and root development of Douglas-fir seedlings. Can. J. For. Res. 2(2):230-242, 1981.

Cleary, B.D. Vegetation management and its importance in reforestation. Res. Note 60. Forest Res. Laboratory, Oregon State Univ., Corvallis. 4 p, 1978.

Conard, S.G., and S.R. Radosevich. Growth responses of white fir to decreased shading and root competition by montane chaparral shrubs. For. Sci. 28(2):309-320, 1982.

Emmingham, W.H., and R.H. Waring. Conifer growth under different light environments in the Siskiyou Mountains of southwestern Oregon. Northwest Sci. 47:88-99, 1973.

Gaweda, F. First-year effects of broadcast burning on soil infiltration and wettability in southwest Oregon. M.S. Thesis. College of Forestry, Oregon State Univ., Corvallis. 110 p, 1983.

Gratkowski, H. Origin of mountain whitethorn brushfields on burns and cuttings in Pacific Northwest Forests. Pages 5-8 In Proc., Western Society of Weed Science, Vol. 27. Hawaii, 1974.

Gratkowski, H., and P. Lauterback. Releasing Douglas-fir from varnish-leaf ceanothus. J. For. 72(3):150-152, 1974.

Greaves, R.D., H.C. Black, E.G. Hooven, and E.M. Hansen. Plantation maintenance. Pages 187-208 In B.D. Cleary, R.D. Greaves, and R.K. Hermann, (Eds.). Regenerating Oregon's Forests. Oregon State Univ., Ext. Serv., Corvallis, 1978.

Greaves, R.D., and R.H. Hermann. Planting and seeding. Pages 131-161 In B.D. Cleary, R.D. Greaves, and R.K. Hermann, (Eds.). Regenerating Oregon's Forests. Oregon State Univ. Ext. Serv., Corvallis, 1978.

Green, L.R., and L.A. Newell. Using goats to control brush regrowth on fuelbreaks. USDA Forest Service Gen. Tech. Rep.PSW-59, Pac. Southwest For. and Range Exp. Sta. Berkeley, CA. 13 p, 1982.

Gutzwiler, J.R. Mechanical site preparation for tree planting in the Inland Northwest. Pages 117-133 In D.M. Baumgartner and R.J. Boyd, (Eds.). Proc., Tree planting in the Inland Northwest. Washington State Univ. Coop. Ext. Serv., Pullman, 1976.

Hanes, T.L. California chaparral. Pages 417-469 In M.G. Barbour and J. Majors, (Eds.). Terrestrial vegetation of California. John Wiley and Sons, New York, 1977.

Harrison, A.T., E. Small, and H.A. Mooney. Drought relationships and distribution of two Mediterranean-climate California plant communities. Ecology 52:869-875, 1971.

Helgerson, O.T. Unpublished data on file at the Oregon State Univ. Forestry Intensified Research Program Office. Medford, OR. 1986.

Helgerson, O.T., and J.D. Bunker. Alternative types of artificial shade increase survival of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seedlings in clearcuts. Tree Planters' Notes 36(4):7-12, 1985.

Hobbs, S.D., and K.A. Wearstler, Jr. Effects of cutting sclerophyll brush on sprout development and Douglas-fir growth. For. Ecol. and Manage. 13:69-81, 1985.

Hobbs, S.D. A reexamination of slashing as a manual method of sclerophyll brush control. Pages 71-80 In Proc., Seventh Annual Forest Vegetation Management Conf. Eureka, CA. For. Veg. Mgt. Conf., Redding, CA. 1986.

Kauffman, J.B., and R.E. Martin. A preliminary investigation on the feasibility of preharvest prescribed burning for shrub control. Pages 89-114 In Proc., Sixth Annual Forest Vegetation Management Conf. Redding, CA. 1985a.

Kauffman, J.B., and R.E. Martin. Shrub and hardwood response to prescribed burning with varying season, weather, and fuel moisture. Pages 279-286 In L.R. Donoghue and R.E. Martin, (Eds.). Proc., Eighth conference on fire and forest meteorology. Soc. Amer. For., Bethesda, MD. 1985b.

Knipe, O.D. Effects of Angora goat browsing on burned-over Arizona chaparral. Rangelands 5(6): 252-255, 1983.

Kosco, B.H., and J.W. Bartolome. Effects of cattle and deer on regenerating mixed conifer clearcuts. J. Range Manage. 36:265-268, 1983.

Lanini, W.T., and S.R. Radosevich. Response of three conifer species to site preparation and shrub control. Forest Sci. 32:61-77, 1986.

Leininger, W.C. Silvicultural impacts of sheep grazing in Oregon's coast range. Ph.D. Dissertation. Oregon State Univ., Corvallis. 203 p. 1983.

Loucks, D.M., S.R. Radosevich, T.B. Harrington, and R.G. Wagner. Prescribed burning in Pacific Northwest Forests: An annotated bibliography. For. Res. Lab., Oregon State Univ., Corvallis. 185 p. 1986.

Martin, R.E. Shrub control by burning before timber harvest. Pages 35-40 In D.M. Baumgartner, (Ed.). Proc., Site preparation and fuels management on steep terrain Symp. Coop. Ext. Serv., Washington State Univ., Pullman. 1982.

McDonald, P. Brushfield ecology and growth of planted pines. USDA Forest Service, Pac. Southwest For. and Range Exp. Sta., Redding, CA. Unpublished data on file. 1980.

McDonald, P.M. Adaptations of woody shrubs. Pages 21-29 In S.D. Hobbs and O.T. Helgerson, (Eds.). Proc., Reforestation skeletal soils workshop. For. Res. Lab., Oregon State Univ., Corvallis. 1982.

McDonald, P.M. Grasses in young conifer plantations - hindrance and help. Northwest Sci. 60(4):271-278, 1986.

Monfore, J.D Livestock - A useful tool for vegetation control on ponderosa pine and lodgepole pine plantations. Pages 105-107 In Proc., Forestland Grazing Symp. Washington State Univ., Pullman. 1983.

Nelson, L.R., R.C. Pedersen, L.L. Autry, S. Dudley, and J.D. Walstad. Impact of herbaceous weeds in young loblolly pine plantations. South. J. App. Forestry 5:153-158, 1981.

Newton, M. Chemical weed control in western forests. Pages 127-138 In Proc., John S. Wright Forestry Conf., Weed control in forest management. Purdue Univ., West Lafayette, IN. 1981.

Newton, M. Vegetation management in plantations of the Pacific Northwest. Pages 250-257 In Proc., Soc. Amer. Foresters National Conv., Quebec, Canada. Soc. Amer. For., Bethesda, MD. 1984.

Oliver, W.W. Early response of ponderosa pine to spacing and brush: Observations on a 12-year-old plantation. USDA Forest Service, Pac. Southwest For. and Range Exp. Sta., Berkeley, CA. Res. Note PSW-341. 7 p. 1979.

Preest, D.S. Effects of herbaceous weed control on Douglas-fir moisture stress and growth. Ph.D. Thesis, School of Forestry, Oregon State Univ., Corvallis, OR. 111 p. 1975.

Radosevich, S.R., and J.S. Holt. Weed ecology: Implications for vegetation management. John Wiley and Sons, New York. 265 p. 1984.

Radosevich, S.R., P.C. Passof, and O.A. Leonard. Douglas-fir release from tanoak and Pacific madrone competition. Weed Sci. 24(1):144-145. 1976.

Roby, G.A., and L.R. Green. Mechanical methods of chaparral modification. USDA Forest Service Agric. Handbook No. 487. 46 p. 1976.

Ross, D.W., and J.D. Walstad. Vegetative competition, site preparation, and pine performance: A literature review with reference to southcentral Oregon. For. Res. Lab., Oregon State Univ., Corvallis. Res. Bull. 58. 21 p. 1986.

Ross, D.W., W. Scott, R.L. Heninger, and J.D. Walstad. Effects of site preparation on ponderosa pine (Pinus ponderosa), associated vegetation, and soil properties in south central Oregon. Can. J. For. Res. 16(3): 612-618, 1986.

Schaap, W., and D. DeYoe. Seedling protectors for preventing deer browse. For. Res. Lab., Oregon State Univ., Corvallis. Res. Bull. 54. 12 p. 1986.

Schubert, G.H. Planting methods for the Inland Northwest. Pages 239-261 In D.M. Baumgartner and R.J. Boyd, (Eds.). Proc., Tree planting in the Inland Northwest. Washington State Univ. Coop. Ext. Serv., Pullman. 1976.

Stewart, R.E. Site Preparation. Pages 99-129 In B.D. Cleary, R.D. Greaves, and R.K. Hermann, (Eds.). Regenerating Oregon's Forests. Oregon State Univ. Ext. Serv., Corvallis. 1978.

Stewart, R.E., L.L. Gross, and B.H. Honkala, (Compilers). Effects of competing vegetation on forest trees: A bibliography with abstracts. USDA For. Serv., Washington, D.C., Gen. Tech. Rep. WO-43. lv. (loose-leaf). 1984.

Strothmann, R.O. Large stock and fertilizer improve growth of Douglas-fir planted on unstable granitic soil in northern California. USDA For. Serv. Res. Note PSW-345, Pac. Southwest For. and Range Exp. Sta., Berkeley, CA. 7 p. 1980.

Strothmann, R.O., and D.F. Roy. Regeneration of Douglas-fir in the Klamath Mountains region, California and Oregon. USDA For. Serv. Gen. Tech. Rep. PSW-81. Pac. Southwest For. and Range Exp. Sta., Berkeley, CA. 35 p. 1984.

Tappeiner, J.C. II, T.B. Harrington, and J.D. Walstad. Predicting recovery of tanoak (Lithocarpus densiflorus) and Pacific madrone (Arbutus menziesii) after cutting or burning. Weed Sci. 32:413-417, 1984.

Tappeiner, J.C. II, W. H. Knapp, C.A. Wierman, W.A. Atkinson, C.D. Oliver, J.E. King, and J.C. Zasada. Silviculture Part II. The Pacific coast. J. For. 84(5):37-46. 1986a.

Tappeiner, J.C. II, P.M. McDonald, and T.F. Hughes. Survival of tanoak (Lithocarpus densiflorus) and Pacific madrone (Arbutus menziesii) seedlings in forests of southwestern Oregon. New Forests 1(1):43-55. 1986b.

Walstad, J.D., J.D. Brodie, B.C. McGinley, and C.A. Roberts. Silvicultural value of chemical brush control in the management of Douglas-fir. W.J. Appl. For. 1(3):69-73. 1986.

Zavitkovski, J., M. Newton, and B. El-hassan. Effects of snowbrush on growth of some conifers. J. For. 67(4):242-246, 1969.

Zedaker, S.M. Growth and development of young Douglas-fir in relation to intra- and interspecific competition. Ph.D. Thesis, School of Forestry, Oregon State Univ., Corvallis. 112 p. 1981.

Zimdahl, R.L. Weed crop competition: A review. International Plant Protection Center, Corvallis, OR. 1980.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Effects of Fire and Fire Suppression on Mortality and Mode of Reproduction of California Black Oak (*Quercus kelloggii* Newb.)[1]

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Abstract: Numerous studies, historical accounts and archaeological evidence suggest that the historical density and abundance of black oak (Quercus kelloggii Newb.) in mixed conifer forests was much greater than today. Reasons for the decline of this species are unknown. However, it is well known that fire suppression since the late 1800's has drastically changed the composition and structure of Sierra Nevada mixed conifer forests. Among the major changes that have occurred is the unnatural accumulation of fuels in an ecosystem with a historical fire regime characterized as that of frequent light surface fires with a mean return interval of 1 to 25 years. Results of this study found that established black oaks were well adapted for survival and resprouting following frequent low intensity/low consumption fires of the past; but not for high intensity/high consumption fires that are possible today. Removal of this heavy organic horizon by prescribed fire resulted in a 2- to 15-fold increase in the number of black oak seedlings for the next 2 years.

Historically, fire played a major role in shaping the composition and structure of Sierra Nevada mixed conifer ecosystems. Kilgore (1981) characterized the fire regime of mixed conifer forests as that of a frequent, low-intensity surface fire with a mean fire return interval of 1 to 25 years. As such, it can be assumed that all native species present in this ecosystem developed adaptations to survive in this fire regime.

As a result of fire suppression, the mixed conifer forest of the present bears little resemblance to that of presettlement times (Biswell et al. 1973, Bonnicksen and Stone 1982, Parsons and DeBenedetti 1979). A century or more of fire suppression has resulted in unnatural accumulations of forest fuels, as well as the creation of a continuous vertical arrangement of fuels. This alteration in fuel dynamics has changed the fire regime from that of frequent, low-intensity surface fires to infrequent, high-intensity crown or stand replacement fires.

Other changes due to fire suppression include alterations in the mosaic of the forest ecosystem (age structure, size and composition). These include increases in shade-tolerant conifers with a greater capacity to germinate in organic horizons. In addition, declines in the abundance of California black oak (Quercus kelloggii Newb.) have occurred (Bonnicksen and Stone 1982, Parsons and DeBenedetti 1979).

The reasons for the decline in black oak are unknown. However, in many communities of the mixed conifer zone, fire may be necessary for the maintenance of black oak in the composition. We hypothesize that fire may affect black oak reproduction in two general ways. The primary effects are those on established individuals from evolution of heat during the combustion process. Depending on severity, environment, and plant factors, fire may result in crown mortality and resprouting, or death to both aboveground and below ground plant organs. The secondary effects are related to the post-fire habitat. Fire may influence the immediate habitat of germinating acorns by increasing the amount of solar insolation and nutrients available to the plant, or by destruction of allelopathic compounds, fungi or other pathogens. Conversely, the loss or decrease of organic horizons may decrease survival of acorns due to increased exposure or predation. The interaction of wildlife, fire and acorn germination, if any, is also unclear.

Objectives of this study were to: (1) document the relationship between fuel consumption (fire severity) and survival of resprouting black oaks, and (2) describe the relationship between the composition and biomass of the forest floor (duff layers or organic horizons) and black oak germination.

METHODS

Two study sites were established in mixed conifer stands of the northern Sierra Nevada of California. The study sites are located at the Blodgett Forest Research Station near Georgetown, California, and the Massak unit of the Quincy Ranger District, Plumas National Forest. Hereafter, these locations will be referred to as the Blodgett and Quincy sites, respectively.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Table 1—The date of burns, environmental conditions during the burns, and fuel consumption of experimental burn treatments.

Location/ Treatment	Date of Burn	Relative Humidity (pct)	Temperature (°C)	Wind Speed (km hr^{-1})	Lower Duff (Oa)[1] Moisture Content (%) (pct)	Fuel Consumption (pct)
Quincy						
Early fall	9/15/83	15-38	22-29	0-3	8.7 ± 1.3^{a}	92.0^{a}
Late fall	10/12/83	46-67	9-20	0-3	63.0 ± 10.2^{b}	77.8^{b}
Early spring	5/7-9/84	21-39	14-20	0-11	35.0 ± 9.2^{c}	57.7^{c}
Late spring	5/24/84	29-57	13-21	0-11	18.7 ± 3.1^{a}	82.8^{b}
Blodgett						
Early fall	9/20/84	25-48	19-23	0-8	23.2 ± 4.6^{a}	74.7^{a}
Late fall	10/8/83	49-63	16-18	0-3	90.1 ± 7.8^{b}	67.8^{b}
Early spring	5/17/84	31-57	16-17	0-3	135.0 ± 16.3^{c}	16.3^{c}
Late spring	6/26-29/84	21-72	17-27	0-3	51.6 ± 10.6^{a}	61.1^{b}

[1]Moisture content is expressed as a mean $\pm$ 1 standard error. Different superscripted letters above moisture contents and fuel consumption denote a significant difference among treatments within the same location ($P \leq .05$).

The Blodgett study location was characterized as a productive second growth stand, approximately 70 years of age. Mean basal area was 72.6 m^2 ha^{-1}. Ponderosa pine (Pinus ponderosa Dougl. ex Laws), white fir (Abies concolor [Gord and Glend.] Lindl. ex Hildebr.) and incense cedar (Calocedrus decurrens Torr.) dominated in the overstory. Very old black oaks and young individuals with a shrub-like physiognomy were present. The soils are classified as occurring in the Holland Family, Moderate Deep Basic (fine-loamy, mixed mesic Ultic Haplo eralfs). Prior to burning, fuel loads ranged from 131 to 177 t ha^{-1}. Organic horizons accounted for 60 to 80 percent of the total fuel load. Slopes were nearly level (<10%), elevation was 1300 m and mean annual precipitation was approximately 1700 mm.

The Quincy area was characterized as an open stand of jeffrey pine (Pinus jeffreyi Grev. & Balf.), Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) and incense cedar. Mean basal area of the overstory was 48.0 m^2 ha^{-1}. Soils were classified into the Holland Family, Basic (fine-loamy, mixed Ultic Haplo eralfs). Prior to burning fuel loads ranged from 75 to 102 t ha^{-1}. Slopes varied in steepness from 35 to 75 percent, elevation was 1350 m and mean annual precipitation is 900 mm.

At each location, six 0.25-ha blocks with four treatment units per block were established. The treatments include four different prescribed burns of varying season and consumption levels and a control (no burn). Burn treatments include an early spring - moderate consumption burn, a late spring - high consumption burn, an early fall - high consumption burn, and a late fall - moderate consumption burn. The date of burn, environmental conditions and fuel consumption can be found in table 1.

Survival of the existing shrub component was estimated by randomly tagging 15 to 50 individuals in each treatment unit in each block prior to burning (1983). Shrubs were examined for mortality and survival the next two years after burning (1984, 1985).

Density of oak seedlings was calculated by two measurements in 15 2m^2, permanent plots in each treatment subunit of each block. These plots were measured prior to burning (1983) and the second growing season after fire (1985).

Fuel loads and consumption were measured by planar intercept (Brown 1974). Four permanent transects were established in each treatment unit prior to burning. Duff depth and biomass were measured at 60 points in each of the subunits.

Significance among treatments was tested by an analysis of variance in an incomplete randomized block design. If a significant F value was found ($P \leq .05$) a Student-Newman-Kuel's test was utilized to determine where differences occurred.

RESULTS

As would be expected, the high fuel consumption burns (early fall and late spring treatments) resulted in the highest rates of mortality for the established black oak shrubs (table 2). However, all burn treatments resulted in significantly higher mortalities (significantly lower rates of survival in table 2) than the control. Though there were inherent differences between the two locations, the general patterns of decreasing survival with increasing fire severity were similar.

From comparisons of survival between the two locations, it is apparent that survival rates at the Blodgett site were lower than those at Quincy, with the exception of the early spring treatment. This is attributed to two site factors. At the Blodgett site, the understory black oak component

Table 2—The survival (percent) of black oak and the associated amounts of duff consumption during prescribed burn treatments.

	Early Fall	Late Fall	Early Spring	Late Spring	Control
BLODGETT					
Survival (pct)	9[a](13)	35[b](26)	69[a](21)	28[ab](20)	100[d](0)
Biomass consumption (t ha^{-1})	110.4	68.0	11.1	63.2	—
Consumption (pct)	93.5[a]	64.2[b]	11.3[c]	75.9[b]	—
QUINCY					
Survival (pct)	45[a](20)	78[b](19)	69[b](21)	45[a](22)	100[d](0)
Biomass consumption (t ha^{-1})	47.9	40.1	50.6	53.2	—
Consumption (pct)	72.8	67.6	82.5	87.6	—

[1]Survival is the mean and standard deviations are in parentheses. Different superscripted letters over survival and consumption (%) indicate a significant different when testing between treatments.

was significantly greater. The mean biomass of understory black oak individuals ranged from 163 to 320 g at Quincy and from 3 to 11 g at Blodgett (Kauffman 1986). At all sites, shrubs in the smaller size classes were most susceptible to fire-induced mortality. The majority of black oaks in small size classes predisposed the Blodgett black oak population to higher mortalities.

Another factor that contributed to higher mortalities was the fuel loadings and associated biomass of fuels consumed by fire. At the Blodgett site, significantly greater quantities of fuels were consumed and hence greater amounts of heat were generated at the base of the shrubs (table 2). Exceptions include the early spring burn treatments. Mean lower duff (Oa) moisture contents were 35 and 135 percent at Quincy and Blodgett, respectively (table 1). As a result, consumption of the duff layer was 50.6 and 11.1 t ha^{-1}, respectively. Even though almost five times as much biomass was consumed by fire at Quincy, the survival rates were equal. These data suggest difficulties in the prediction or comparison of mortality rates without prior quantification of the fuel load and consumption. But when comparing mortality rates at a single location, fuel consumption variables were most often the most significant factor in predicting shrub mortality (Kauffman and Martin 1985).

Two growing seasons after fire, black oak germinants began to appear in significantly greater densities in all burn treatments with the exception of the early spring treatment at the Blodgett location (table 3). In these treatments, the number of germinants was 2 to 10 times greater in the burn units than the unburned controls. As previously indicated, this burn did not significantly reduce the biomass of the duff component. The post-fire biomass of the duff component in all other treatments was significantly less than control. Apparently, when the duff component was less than 38 t ha^{-1}, seedling establishment was enhanced.

DISCUSSION

The fuel loads of these mixed conifer sites represent an unnatural buildup of downed woody materials. The heat loads produced by the combustion of 60 to 100 t ha^{-1} in high consumption burn treatments at Blodgett and 48 to 50 t ha^{-1} in high consumption burn treatments at Quincy were probably a rare occurrence prior to the era of suppression. The frequent surface fires of the past maintained fuel accumulations much lower than today. Therefore, presettlement fires probably affected the resprouting component much like the burn treatment which consumed only moderate amounts of fuels (i.e. 11 t ha^{-1} as in the early spring burn at Blodgett). This low intensity, low consumption burn killed only the smallest of black oak individuals.

Results of this study indicate that successful germination of acorns is enhanced in areas where the duff layers are weakly developed. These are the probable seedbed conditions in which the black oak evolved. Accumulations of forest floor fuels apparently represent degraded seedbed conditions for black oak.

It is doubtful that black oak is declining in all areas of the mixed conifer zone. At open sites with shallow soils (such as the Quincy site), black oak was found in all size classes. However, prescribed burns did increase the density of germinants at this site. In addition, a different situation existed at the Blodgett site. Black oak was not represented in all size classes. Rather it was only present as seedlings (<1 m in ht) or as very old decadent individuals. In the vicinity of the Blodgett site, there are archaelogical sites where Indians ground acorns for consumption. This would suggest a past composition containing a significant amount of oaks. At this location, we suggest that black oak has declined in abundance just as it has at the Sequoia National Park (Bonnicksen and Stone 1982, Parsons and DeBennedetti 1979) and Yosemite National Park (Anonymous 1971). The decline of black oak represents a degradation of the community diversity and structure of these communities. The resultant declines in the wildlife habitat values, aesthetic and cultural values should be considered.

The unnatural accumulations of downed fuels are not the only nor necessarily the major factor for

Table 3—The density of black oak seedlings in experimental burn plots at the Blodgett and Quincy locations. Numbers are mean and standard error.

Location/Treatment	#/ha	Percent of Seedlings in the Population	Post Fire Biomass of Duff Layers (t ha^{-1})
BLODGETT			
Early fall-high	367 (±327)	[1]79*	[2]7.7[a]
Late fall-moderate	333 (±152)	67*	37.8[b]
Late spring-high	267 (±200)	80*	20.1[b]
Early spring-moderate	67[a] (±67)	15	86.4[c]
Control-no burn	133[a] (±133)	17	-100.0
QUINCY			
Early fall-high	217 (±158)	37*	17.9[a]
Late fall-moderate	500 (±273)	52*	19.2[a]
Late spring-high	200 (±133)	40*	7.5[a]
Early spring-moderate	467 (±232)	67*	10.8[a]
Control-no burn	55[a] (±55)	7	-80.0[b]

[1]An * indicates that the percentage of seedlings in the population is significantly greater than that of control (x^2, p≤.005).

[2]Different superscripted letters denote a significant difference among treatments.

the decline in black oak. Though black oak does not require a mineral seedbed, germination is enhanced by such. It is probable that it does require openings in the overstory through which sunlight can reach the ground. The historic fires created gaps in the canopy and maintained an open character of the stands resulting in greater amounts of sunlight reaching the forest floor. With fire suppression, canopy closure has occurred and a dense midstory of shade-tolerant conifers has developed. This has decreased the amount of sunlight reaching the forest floor.

Reasons for the increase in the density of black oak seedlings in burn treatments are unknown. But it is apparent that the post-fire seedbed conditions enhanced the successful germination of black oak. The acorns do not require a thermal scarification treatment, nor are there any other dormancy mechanisms similar to those of the Arctostaphylos Adans. or Ceanothus L. genus. Therefore, this response is probably the result of modifications in the habitat which allowed for higher densities of seedlings to establish in burned plots.

Decay of seeds by molds in duff and litter has been suggested as an explanation for pool seedling emergence (Parmeter 1977). Damping off can be decreased by burning duff and litter. Parmeter (1977) stated that it was likely that the often observed success of seedlings on burned seedbeds was due to removal of seed decay, damping off and seedling root rot fungi.

Other factors were also observed to have influenced oak seedling densities. Undoubtedly, wildlife play a major role in acorn dispersal. Snow (1973) found that factors influencing the distribution of southern California oaks included concentration of coast live oak (Q. agrifolia Nee) around rock outcrops due to ground squirrels.

Most of the black oak seedlings were thought to have originated from acorns deposited by seed caching animals (i.e. squirrels and stellar jays). Often seedlings were as far as 50 m in distance from the nearest acorn-producing tree. Apparently a symbiotic relationship between the squirrels and black oak exists as squirrels (Sciurius griseus and/or Tamiasciurus douglasii) also tended to benefit from this relationship. After germination many acorns that were still attached to the seedlings contained dormant embryos which were palatable to the squirrels at a period when few other seeds or acorns were present. Squirrels removed almost all of these attached acorns. This appeared to cause few adverse reactions to the established seedling except the loss of ability to resprout from the acorn.

Whether animals preferred burned areas as cache sites or if the rate of acorn germination in burned environments is higher due to increased survival of the acorns, or some combination, is unknown. Additional investigations are needed to describe the animal-fire-acorn germination relationship.

CONCLUSIONS

Several authors have stated that since the era of fire suppression, most mixed conifer communities have only been exposed to "minor disturbance." We suggest that fire suppression in ecosystems with a fire return of 8 to 10 years is a major disturbance in itself. The vegetation composition and structure have been severely altered. The resultant and inevitable fire, which in all likelihood will be a crown or stand replacement fire, is the ultimate result of this man-caused disturbance (i.e. fire suppression).

Adaptations of plants to fire are better termed plant adaptations to certain fire regimes (Kilgore 1981). These results indicated that black oak is well adapted to the presettlement fire regime and environment in the mixed conifer zone of the Sierra Nevada. This includes frequent low-moderate intensity, surface fires and the resultant weakly developed organic horizons. In this study, few black oaks were killed by low consumption prescribed fires. High consumption burns that are possible today will kill high percentages of those black oaks in a shrub form.

Prescribed burns should be implemented to consume moderate-low amounts of fuels where increases or maintenance of the black oak population is desired. In order to increase germination success, forest floor reductions to less than 20 to 40 t ha^{-1} are suggested. This may require a high consumption burn or several burns of low-moderate consumption.

Black oak provides numerous values to society. It is very palatable to big game and domestic livestock. Numerous animals also utilize acorns as forage and the trees as nesting or roosting habitat. The tree also is of commercial value as a timber species. Newell (1983) stated that the greatest values of California oaks are the richness and diversity that they add to our ecosystems and to our lives beyond the value in a commodity sense. Fire may be necessary to maintain, increase or allow for the reinvasion of California black oak into many mixed conifer communities.

Acknowledgments: We thank Mr. Joe Davis, Fuel Specialist, Plumas National Forest; Mr. Bob Heald, Forester, Blodgett Forest Research Station; and Dr. Phil Weatherspoon, Research Forester, Pacific Southwest Forest and Range Experiment Station, stationed in Redding, California, for their invaluable assistance. This research was supported in part by the USDA Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

REFERENCES

Biswell, H. H.; Kallander, H. R.; Komarek, R.; Vogl, R. J.; Weaver, H. Ponderosa fire management. Misc. Publ. No. 2. Tallahasee, FL: Tall Timbers Res. Stn.; 1973. 49 p.

Bonnicksen, T. M.; Stone, E. C. Reconstruction of a presettlement giant sequoia - mixed conifer forest community using the aggregation approach. Ecology 63:1134-1148; 1982.
Brown, J. K. Handbook for inventorying downed woody material. Gen. Tech. Rep. Int-16. Ogden, UT: Intermountain Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture; 1974. 24 p.
Kauffman, J. B. The ecological response of the shrub component to prescribed burning in mixed conifer ecosystems. Berkeley, CA: University of California; 1986. 235 p. Dissertation.
Kauffman, J. B.; Martin, R. E. Shrub and hardwood response to prescribed burning with varying season, weather and fuel moisture. In: Donoghue, L. R., and Martin, R. E., eds. Proceedings, 8th Conf. on Fire and Forest Meteorology; Detroit, MI; 1985; 279-286.
Kilgore, B. M. Fire in ecosystem distribution and structure: western forests and shrublands. In: Proc. of the Conf. on Fire Regimes and Ecosystem Properties; 1981; Gen. Tech. Rep. WO-26. Forest Service, U.S. Department of Agriculture; 58-89.
Newell, L. A. The fire ecology of California oaks. (A paper presented at the California Oak Heritage Conservation Conf.). Santa Ana, CA: Audobon Society; 1983. 18 p.
Parmeter, J. R. Effects of fire on pathogens. In: Proceedings, symposium on environmental consequences of fire, fuel management of Mediterranean ecosystems. Gen. Tech. Rep. WO-3. Forest Service, U.S. Department of Agriculture; 1977; 58-64.
Parsons, D. J.; DeBenedetti, S. H. Impact of fire suppression on a mixed-conifer forest. For. Ecol. and Manage. 2:21-33; 1979.
Snow, G. E. Some factors controlling the establishment and distribution of Quercus agrifolia Nee and Q. engelmanni Greene. in certain southern California oak woodlands. Corvallis, OR: Oregon State University; 1973. 105 p. Dissertation.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Modelling the Distribution of Leaves, Oakworms and Damaged Foliage for the Coast Live Oak[1]

Vernard Lewis, W. Jan A. Volney, and James E. Milstead[2]

Abstract: A single Coast Live Oak tree (Quercus agrifolia) from Marin County California was selected for modelling the distribution of leaves, damaged foliage and the number of California Oakworms (Phryganidia californica). Branches for the study tree were classified according to crown level and compass direction. Twenty-four branches were randomly selected, each terminal shoot tagged. Resulting data collected per tagged shoot included number of leaves (damaged and undamaged) and oakworm larvae. Numbers of damaged and undamaged leaves, varied with crown level and branch diameter. Modelling of leaf totals and oakworm counts showed little difference when compared with totals from field observations. The ecological and pest management aspects of results are discussed.

The evergreen oak flora is an extensive and important resource in California. America north of Mexico has 68 species of oaks, of which 16 are native to California (Munz, 1970). In California, the dominant evergreen oak is the Coast Live Oak, Quercus agrifolia. Quercus species grow on 15-20 million acres making them one of the largest, although under-utilized, natural resources in the state (Callaham, 1980). Leaf distribution, foliage damage and defoliator number models are exiguous or nonexistent.

In California, the principal insect herbivore of the Coast Live Oak is the California Oakworm, Phryganidia californica Packard (Furniss and Carolin, 1977). This insect is a native California species whose populations erupt sporadically, every 5 to 7 years, in the state (Harville, 1955). Oakworms feed almost exclusively on oaks: all native and many introduced species are susceptible (Koehler et al., 1978). The population dynamics (Sibray, 1947; Harville, 1955; and Young, 1977), nutritional ecology (Volney et al., 1983a; Puttick, 1986), sex pheromone (Hochberg and Volney, 1984) and frass-drop measurement (Volney et al., 1983b) have been studied in some detailed. Still many gaps remain in our knowledge of this pest's biology, behavior and ecology.

Modelling urban pest populations is a recent innovation that is still undergoing development. The greatest advances in modelling are in agriculture (Getz and Gutierriez, 1982) and forestry (Waters and Stark, 1980). Early attempts of modelling shade-tree defoliator systems were by Olkowski et al., 1978. However, no data was presented revealing the number of leaves, foliage damage nor number of insect defoliators. Here, Q. agrifolia leaves from a study tree were counted to produce a model which allows for projections of foliage damage and numbers of P. californica.

METHODS

Field Methods

A Coast Live Oak tree, Q. agrifolia Nee, was selected for sampling from Marin Municipal Water District land near Mount Tamalpais in Marin County California. All major branches 15 mm in diameter or larger were grouped into three size categories. Every major branch was tagged and assigned to the crown location from which its foliage was borne. These crown locations were obtained by stratifying the crown into three vertical levels and into four compass directions. Vertical levels were obtained by dividing the tree canopy into three equal upright positions. Level 1 being the nearest the ground, Level 2 mid-crown height and Level 3 the uppermost third of the crown. Compass direction was defined using standard designations (e.g., north, east, south and west).

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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The branch selection method employed for this study was a randomized design adapted from Jessen (1955). Each selected branch was followed by climbing and use of ladders until a fork along the limb was reached. At the fork, the choice as to which lateral limb was to be followed was based on a probability distribution of the cross-sectional branch diameter. At each selection stage, the branch selection probability was recorded. The process was continued until a terminal leaf cluster was reached, later being tagged with weather resistant identifying labels for future observations. This process was repeated two times per crown sampling quadrant,resulting in a total of 24 tagged shoots per tree.

Tagged leaf clusters were visited monthly for one year (February 1985-1986) to make observations on:

1. Total number of leaves.
2. Total number of leaves damaged by oakworms (other defoliator species were excluded).
3. Total number of oakworm larvae.

These observations were made from ladders at the periphery of the crown.

Laboratory Methods

In February 1986, 22 randomly selected branches (32 - 72 mm in diameter) were excised from the sample tree and brought back to the laboratory. All leaves from field collected branches were sorted into damaged and undamaged categories, their totals recorded and entered into a computer. All data manipulations and statistical testing (Chi-Squared, t-test, F-test, Regression and ANOVA) were accomplished using the Statistical program StatView (Feldman and Gagnon, 1985) on an Apple MacIntosh computer.

RESULTS

Leaf Distribution

Mean totals for field collected leaves are presented in Table 1. Total oak leaf numbers increased proceeding up the crown of the tree. These results were shown to be statistically significant. Controlling for crown level differences, damaged and undamaged leaf totals were greatest for branches 49 - 64 mm in diameter, Table 2. All row means were statistically significant.

TABLE 1. Mean damaged, undamaged, and leaf totals per crown level 1*

Crown Level	Damaged2*	Undamaged3*	Total4*
1	67,186	19,642	86,828
2	79,732	29,005	108,737
3	114,939	44,541	159,480

1* Total height of tree divided into three equal vertical quadrants; 1 being the quadrant nearest the ground and 3 the uppermost quadrant of the tree crown

2* Statistically significant at $\alpha = .05; F_{2,19} = 5.473$

3* Statistically significant at $\alpha = .05; F_{2,19} = 6.764$

4* Statistically significant at $\alpha = .05; F_{2,19} = 6.136$

TABLE 2. Mean damaged, undamaged, and leaf totals per branch diameter

Diameter Interval (mm)	Damaged1*	Undamaged2*	Total3*
32 - 48	27,137	6,897	34,034
49 - 64	153,045	53,505	206,550
65 - 78	79,402	48,672	128,074

1* Statistically significant at $\alpha = .05; F_{2,19} = 5.779$

2* Statistically significant at $\alpha = .05; F_{2,19} = 5.408$

3* Statistically significant at $\alpha = .05; F_{2,19} = 5.921$

TABLE 3. Actual vs predicted leaf counts by crown level

Crown Level	Actual Counts	Predicted Counts 1*	Z statistic
1	86,842	105,164	
2	108,737	70,796	
3	159,480	99,722	
total	355,059	275,682	.85 2*

1* calculated using model equation

2* not significant at $\alpha = .05; r = .929, r^2 = .863$

TABLE 4 Actual vs predicted larval counts

	Larval Counts
Actual[1*]	68,250
Model[2*]	55,135

1* Data summed over 48 branches from one sample tree during summer 1981. The observed field rate was one larvae for every five leaves

2* Equation Used $l_m = \left(\frac{obs}{p_1 \cdot p_2} \right) (l_v)(b_r)$

See results section for model specifics

Modelling

Actual leaf counts were compared to predicted leaf counts obtained by modelling, Table 3. The model equation used was:

lm = (obs/p1 * p2) (lv) (br)

Explanation of aforementioned variables contained in the equation are listed as follows:

- lm = Predicted leaf totals.
- obs= Observed leaf counts from tagged shoots in the field.
- p1 = Overall between branch selection probability.
- p2 = Overall within branch selection probability.
- lv = Correction constant for differences in crown-level leaf counts.
- br = Branch totals per crown level corrected for diameter differences.

Correlation statistics show this leaf prediction model to describe 86 percent of the total variance, Table 3. Using the above model, estimates for oakworm larval counts were obtained, Table 4. Larval estimates were obtained by substituting Predicted Larval Counts (lar) for Predicted Leaf Totals (lm) in the equation. An additional equation modification was changing Observed Leaf Counts (obs) to Observed Oakworm Counts. Field larval counts were collected from another sample tree (Berkeley, California) in the summer 1981. These data were compared with modelled larval values, Table 4. Both estimates of larval number approximate the same value (86 percent of variance explained). No test of significance was attempted.

DISCUSSION

Ecological Considerations

Although studies exist for other hardwood species (Red Maple, *Acer rubrum* L.) which disclose foliage and defoliator distribution patterns (Volney, 1979), no attempts were made to estimate actual leaf counts. From the current study, the majority of leaves (damaged and undamaged) were found in the upper two-thirds of the crown. The percentage of damaged leaves (75 percent) was high compared to defoliator damage for other oak species (Puttick, 1986). Compass direction and leave growth patterns were not statistically correlated. However, data from a larger tree sample (nine trees) shows differences in leaf counts (Lewis, 1986). As previously reported, oak leaves survive at least 2 years on shoots. The peak leaf flushing period being, March-April.

Of particular research interest, is estimating the number of oakworm causing visual damage. Published findings forward conflicting values. A CIAS pamphlet (CIAS, 1981) states larval densities of 0.5 per shoot as not causing appreciable damage. Yet other workers report complete defoliation at larval densities of 1 per shoot (Volney et al., 1983a). Field observations for this study indicate larval densities of 3 per shoot resulted in total defoliation (Lewis, 1986). The discrepancies in insect counts may be due to varying sampling designs and the difficulty of randomly sampling trees, especially in the higher crown levels.

Nutritional ecology studies conclude older oak leaves are less digestible, particularly late in the summer (Feeny, 1970). This decrease in digestibility is due to increases in Tannin content and leaf toughness. Concurrently, protein availability is diminishing as leaves approach maturity. Similar results were obtained for *Q. agrifolia* (Puttick, 1985). Because of this process, larval feeding and leaf damage are accelerated as oakworms obtain their nutritional requirements for growth and development. Given this to be true, fewer larvae than expected may cause significant defoliation in the summer compared to the spring generation. However, longitudinal studies on field defoliation rates show elevated levels of Tannin to correlated poorly with protein decline (Faeth, 1985). This finding may explain the patchiness of defoliated trees observed in the field. It has been theorized that temperature or chemical and physical changes within damaged leaves are more important parameters in describing defoliation patterns (Faeth, 1985).

Reviewing previously mentioned data tables, most leaves show signs of damage (Tables 1, 2). Damage is greatest at the top of the crown. This is consistent with published reports of oakworm infestations starting at the top and proceeding down the crown (CIAS, 1981). The greatest leaf numbers are for branches 49-64 mm in diameter. It is not known why branches of this size have the more leaves. A possible explanation is that asymmetry of leaves on some branches is due to the asymmetry of sunlight on different compass directions. In Table 3, the model overestimated leaves in the lowest crown level (1). This is due to a bias in the model from more branches being located in level 1 compared to other levels. A weighted correction factor is needed when computing values. Predicted larval and field result are similar (Table 4). However, until the data from all nine sample trees are analyzed, generalizations would be premature.

Pest Management Considerations

Oakworm populations have been reported to sporadically outbreak. The causes for these outbreaks are unknown. Natural enemies are often cited as the cause for the cyclic demise of field larval populations. The exact mechanism is unknown. One possible explanation forward is that at high population densities defoliation allows more light penetration. By reducing foliate surface area, host location by predators and parasites is easier. Another possible mechanism, is chemical and physical changes that occur in damaged leaves act as attractive lures for predators and parasites.

Random insecticidal treatments are of little benefit if parameters for success (e.g., undamaged leaves, reduced larval and egg counts) are dismissed. Since branch sampling high in the crown is laborious an easier and economical sampling protocol is needed. Frass-drop measurements provides the necessary variable inputs for quick and accurate estimates of insects and resulting damage (Morris, 1949). Oakworm Frass-drop experiments from the laboratory and field have been conducted (Volney et al., 1983b). Reviewing these workers regression equations, the slope value of (1) imply an one-to-one relationship between leaf weight consumed (leaf damage) and weight of frass produced (monitoring tool reflecting damage). In depth refinement of this relationship by correlating leaf biomass consumed by oakworm with biomass lost by damaged leaves is needed. The intended result being, safe and efficacious control campaigns with minimal expense to the consumer and environment.

Acknowledgments: We thank Gordon W. Frankie, Professor of Entomology, Department of Entomology; Flordeliza L. Kala, School of Education, respectively, University of California, Berkeley and the Marin Municipal Water District.

REFERENCES

Callaham, R. Z. 1980. Opening Remarks. In: Plumb, Timothy R., tech. coord. 1980. Proceedings of the Symposium on the ecology, management, and utilization of California oaks, June 26-28, 1979, Claremont, California, Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; pp. 1-2.

(CIAS) Center for Integration of the Applied Sciences. 1981. The California Oakmoth: An Integrated Pest Management Approach. 1307 Acton Street, Berkeley, California. 2p.

Faeth, S.H. 1985. Quantitative defense theory and patterns offeeding by oak insects. Oecologia (Berlin). 68:34-40.

Feeny, P. 1970. Seasonal changes in oak tannins and nutrients as a cause of spring feeding by winter moth caterpillars. Ecology, 51:565-581.

Feldman, D. and J. Gagnon. 1985. Statview: The Graphics Statistics Utility for the Macintosh. Brainpower. Calabasas, California.

Furniss, R.L. and V.M. Carolin. 1977. Western Forest Insects. USDA Forest Service Misc. Publ. 1339, 654p.

Getz, W.A. and A.P. Gutierrez. 1982. A perspective on systems analysis in crop production and insect pest management. Annual Review of Entomology 27: 447-66.

Harville, J.P. 1955. Ecology and population dynamics of the California oak moth Phryganidia californica Packard (Lepidoptera: Dioptidae). Microentomology 20:88-166.

Hochberg, M.E. and W.J.A. Volney. 1984. A sex pheromone in the california oakworm Phryganidia californica Packard (Dioptidae). Journal of the Lepidopterists' Society 38(3): 176-178.

Jessen, R.J. 1955. Determining the fruit count on a tree by randomized branch sampling. Biometrics 11:99-109.

Koehler, C.S., C.S. Davis and D.R. Donaldson. 1978. Oakworm (oakmoth) and its control. University of California Division of Agricultural Science Leaflet 2542.

Lewis, V.R. 1986. Personal communications. Graduate student, Department of Entomology, University of California, Berkeley. 1 June 1986.

Morris, R.F. 1949. Frass-drop measurement in studies of the European spruce sawfly. Univ. Mich. Sch. Forestry and Conserv. Bull. 12. 58p.

Munz, P.A. and D.D. Keck. 1970. A California flora. University of California Press, Berkeley, California. 1681 p.

Olkowski, W., H. Olkowski, T. Drlik, N. Heider, M. Minter, R. Zuparko, L. Laub and L. Orthol. Pest Control Strategies: Urban Integrated Pest Management. In: Pest Control Strategies. E.H. Smith & Pimental, eds. Academic Press. 215-34.

Puttick, G.M. 1986. Utilization of evergreen and deciduous oaks by the Californian oakmoth Phryganidia californica. Oecologia (Berlin) 68: 589-594.

Sibray, W.S. 1947. Bionomics of the California oakmoth. M.S. Thesis. Dept. of Entomology, University of California, Berkeley, California.

Volney, W.J.A. 1979. Estimating epidemic populations of the lesser maple spanworm (Lepidoptera: Geometridae). The Canadian Entomologist 111:189- 200.

Volney, W.J.A., J.E. Milstead and V.R. Lewis. 1983a. Effect of food quality, larval density and photoperiod on the feeding rate of the California oakworm (Lepidoptera: Dioptidae). Environmental Entomology 12:792-798.

Volney, W.J.A., C.S. Koehler, L.E. Brown, L.W. Barclay, J.E. Milstead and V.R. Lewis. 1983b. Sampling for California oakworm on Landscape Oaks. California Agr. 37: 8-9.

Waters, W.E. and R.W. Stark. 1980. Forest pest management: concept and reality. Annual Review of Entomology. 25: 479-509.

Young, L.C. 1977. Pupal parasites of the california oakmoth Phryganidia californica Packard: a biological and ecological study. Ph.D. thesis, University of California, Berkeley, California.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Environmental Factors Influencing California Oakworm Feeding on California Live Oak[1]

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Abstract: Foliage consumption, frass production, assimilation efficiency and developmental rate are influenced by ambient temperature, sex, larval population density and the quality of host leaves. The larval feeding threshold lies between 1.7 and 4.4°C. The temperature optimum for larval development is approximately 20°C. Males have shorter larval and longer pupal periods and emerge shortly before females. Both high larval population density and leaf maturation tend to depress consumption and assimilation values and result in the production of smaller adults associated with diminished fecundity.

Throughout its recorded range, which extends in California along the coastal mountains from San Diego County north to Humboldt County (Harville, 1955) and into Oregon (Wickman and Kline, 1985) the California oakworm (Phryganidia californica (Pack.), feeds primarily on Quercus, Lithocarpus and Castanopsis.

The oakworm characteristically occurs at low population densities which periodically increase to outbreak levels resulting in severe defoliation to host trees (Furniss and Carolin, 1977).

In the San Francisco Bay Area, there are usually 2 generations per year. Oviposition customarily occurs in June and July and again in October and November. First and early second instar larvae overwinter on the lower leaf surface of California live oak (Quercus agrifolia Née). During the winter months there is usually little feeding and, if the temperature remains low for an extended period, populations may suffer high mortality. As the season progresses the developmental rate gradually rises in response to an increase in temperature. Because the distribution of host species (Harville, 1955; Griffin and Critchfield, 1972) clearly extends beyond the limits of the occurrence of sustained oakworm populations, it is probable that temperature and relative humidity are the major abiotic limiting factors. Within areas where temperature extremes allow the continued presence of oakworm populations, older instars may be found feeding at the margins of leaves of all age classes during the spring, summer and fall months.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, Cal Poly, San Luis Obispo, Calif.

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Although it is associated with a large complement of natural enemies few quantitative assessments of their impact have been reported. Harville (1955) working with oakworm populations at Alum Rock Park in San Jose and Jasper Ridge at Palo Alto attributed approximately 20 percent of the observed mortality to the combined action of the predatory bug Podisus and the tachnid Actia and 50-75 percent to the parasitic wasps Brachymeria and Itoplectis. Later work by Horn (1974) reaffirmed the importance of these pupal parasites and related the parasitization percentage to pupal population density. Recently, Young (1980) showed that Itoplectis operates in a density dependent manner over host densities ranging from 6 to 13 pupae per m^2 while above this density the parasitization rate declines. The effectiveness of these primary pupal parasites may be reduced by as much as 63 percent through the action of secondary parasites (Horn, 1974).

The major pathogens, excluding the microbial control agent Bacillus thuringiensis; are protozoan and viral. Infection levels of 33-35 percent for Nosema and approximately 2 percent for Leidyana have been reported for an Orcutt population sampled between 1958 and 1960 (Lipa and Martignoni 1960, 1984). While the field incidence of viral infections has not been quantified, Harville (1955) regarded viral disease to be a primary mortality factor exceeded in importance only by mass starvation. Martignoni and Schmid (1961) by means of laboratory bioassays have demonstrated significant differences in viral resistance between oakworm population at Albany and Orcutt and suggested that tolerance, population density and the presence of the virus and its inductors may account for the recurrence of virus epizootics. Because susceptibility to infectious organisms is determined in part by body weight and pathogen dosage, feeding rates may be a major factor influencing mortality in natural populations.

The nutritive quality of host foliage has been reported to decline with leaf aging (Mattson, 1980) and in response to herbivore feeding (Shultz and Baldwin, 1982).

The effect of food quality and larval

population density on oakworm foliage consumption has been previously reported (Volney et al., 1983). The current study, an extension of that work covering both spring and summer generations, uses herbivore dry weights in computing nutritional indices and considers the influence of gender in oakworm herbivory.

METHODS

In the initial experiments extending from February through August, 1981, third instar larvae were fed in 600 ml. waxed paper cups. The larvae had free access to weighed leaves which were changed 3 times per week. Leaf moisture was maintained by means of a cotton-plugged water-filled vial in which the excised leaf was inserted. Undamaged mature current flush (new) leaves and those from the previous (old) flush were selected from each of 2 trees differing in their oakworm infestation levels (sparse = less than 0.05 larvae per shoot; high = ca. 1.0 larvae per shoot). Initial population densities were 1, 2 and 4 larvae per feeding arena. Laboratory temperature and relative humidity was monitored by means of a hygrothermograph. Mean temperature ranged from 18.4°C to 24.5°C. Mean relative humidity ranged from 35.1 percent to 45.6 percent.

In later experiments (1986) utilizing foliage taken from 2 sparsely infested trees, growth rates were compared on newly flushed (immature) leaves and the preceeding generation's mature leaves. First instar larvae were reared singly at 20°C and 58 percent relative humidity in 13 dram plastic vials. The leaves fed to the larvae were changed 3 times per week. No attempt was made to maintain leaf moisture in these experiments. When adults emerged, clean vials were used as mating arenas. Leaves were changed 3 times per week to provide an ovipositional stimulus.

Consumption rates and utilization efficiencies were determined by means of the methods previously reported (Volney et al., 1983). All leaves were weighed prior to feeding (fresh weight) and the dry weights of leaf remnants and frass were obtained after a 24 hour ovenization at 105°C. Foliage consumption (I) was determined by subtracting the weight of the leaf remnant from the dry weight of the original leaf estimated from the regression relationship: (oven dry weight = 13.425 + 0.517 fresh weight; r^2 = 0.92; P = 0.0001).

The dry weight gain (G) was computed by subtracting the initial estimated dry weight of the larvae (larval dry weight = 0.356 + 0.151 larval wet weight; r^2 = 0.92; P = 0.001) from the estimated dry weight of the pupae (pupal dry weight = -3.6 + 0.273 pupal wet weight; r^2 = 0.95; P = 0.001).

The population density (D) in the feeding arena was determined by dividing the sum of the products of the number of live larvae (N) in each feeding period and its duration (t) by the total duration (T). (D = NT/T).

The mean weight (W) was obtained by dividing the sum of the products of the initial weight (w) of the larvae entering the feeding period (t) by T. (W = wt/T).

The following consumption and utilization rates were derived:

CR (consumption rate) = I/D.T (Mean dry weight of food consumed per larva per day)

FR (frass rate) = F/D.T (Mean dry weight of frass produced per larva per day)

CI (consumption index) = I/W.T (Mean dry weight of food consumed per mg. larval weight per day)

GR (growth rate) = G/W.T (Mean dry weight gained per mg. larval weight per day)

AD (approximate digestibility) = (I-F)/I (Proportion of ingested food assimilated)

ECI (efficiency of conversion of ingested food) = G/I (Proportion of ingested food converted to body substance)

ECD (efficiency of conversion of digested food) = G/(I-F) (Proportion of digested food converted to body substance)

RESULTS

Within the range of temperatures that allow survival (table 1) the population dynamics of the California oakworm is affected by many natural enemies (table 2).

Leaf age; the impact of herbivory (reflected in host infestation level), larval population density and sex are among many factors reported to influence consumption and utilization rates (Scriber and Slansky, 1981; Schowalter et al., 1986).

The results of feeding trials with immature leaves from the current flush, mature leaves from the current flush, and mature leaves from an earlier flush are presented in tables 3-5. The assimilation values fall within the ranges reported for lepidopterous larvae feeding on tree foliage (Slansky and Scriber, 1982).

Leaf Age

A diet of immature leaves is associated with more rapid developmental rates, larger insects and enhanced egg productivity (table 5). Larvae feeding on older mature leaves have lower CR and AD values.

No significant differences in developmental rate or insect size can be attributed to leaf age differences in mature leaves.

Infestation Level

As in the case with mature leaves, infestation level differences are not reflected in significant differences in consumption rate, nutritional efficiency, development or size.

Sex

Female larvae have appreciably higher CR, FR, GR, ECI and ECD values. These along with a longer larval period result in larger pupae and adults. Male larvae have higher AD values and a more rapid developmental rate.

Larval Population Density

At the highest population density, all of the consumption and assimilation values with the exception of ECD are drastically depressed resulting in the production of smaller pupae and adults.

DISCUSSION

Leaf aging is associated with a decline in Nitrogen and water concentrations (Scriber and Slansky, 1981). Young, actively growing tissues contain the highest levels of Nitrogen (Puttick, 1986) and, as the growth rate begins to diminish the Nitrogen concentration drops sharply, decreasing gradually thereafter until just prior to senescence. Both ECI values and relative growth rates have been shown to be correlated with leaf Nitrogen and water content (Mattson, 1980; Scriber, 1978, 1984). These correlations serve to explain our observations relating leaf age and herbivore response throughout the growing season where the greatest differences occur between oakworm larvae feeding on young foliage and those feeding on mature leaves.

In contrast, Puttick has reported higher GR, ECI and ECD values for oakworm larvae feeding on mature leaves of Q. agrifolia. Since neither gender differences nor the influence of leaf age on growth rate and fecundity were considered it is difficult to compare her findings with those presented here.

While it is known that herbivory can result in the mobilization of facultative defenses in host trees (Schowalter et al., 1986) our data, derived from the feeding of mature leaves, gives only slight indication of this. The phenomenon may be more readily descernable in actively growing leaves sampled from trees exhibiting higher levels of infestation.

Disparities in weight between male and female larvae, pupae and adults have been attributed to differences in the length of the developmental period, a faster relative consumption rate and a higher ECI (Scriber and Slansky, 1981). Our data support these findings. While the CI values are essentially equal for the sexes, female larvae consume foliage at a faster rate over a longer period of time.

The slower developmental rate of female larvae suggests that the application of microbial insecticide during the last instar, while not affording current foliage protection, should serve to greatly reduce the population base of the succeeding generation.

Our data indicate that at high population densities increased intraspecific competition for food results in the production of smaller adults with lessened fecundity. This is supported by data (Milstead, unpublished) collected during two oakworm outbreaks in 1982 and 1986 where severe defoliation was associated with diminished oakworm size and fecundity.

It is clear from these results that foliage quality and population density can have profound consequences on the population dynamics of the oakworm.

Table 1—Influence of Temperature on Survival, Developmental Rate and Pupal Size of California Oakworm

Year, Season	Temperature C°	N	Survival Pct.	N	Larval Period (Days) x̄ ± SE	Pupal Weight (Mg.) x̄ ♀	x̄ ♂	x̄ ± SE ♀ + ♂
1945[1]	1.7	20	0		-			
	4.4	20	0		-			
	10.0	20	30.0	6	178.0	113.0	99.3	106.2
	15.6	17	82.4	14	54.3	208.5	125.5	167.0
	18.3	20	68.4	14	43.8	191.8	127.1	159.5
	21.1	20	60.0	12	38.8	155.0	120.7	137.9
	27.2	21	20.0	4	47.0	123.0	104.0	113.5
	29.4	37	3.0					
	35.0	40	0					
1983, Spring	14.0	8	0	1	224PP			
	16.0	8	62.5	5	113.6 ± 5.7			81.8 ± 8.7
	18.0	8	62.5	5	84.8 ± 7.9			89.1 ± 9.0
	20.0	9	77.8	7	52.1 ± 1.5			145.2 ± 7.1
	26.0	10	70.0	3	64.7 ± 3.5			105.3 ± 9.9
1983, Summer	14.0	16	0		-			
	16.0	16	0		-			
	18.0	15	18.7	3	91.0 ± 5.8			109.4 ± 12.4
	20.0	16	25.0	5	59.5 ± 0.8			121.7 ± 6.7
	26.0	16	43.7	7	57.6 ± 1.0			87.0 ± 1.4

[1]from Sibray 1947
[PP]prepupa

Table 2--Natural Enemies of the California Oakworm

Host Stage	Pathogen (O)/Predator (P) Primary Parasite (PP)	Secondary Parasite (SP)	Primary Parasite Hosts
Egg	*Podisus maculiventris* (P)		
	Tetrastichus sp (PP)		
Larva	*Entomophthora sp* (O)		
	Borrelinavirus (O)		
	Nosema phryganidae (O)		
	Leidyana phryganidiae (O)		
	L. berkeleyi (O)		
	Mermithid nematode (PP)		
	Podisus (P)		
Pupa	*Actia sp* (PP)		
	Zenillia virilus (PP)	*Mesochorus sp* (SP)	*Zenillia*
	Beauveria bassiana (O)		
	Podisus (P)		
	Ephialtes ontario (PP)	*Gelis tenellus* (SP)	*Ephialtes*, *Brachymeria*, *Itoplectis*
		Dibrachys cavus (SP)	*Ephialtes*, *Brachymeria*, *Itoplectis*
	Brachymeria ovata (PP)		
	Itoplectis behrensii (PP)	*Mastus acidulatus* (SP)	*Itoplectis*
		Bathythrix sp	*Itoplectis*
	Leptocoris rubrolineatus (P)		
Adult	*Podisus* (P)		

Table 3--Influence of Mature Leaf Age, Host Tree Infestation Level, Sex and Larval Population Density on Mean Daily Consumption, Elimination, Growth Rate, and Assimilation Efficiency[1,2]

Factor	CR (Mg. dry wt./larva) N	CR $\bar{x} \pm SE$	FR (Mg. dry wt./larva) N	FR $\bar{x} \pm SE$	CI N	CI $\bar{x} \pm SE$	GR N	GR $\bar{x} \pm SE$	AD (PCT.) N	AD $\bar{x} \pm SE$	ECI (PCT.) N	ECI $\bar{x} \pm SE$	ECD (PCT.) N	ECD $\bar{x} \pm SE$
Leaf Age														
NEW	30	16.61 ± 1.1	30	13.52 ± 0.7	30	1.99 ± 0.12	30	0.082 ± 0.005	30	17.1 ± 1.4	30	4.2 ± 0.2	30	31.8 ± 3.7
OLD	33	15.55 ± 0.6	33	13.26 ± 0.4	33	2.02 ± 0.08	33	0.085 ± 0.006	33	14.0 ± 1.6	33	4.3 ± 0.2	28	35.8 ± 4.5
Host tree Infestation Level														
SPARSE	33	16.36 ± 1.03	33	13.54 ± 0.67	33	1.99 ± 0.12	33	0.088 ± 0.006	33	15.4 ± 1.4	33	4.4 ± 0.2	32	35.4 ± 4.3
HIGH	30	15.72 ± 0.55	30	13.22 ± 0.5	30	2.02 ± 0.08	30	0.079 ± 0.005	30	15.6 ± 1.6	30	3.9 ± 0.2	27	28.6 ± 3.5
Sex														
♀	12	19.82 ± 1.1	12	16.18 ± 0.8	12	2.2 ± 0.14	12	0.109 ± 0.008	12	17.8 ± 2.7	12	5.0 ± 0.3	12	37.6 ± 6.4
♂	6	16.02 ± 1.8	6	12.30 ± 1.2	6	2.1 ± 0.12	6	0.090 ± 0.009	6	21.8 ± 4.3	6	4.3 ± 0.4	6	26.2 ± 7.1
Larval Density														
1 larva	18	18.55 ± 1.03**	18	14.89 ± 0.8**	18	2.16 ± 0.1**	18	0.102 ± 0.006**	18	19.1 ± 2.2**	18	4.8 ± 0.3*	18	33.8 ± 4.9
4 larvae	24	13.86 ± 0.55	24	12.25 ± 0.5	24	1.74 ± 0.1	24	0.070 ± 0.007	24	11.7 ± 1.4	24	4.0 ± 0.2	21	38.4 ± 5.5

[1] Values within a group followed by * and ** are significant at the 0.05 and 0.01 level respectively.

[2] Larval instars 1 and 2 excluded.

Table 4--Influence of Mature Leaf Age, Host Tree Infestation Level, Sex and Larval Population Density on Pupal Weight, Adult Weight and Duration of Developmental Period[1,2]

Factor	Sex	Pupal wt. (Mg.) N	Pupal wt. (Mg.) x ± SE	Adult wt. (Mg.) N	Adult wt. (Mg.) x ± SE	Larval Period (Days) N	Larval Period (Days) x ± SE	Pupal Period (Days) N	Pupal Period (Days) x ± SE	Total (Days) N	Total (Days) x ± SE
Leaf Age											
NEW	♀	34	112.0 ± 4.9	20	83.2 ± 0.5	32	33.7 ± 1.2	32	7.3 ± 0.3	32	40.9 ± 1.2
OLD		30	118.9 ± 6.5	18	83.1 ± 8.4	30	32.2 ± 1.2	30	7.4 ± 0.2	30	39.5 ± 1.2
NEW	♂	25	79.9 ± 3.2	15	36.3 ± 4.7	25	27.8 ± 0.9	25	9.6 ± 0.5	25	37.3 ± 1.0
OLD		31	77.3 ± 3.2	19	34.3 ± 3.4	31	28.0 ± 0.9	31	9.6 ± 0.4	31	37.6 ± 1.0
Tree Infestation Level											
SPARSE	♀	34	116.2 ± 5.5	22	83.2 ± 7.1	32	32.8 ± 1.4	32	7.5 ± 0.3	32	40.3 ± 1.3
HIGH		30	114.1 ± 5.9	16	83.0 ± 6.9	30	33.1 ± 1.0	30	7.2 ± 0.3	30	40.2 ± 1.1
SPARSE	♂	28	78.0 ± 3.1	19	37.3 ± 4.2	28	27.2 ± 1.0	28	9.6 ± 0.4	28	36.8 ± 1.1
HIGH		28	78.9 ± 3.4	15	32.5 ± 3.4	28	28.6 ± 0.8	28	9.6 ± 0.4	28	38.2 ± 0.9
Sex	♀	64	115.2 ± 4.0**	38	83.1 ± 4.9**	62	32.9 ± 0.9**	62	7.3 ± 0.2**	62	40.3 ± 0.9*
	♂	56	78.5 ± 2.3	34	35.2 ± 2.8	56	27.9 ± 0.6	56	9.6 ± 0.3	56	37.5 ± 0.7
Larval Density											
1 larva	♀	12	128.7 ± 9.0	8	93.6 ± 8.1	12	30.8 ± 1.8	12	7.7 ± 0.4	12	38.4 ± 1.9
4 larvae		36	111.8 ± 5.2	20	80.3 ± 6.7	35	33.8 ± 1.0	35	7.3 ± 0.3	35	41.1 ± 1.0
1 larva	♂	6	87.6 ± 4.8	3	44.9 ± 11.6	6	28.3 ± 2.8	6	10.5 ± 0.2	6	38.8 ± 2.8
4 larvae		33	77.2 ± 2.8	20	33.7 ± 3.4	33	27.6 ± 0.7	33	9.9 ± 0.3	33	37.5 ± 0.7

[1]Values within a group followed by * and ** are significant at the 0.05 and 0.01 level respectively.

[2]Larval-instars 1 and 2 excluded.

Table 5--Influence of Leaf Maturity on Weight, Duration of Developmental Period and Egg Production[1]

		Larval Period (Days) $\bar{x}$ ± SE				Pupal Weight (Mg.) $\bar{x}$ ± SE				Adult Weight (Mg.) $\bar{x}$ ± SE				Total Eggs laid per ♀ $\bar{x}$ ± SE			
Host Plant	Sex	N	Immature foliage	N	Mature foliage	N	Immature foliage	N	Mature foliage	N	Immature foliage	N	Mature foliage	N	Immature foliage	N	Mature foliage
1	♀	7	52.0±3.9	17	54.9±0.6	7	151.6±11.3**	17	97.6±4.6	7	121.4±9.2**	17	79.0±3.7	9	141.8±20.8**	12	77.3±8.1
	♂	4	37.5±1.9**	9	45.1±1.3	4	90.0±10.8**	9	58.0±2.6	4	53.6±7.9**	9	29.6±2.7				
2	♀	7	44.4±2.3	2	56.5±7.5	7	147.1±22.5	2	105.5±17.3	7	123.6±19.0	2	83.8±12.8	9	152.7±36.0	2	82.0±20.0
	♂	4	36.3±3.3**	11	45.6±1.0	4	93.4±13.7**	11	58.8±2.4	4	41.1±3.4	11	36.6±2.5				

[1]Values within a row followed by * and ** are significant at the 0.05 and 0.01 level respectively.

REFERENCES

Furniss, R. L.; Carolin, V. M. Western forest insects. Misc. Publ. 1339. Washington, DC: U.S. Department of Agriculture, Forest Service; 1977. 654 p.

Griffin, J. R.; Critchfield, W. B. The distribution of forest trees in California. Res. Paper PSW-82. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1972. 114 p.

Harville, J. P. Ecology and population dynamics of the California oakmoth Phryganidia californica (Lepidoptera: Dioptidae). Microentomology 20:88-166; 1955.

Horn, D. J. Observations on primary and secondary parasitoids of California oakworm, Phryganidia californica pupae. Pan. Pacific Entomologist 50:53-59; 1974.

Lipa, J. J.; Martignoni, M. E. Nosema phryganidiae n.sp., a microsporidian parasite of Phryganidia californica Packard. J. Insect. Pathol., 2:396-410; 1960.

Lipa, J. J.; Martignoni, M. E. Leidyana phryganidiae and Leidyana berkeleyi: two new species of gregarines from Phryganidia californica. J. Invertebr. Pathol. 43:69-76; 1984.

Mattson, W. J., Jr. Herbivory in relation to plant nitrogen content. Ann. Rev. Ecol. Syst. 11:119-161; 1980.

Martignoni, M. E.; Schmid, P. Studies on the resistance of virus infections in natural populations of lepidoptera. J. Insect Pathol. 3:62-74; 1961.

Puttick, G. M. Utilization of evergreen and deciduous oaks by the California oak moth Phryganidia californica. Oecologia. 68:589-594; 1986.

Schowalter, T. D.; Hargrove, W. W.; Crossley, D. A., Jr. Herbivory in forested ecosystems. Ann. Rev. Entomol. 31:177-196; 1986.

Schultz, J. C.; Baldwin, I. T. Oak leaf quality declines in response to defoliation by gypsy moth larvae. Science 217:149-151; 1982.

Scriber, J. M. The effects of larval feeding specialization and plant growth form on the consumption and utilization of plant biomass and nitrogen: an ecological consideration. Ent. exp. and appl. 24:494-510; 1978.

Scriber, J. M. Host Plant Suitability. In Chemical Ecology of Insects, W.J. Bell and R.T. Carde, Ed., London, Chapman and Hall Ltd.; 1984:159-202.

Scriber, J. M.; Slansky, F., Jr. The nutritional ecology of immature insects. Ann. Rev. Entomol. 26:183-211; 1981.

Sibray, W. S. Bionomics of the California oakmoth. Dept. of Entomology, University of California, Berkeley; 1947. Dissertation.

Slansky, F., Jr.; Scriber, J. M. Selected bibliography and summary of Quantitative Food Utilization by immature insects. Bull. Ent. Soc. Amer. 28:43-55; 1982.

Volney, W. J. A.; Milstead, J. E.; Lewis, V. R. Effect of food quality, larval density and photoperiod on the feeding rate of the California oakworm (Lepidoptera: Dioptidae). Environ. Entomol. 12:792-798; 1983.

Wickman, B. E.; Kline, L. N. New Pacific Northwest Records for the California oakworm. Pan. Pac. Entomol. 6:152; 1985.

Young, L. C. Field estimation of the functional response of Itoplectis behrensii, a parasite of the California oakworm, Phryganidia californica. Environ. Entomol. 9:496-500; 1980.

Urban Forestry-Recreation

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

What is the Urban Forest?[1]

Bailey Hudson[2]

The urban forest can be defined simply as the planted environment within the city. Collectively it includes trees, shrubs and lawns in urban parks, public areas, private yards and commercial and industrial areas--the overall green environment. It is a people-oriented forest designed to provide a quality living environment and enhance the social, cultural, sensory and economic dimensions of urban life.

The urban forest also has ecological value. It modifies the environment in a positive way by providing shade, wind protection, air filtering, noise reduction and soil protection. It can also modify the environment negatively when it requires more energy and water resources to maintain than are reasonably available in the long term. The measure of the forest's value would be in how well the positive benefits are balanced with the consumptive requirements.

Urban forestry functions are influenced by a variety of professional and lay backgrounds that are extremely diverse. Involved are scientists, engineers, activists, politicians, landscape architects, urban planners, practitioners, and many others who ultimately affect the character and management of urban vegetation. Considering the myriad professionals and lay people involved in urban forestry and the variety of urban forest values, we must employ an eclectic system of management for urban vegetation. To perpetuate the values of urban forestry, urbanites must understand the urban forest complex collectively as an ecosystem. Further, the urban forester must practice multiple-use, sustained yield management for people. The city tree, which is the largest and most impressive statement in the urban landscape, will receive the most attention from the papers in this section.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

[2]Superintendent of parks, California Urban Forests Council, Santa Maria, California.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Urban Forestry and the Role of the Community[1]

Julie K. Oxford[2]

Abstract: Oak-woodlands and wildlands are converted into urbanized developments and recreational areas at an alarming rate, often with little or no understanding of the resulting impacts to these areas. This trend, together with the public's general lack of awareness of California's oak regeneration problem, is rationale for promoting urban forestry programs at the community level, to educate the public on the protection of these forests. This paper highlights one such urban forestry project--ACORN--designed to aid the declining valley oak at Lopez Lake Recreational Area in southern San Luis Obispo County. The ACORN newsletter was then published, serving to establish a statewide "information network" to further the dissemination of technical information on managing California's hardwood forests.

The urban forest has been broadly defined as trees and forested areas in the city, suburban areas and small woodlots outside the traditional wildlands. As California's burgeoning population pushes urban development onto woodland areas, the urban forest takes on new characterisics, and its caretakers take on new responsibilities: No longer do these urban forests resemble the typical urbanscape of ornamental trees and shrubs; rather, these urbanized woodlands, comprised of nature's indigenous species, are indeed another type of urban forest, requiring altogether different regimes of cultivation and care.

The professional urban forester is involved in the scientific management, protection and regeneration of the urban forest. Forestry programs which identify these objectives are critical not only to cities and communities but to recreational areas--the forested interfaces whose survival depends directly on the wise use and proper management by its human caretakers.

Management of Oak-Woodlands

Management techniques of the urban forester, tested successfully on city lots and corridors, are not readily applicable, however, to the ecology of an oak-woodland: Oaks are adapted to summer droughts and seasonal winter rains, a mediterranean climatic regime unlikely to be consistent with that of an abutting ornamental landscape installed by an urban neighbor.

The human element, residing or recreating in increasing numbers among the oak-woodlands, has introduced new challenges to the management of these fragile forest areas, imparting as yet unknown factors to the ecological dynamics of the forest. New techniques are being developed and updated with each experimental urban forestry program. Skilled, technical management implemented by the professional urban forester, however, has little merit if long-term maintenance practices of uninformed residents and recreationists of that community persist.

To offset this problem of counterproductive management practices, an urban forester can introduce educational programs to residents of a forest community. In so doing, he can function not merely as an espouser of sound scientific management, but as a leader supporting his methods with values which can be broadly contagious within a locality: those of aesthetics, environmental concerns and community pride. For urban forestry programs to sustain and perpetuate themselves, forest management in populated or recreational areas requires the awareness and cooperation on the part of the community in which it is based.

THE BIRTH OF THE ACORN PROJECT

Establishing a Mission Statement

Concern about the lack of knowledge and wise management of California's oaks led to the development of ACORN--The Association for California Oak Resource News. Aided by a grant from the Conservation Endowment Fund and other supporting groups and individuals, the Natural Resources Management Department of Cal Poly, San Luis Obispo served as headquarters for the program, providing a director, a project coordinator and a faculty advisory committee. Together we established ACORN's mission: (1) to generate public awareness of the oak-regeneration problem with hands-on community involvement of oak-planting and protection and (2) to create an information network for the purpose of disseminating hardwood-related updates and information by publishing a newsletter and other educational materials. The intent is that the public--by taking an active role in local urban forestry activities--will become better informed of the state's oak-regeneration problem, and will then be better able to make decisions regarding the future of California's hardwood forests.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, California Polytechnic State University, San Luis Obispo, Calif.

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Identifying Problem Areas

The valley oaks *(Quercus lobata* Neé*)* at Lopez Lake Recreational Area, Arroyo Grande, have been declining due to a combination of factors: Edaphic, physiologic and wildlife relationships and soil compaction are factors being investigated by the park. In cooperation with the park management, ACORN's oak planting project was designed to regenerate the oaks in the recreational area. December 7, 1985 more than 200 volunteers from the community planted 1500 valley oak acorns on four acres of the oak-woodland site.

THE ROLE OF THE COMMUNITY

Addressing a Community Profile

Before embarking on a particular program, targets, such as groups representing strong bases echoing the voice of the county, were earmarked to assess probable pathways to support. In the case of San Luis Obispo, a strong slow-growth sentiment echoes throughout this largely agricultural county; its residents boast a strong pride in maintaining and protecting the beauty and simplicity of its rural countryside. ACORN was welcomed by literally every group encountered.

Networking the Community: The Media

A major event affecting the status of the community generated momentum for the ACORN PROJECT. Ironically, five months before the project was to begin, the proposed site, the recreational area at Lopez Lake, narrowly escaped the 75,000-acre Las Pilitas Fire, charring the lake's perimeters. Capitalizing on the timing of an otherwise devastating event, ACORN's press releases were mailed to county newspapers, all eight of whom were eager to promote an oak-regeneration project which, they wrote, offered at least a partial solution to recover the damage effected by the midsummer fire. Our public service announcements were aired county-wide, the result: ACORN 's message was carried repeatedly over six radio stations. Thus, on the "coattails" of the fire, an intensive community outreach program was well underway, as volunteers began calling daily, offering assistance to the regeneration project.

Tapping Community Resources: Civic and Special Interest Groups

Press releases and letters of introduction were mailed to civic and community groups thought to have a special interest in our project, the response being that our regeneration project was highlighted in more than a dozen newsletters and leaflets published by organizations such as University of California Cooperative Extension; California Native Plant Society; Sierra Club; Audubon; Natural History Association; Sportsmen's Association; Wildlife Rehabilitation Guild; 4-H clubs; FFA; Girl Scouts and Boy Scouts--all of whom were represented at the planting. Slideshow presentations offered these organizations a visual introduction to the project, emerging as one of the most effective educational tools for garnering community support.

The Function of Community Leaders

Each community has public figures, civic and private spokespeople who seek to affiliate themselves with community service projects. Non-partisan urban forestry programs are ideal functions in which to involve local dignitaries. ACORN flourished from its ad hoc consortium of celebrated supporters. Among the roster of invited speakers and dignitaries honored at the ceremony were the mayor of Arroyo Grande; San Luis Obispo County Agricultural Commissioner; representatives from the County Board of Supervisors; County Parks Facilities Manager; representatives from the USDA-Forest Service, California Department of Forestry, University of California Cooperative Extension and the California Conservation Corps.

Local and National Recognition

Community networking was self-perpetuating, as word of our mission traveled. *Sunset* magazine photographed ACORN's planting activity and carried an editorial in their May 1986 issue. *The Journal of Forestry* publication gave us national coverage and a local television station broadcast the community planting. ACORN was also selected as a finalist in the *National Arbor Day Foundation Awards.*

THE AFTERMATH OF THE URBAN FORESTRY PROJECT

Developing a Database

A computerized database was essential as our base grew to 1200 supporters, half of whom were residents of San Luis Obispo county. Statewide hardwood research rosters were sought. Requests for mailing lists of members of civic and community groups were met with strong resistance; bylaws protecting the privacy of those lists are strictly enforced. Despite this setback, many such members attended slide presentations introducing ACORN, and became active promoters and supporters of the project.

Publishing a Newsletter

ACORN's success effected a growing database, indicating a strong support system. A newsletter was published, highlighting the success of the urban forestry project, communicating objectives and offering updates of oak-related events, research and a punctuated bibliography of books and articles of interest. The timing of a newsletter, fitting it in where it best sustains the growing momentum--may be crucial to keeping a project alive. Unforseen difficulties rendered the ACORN publication months late in its delivery, the effects of which are difficult to postulate.

THE ACORN PLANTING ACTIVITY

A group of some 200 volunteer planters arrived at the selected park site, Vista Lago Island. Youth groups had been organized who set up booths depicting historic acorn use by the indigenous Chumash, and several species of oak seedlings were available for purchase. A brochure was distributed, which outlined our acorn planting technique and described the problems associated with the oaks' unsuccessful regeneration locally and statewide. Bluegrass minstrels led the group to a clearing under several aging valley oaks, where a dedication ceremony and planting demonstration readied the groups for action. Cal Poly forestry clubs provided leadership, forming groups, each taking acorns and planting gear with them to the nearby planting site.

Developing a Planting Technique

A special technique had been developed for planting acorns at the park, ensuring their protection. Wildlife species, known to inhabit the oak-woodland site, were a primary consideration: Among the 150 avian species observed around the lake, the locally abundant acorn woodpecker *(Melanerpes formicivorus)* feeds voraciously on the valley oak acorns. The California ground squirrel *(Spermophilis beecheyi)* and the valley pocket gopher *(Thomomys bottas)* are among some 28 species of small mammals known to occur near the planting site. Mule deer *(Odocoileus hemionus)* roam freely throughout the park. Protection from annual grassland mowing, one of the park's measures for maximizing fire protection, was also a consideration.

The Technique

Holes of 2-feet depth had been prepared in advance by the California Conservation Corps, using gas-powered augers. A piece of aviary netting (1/2-inch-mesh) was rolled into a cylinder, 2-feet-high, 5-inches in diameter. Overlapping edges were threaded through the solid mesh, securing a closed unit, except for the top 6 inches, which were kept open temporarily, for planting access. The base was bent inward, forming a lid closure to prevent rodents entering from underground. The cylinder was then located so that it protruded 6 inches above the ground and was filled to within 2 inches of the ground surface with "native" soil and soil amendment, in equal proportions. After firmly tamping the soil to remove air spaces, five acorns were layed on their sides and 2 inches of soil gently firmed over them. The top 6 inches of netting were then threaded closed and the cylinder top bent inward, forming a lid to discourage above-ground foragers. Numbered aluminum labels were secured to each cage and berms were formed to allow for deep irrigation.

Follow-up Maintenance

Intending for the seedlings to be without cultivation, Lopez park personnel watered the oak seedlings just twice the first year, and only during a prolonged seasonal drought. Six months after planting, a work party was organized to tend to the seedlings. A count determined that 98.9 percent of the planting sites had at least one surviving seedling. To minimize competition for water, light and root space, the sites were cleared of weeds. The berms were rebuilt and the cages, which the seedlings had outgrown, were extended to a height of four feet and a width of three feet.

DISCUSSION

In eight month's time, the city and portions of the county of San Luis Obispo were to become whole-hearted supporters of ACORN in its efforts to aid the non-regenerating hardwood resource in their community. Through extensive use of the media, a highly effective public relations campaign was launched. Slideshow presentations were developed; as educational tools, these interpretives promoted awareness within civic and community groups, conservation and youth organizations. A site was selected for the oak-regeneration project, where a dedication ceremony was attended by more than 200 members of the community, including community leaders and dignitaries, each planting a tree in their honor. A newsletter was then published, highlighting the success of the ACORN PROJECT, further promoting awareness of the problems threatening California's hardwood forests.

CONCLUSION

The success of ACORN's urban forestry program is owed, in large part, to our developing an educational package which was tailored to the personal needs of the community it intended to serve: By researching and targeting those groups most suited to our goals, and by making personal appearances at numerous meetings, our educational presentations could be adapted to each group's special interests. While personal appearances helped introduce our program, distributing printed material left our message in their hands.

Networking the community media in person stirred an interest in the editorial staff, who, by virtue of their profession, are always looking for a story! Small budgets require large support systems: We asked for support in the form of air time, press and community participation--the three ingredients most important to the success of the ACORN PROJECT: The media spoke to our efforts, thus uniting the community for a worthy cause; the overwhelming community response reflected back the certainty that ACORN's mission had indeed reached its first stronghold.

REFERENCES

Brown, Leland R., et. al.
Oaks on Home Grounds. Division of Agriculture and Resources. University of California Cooperative Extension. Leaflet 2783. 1984.

Koehler, C.S.; Hunt, R.H.; Lobel, D.F.; Geiger, J.
Protecting Trees When Building on Forested Land. Division of Agricultural Sciences. University of California Cooperative Extension. Leaflet 21348. 1983 July

Lobel, F.; George, Alan G.
Plant Your Own Oak Tree. Division of Agricultural Sciences. University of California Cooperative Extension. Leaflet 21334. 1983 March

Ruppert, Ron M.; Ruppert, C.L.
Biological Inventory of the Lopez Lake Recreational Area. Special report under contract PS 82-29 to San Luis Obispo County; 1983: 24-29.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Some Implications of Public Involvement in Hardwood Management[1]

Alex A. Pancheco[2]

Abstract: Man's economic and social activities have long placed pressure on California's hardwood resource. This has resulted in significant modifications to the resource, especially near urban areas. Improvements in hardwood management will not occur unless the public begins to perceive hardwoods as a resource. TreePeople has worked for a number of years to change the public's perception of the resource through education and involvement in urban forestry. This paper will discuss some of TreePeople's methods and introduce our efforts to educate the public about hardwoods through our oak reforestation efforts.

California's hardwood resource has felt the impact of the activities of man since before the arrival of Western civilization. Native Americans utilized acorns and other hardwood products in their everyday life. With the Spanish colonization in the 1700's, the resource began to be negatively affected, as more trees were cut for firewood, and as cattle were introduced to the landscape. Since then, development and accelerating urban influences have increased the pressure. Today, while many do not agree on the ultimate reason for some oaks' failure to regenerate properly, or what impact the removal of cattle grazing would have on regeneration, or the adequacy of current regulations in protecting the resource, there is a common denominator. The basic problem is people and their attitudes.

The economic and social activities of humans in California, and the pressures that they have placed on the hardwood resources are the primary reason that we are here today. Since people are causing the problem, it follows by extension that they must be the solution. It sounds simplistic, but the cure indeed will not be. The only way to ensure the wise use of our hardwoods is to change the way people view the nature of the resource. Too many take our hardwoods for granted, or ignore them altogether. Many others perceive them as a hindrance to their development plans. The public must begin to perceive California's hardwoods as a resource to be managed, utilized where practical and preserved when necessary.

This increase in public awareness must come about through education and by involving the public in the management process. By involving private citizens in the issues of resource management, the public becomes better informed and can begin to support the resource manager. This has many advantages to the manager, from support for increased budgets by creating a visible constituency, to creation of volunteer corps that can assist in many of the actual facets of urban forestry.

For 15 years, TreePeople has taken the approach that public involvement in urban forestry is a good way to assist traditional resource managers by tackling projects that might otherwise not be attempted. Our success has been based upon the idea that people can make a difference and that they must be involved in solving problems relating to urban pressures upon our resources.

We have attempted to achieve this through a two fold process. First, through our education program, and second, through ongoing citizen involvement in urban and forest planting programs. In the rest of my presentation, I will discuss these approaches and introduce our oak reforestation efforts.

Our education program is run along two main fronts. We reached over 20,000 kids last year alone, through both school assemblies and field trips to our park headquarters and environmental education center. That's 20,000 people that, when they grow up, will have an increased awareness of environmental issues, and be able to support the idea of urban forestry. And that doesn't include their teachers, parents or friends who were exposed to the same ideas. Many of these kids have never been aware of these issues before, but now each of them is a potential asset to the resource manager.

Education is not restricted to children alone. TreePeople has an active "guest speaker" program that covers a variety of topics--from global forestry issues to proper pruning methods. In addition, we conduct training sessions to give volunteers the skills needed to support traditional urban forest managers through our planting and maintenance programs.

Utilizing the media is another way to "educate" the public. We have developed a number of public outreach campaigns, basing them upon resources available in the community rather than spending

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo,California

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large amounts of money to get the point across. This is especially important today in the age of shrinking public budgets and private contributions. If well planned and guided, a campaign thus produced can provide much more exposure than a multi-million dollar advertising campaign, and result in far greater public involvement.

TreePeople's success in these efforts has been based upon the method of using an issue that has a high public awareness factor to focus upon a single problem. Be it destructive brush fires, floods, air quality issues or an Olympic Games, the trick has been to use these highly visible occurrences to garner public support for programs specifically designed to tackle one issue. Let me focus on our largest campaign to date, the Million Tree Campaign. In 1981 TreePeople launched a campaign to inspire the planting of one million trees in the Los Angeles Basin before the start of the 1984 Olympics. The one million figure was based upon a city Planning Department report on the effect on air quality of massive tree planting in urban areas. The report concluded that one million trees, when they were 20 years old, would bring the Los Angeles area to within 80 percent of meeting the Clean Air Act Standard. The City's projected timeline for completion of such a project was 20 years at a cost of $200 million. Our setting a goal of 3 years, with a minimal budget, was viewed as being "impossible"--but it fired the public's imagination.

Using what we found in the community, we created a successful ad campaign that kept the issue before the public for those 3 years. While we ourselves accounted for only some 40,000 trees planted, the seed we planted produced a flood of public interest and support. The people took it upon themselves to help achieve this goal rather than wait for government to do it. By the time the Olympics opened, we had hit the mark. Based on planting confirmation cards, letters and phone calls we received from individuals and agencies, more than one million trees were planted due to this campaign, at a savings to city and county governments of hundreds of millions of dollars.

Recently, our efforts have taken on a new approach. That is to keep the public inspired and involved in urban forestry issues even without the impetus of a major event or cause to organize around. This is taking the shape of an ongoing series of training programs, called "Citizen Foresters," in which we teach people from the community the skills needed to undertake the planting of trees in the urban areas of Los Angeles. By being closer to the needs of their individual communities, these people will be able to work to solve problems or take advantage of opportunities we at TreePeople may not have seen.

Their training consists of three basic parts: (1)how to plant and maintain trees in an urban environment, (2)how to develop plantings and (3)how to serve the community as an informal consultant on matters of urban forestry. The skills they learn include how to deal with the various levels of bureaucracy, site evaluation procedures, proper tree choices, how to organize a planting from start to finish, and where to look for what they need. Most importantly, they serve as a source of information and inspiration to the community, and can deal with the public on a much closer level than we could. By using their assistance, those neighborhoods that might otherwise abandon their plans to plant due to being rebuffed by the city, or being scared off by the amount of work involved, will be able to get their trees. In addition, this program will likely result in a savings to the city as the cost of new trees are borne directly by the community.

This problem of not having a major event or cause to focus public attention upon (in organizing a campaign) has had repercussions in the management of hardwoods, primarily oaks, in the Los Angeles urban area. The pressure upon oaks in this area is primarily from rapidly expanding development. Large oaks continue to fall as new housing moves farther out into prime oak woodland. This pressure has begun to seriously threaten the population of the Valley Oak (Quercus lobata Nee), as the best oak sites are often the most desirable from a development standpoint. Valley Oak regeneration in many parts of Southern California has basically ceased to keep up with the pace of mortality, as much due to removal of land from "circulation" as from any other factor.

The response from the public has been mixed. Education is needed to increase awareness of the threat to local hardwoods, especially the Valley Oak. Some segments of the population have changed their response from apathy to concern. These are people who are either more environmentally attuned or who are more aware of oaks due to having lived with them in their area. Many have become aware as mature oaks maintained in the urban environment after development have begun to decline, or have died as the combined injuries due to soil compaction, paving, smog and excess watering become too severe.

Some organized groups such as the Oak Tree Coalition and the Sierra Club have taken stands against the further removal of oaks. Legislation has been enacted to attempt to protect existing oaks threatened by development, and require their replacement if removed. On some occasions, heavy fines have been levied against those convicted of illegal cutting. As far as ensuring a new generation of oaks however, not much had been done.

Our concern at TreePeople was that the rapid decline in numbers of the mature Valley Oak would threaten the population's ability to regenerate naturally. The efforts of one of our staff members, who was not even directly involved in our forestry programs, led to an attempt to see if artificial regeneration could be used to get seedlings established past the critical 4-5 year period in which many natural trees seem to fail. We contacted the NPS (National Park Service), who manage quite a bit of existing oak habitat as part of the Santa Monica Mountains National Recreation Area.

A site was selected in Cheseboro Canyon, just outside Agoura. The NPS acquired 1,800 acres of former ranch land here in 1982, with a further 300 acres purchased in 1985. The hardwoods located here are fairly clearly distributed according to geologic and topographic factors. Valley Oaks are scattered along the banks of Cheseboro Creek and in pockets of deep alluvium across the valley floor. Coast Live Oaks (Quercus agrifolia Nee) are found mostly on the slopes above the valley floor, especially on the north facing slopes. At the mouth of the canyon, live oaks dominate the drier sites, with scattered California Sycamores (Platanus racemosa Nutt.) found on the pockets of poorest soil. Black Walnut (Juglans californica Wats.) is found in the canyon, but only on areas of weak unstable shales on the north facing slopes.

Valley Oak regeneration was basically nonexistent. Heavy grazing for many years, high rodent populations, roving deer and heavy mustard cover in relatively undisturbed spots all combined to limit seedling success. The site chosen for planting was a wide flat area on the east side of the creek bed. The mature oaks here are widely scattered.

The first planting of 160 seedlings occurred in March of 1985, on part of the land acquired in 1982. There was a fairly heavy herbaceous cover due to the absence of grazing for more than 2 years. It was therefore necessary to scalp each planting location to reduce competition. The trees were placed 50 feet or more from each other and from any existing tree.

To keep costs down, and to ensure good stock, the trees were grown in TreePeople's nursery from acorns gathered in Cheseboro Canyon in the fall of 1984. Damaged, hollow or insect infested seeds were rejected, through inspection and the "float test"--throwing them in a bucket to see if they float. Sound seed was germinated in November by layering in newspaper and/or sphagnum moss, and then planted in quart milk cartons or deep half-gallon pots. Percentage of successful germination for this group was not calculated. We did find that even though the trees spent only 3 or 4 months in the container, the tap root rapidly outgrew whatever space was available. This did not appear to reduce the first year survival, but may have reduced the amount of new growth.

To reduce mortality due to animal damage, each tree was planted in a protective cage. Below the soil surface, a 1/2 inch aviary mesh was used. The wire was formed into a pocket and the tree planted within it. We estimate that this wire will protect the roots from gophers for 2 to 3 years before rusting out. Apparently, galvanization would probably not extend this period much beyond that 3 year figure. Over the planted tree, a 1 inch poultry wire (chicken wire) was used to protect from browsers. This added a cost of slightly more than one dollar per tree, but the effort was successful. While many trees were damaged by browsing, mostly due to wandering cattle pushing over the screens, apparently none were lost over the first season. The upper cages were pinned into the soil using heavy gauge wire formed into a long u-shaped pin. While this worked, a more effective way probably would have been to use rebar. This would have added significantly to the cost.

A second group of 195 trees was planted in March 1986. These were from acorns gathered in the fall of 1985. The procedures used for germination were the same. Germination varied from 60 to 90 plus percent for four groups of acorns from as many sites. These trees were planted in the part of the Cheseboro property acquired in 1985, so cattle had only been off the site for a year. Weed cover was heavier than the other site, probably due to a very wet spring. The planting method used was the same, except that the upper cage was modified somewhat so that the edge could be buried an inch or so below ground surface or held down with rocks. Since cattle were less of a problem in the area than before, this method has sufficed. The value of caging the trees was proven when the National Park Service decided to plant the remainder of the oaks from their nursery without any protection. Within 2 weeks all but a handful of trees had been clipped off, and many of the acorns had been dug out by rodents.

In order to improve chances for survival, the trees were watered when planted and supplemental water has been provided during the driest summer months. While some concern has been voiced over the effect this procedure might have on the drought tolerance and therefore upon the ultimate survival of these trees, it must be remembered that these plantings are primarily demonstrative in nature. In a planting of larger size, where the aim is simply regeneration of an oak stand, supplemental water would most likely be out of the question. TreePeople was able to expend such an effort due to the small planting size and through the use of volunteer labor. Additionally, both planting sites were weeded by the California Conservation Corps during the summer of 1986. All vegetation was cleared in a 3 to 4 foot circle around each tree.

Calculating survival rates has been difficult, as the National Park Service planted trees from their nursery in the 1985 plantation to replace mortality. Survival has been fairly good, however. Even with an extremely hot, dry late summer 1986, roughly 70 percent or more of the trees planted in 1985 were alive in December, 1986. The trees planted in 1986 suffered worse from the dry weather. Many trees that were alive in late summer had died by December. Their root systems were not as developed as those from 1985, and they were not able to survive the lack of any real rain during the 8 months prior to December 1986. Survival for the 1986 group has been about 50-60 percent.

Overall, lack of moisture has been the primary cause of mortality. The ability of a tree to get its roots down to where year round water was available seemed to be a bigger factor than competing herbaceous vegetation. Damage due to browsing animals was fairly high, but seemed to not be a major cause of mortality. Many of the surviving trees have multiple stems, the result of browsing. The tallest trees in both plantings are about 2.5 feet high.

The plantings in Cheseboro Canyon appear to be a success, not only from the standpoint of having ensured a new generation of Valley Oaks in the canyon, but in that all the labor was voluntary. All the tasks involved, from gathering the acorns, to potting the germinated seeds, to planting the trees, were done by TreePeople volunteers. These plantings created a new awareness and concern for the Valley Oak resource that can only help the efforts of National Park's managers, and increase understanding of the problem among the public. As a follow-up to these plantings, TreePeople and the NPS sponsored two walks in the canyon which focused on oaks as well.

TreePeople has shown that involving the public in issues related to urban forest management, in this case the issue of oak management and regeneration, has major advantages to the resource manager. The public becomes better informed, and they begin to view the resource in a different light. A better informed public becomes an asset to the manager, rather than a hindrance. This can be in the manner of support for increased budgets, or as in TreePeople's case, a volunteer force that can assist in achieving projects stymied by lack of funds or other restrictions on the resource manager.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Oak Tree Ordinances[1]

Herbert A. Spitzer[2]

Abstract: For decades, California has been using zoning, ordinances, and forest practice law to control the removal of hardwood tree species. In 1982, Los Angeles County established an Oak Tree Ordinance to control native oak tree removal in all the unincorporated portions of the County. This ordinance is currently being revised. A more comprehensive ordinance based on tree value is being promoted.

Native vegetation has often been indiscriminately removed by development. In California, many cities and counties have found that the only way to curb the often senseless removal of native plants is to enact tree or vegetation ordinances. These ordinances cover such topics as proper construction and maintenance practices, replacement requirements and often set conditions for plant removal.

In the late 1970's, people living in the rural portions of Los Angeles County formed local coalitions to save native oak trees. Through their efforts, oak tree consultants and County personnel, an Oak Tree Ordinance was established in 1982. Its purpose was to recognize oak trees on unincorporated land as significant historical, aesthetic and ecological resources and to create favorable conditions for the preservation and propagation of this plant heritage (Los Angeles County Code, 1982).

CURRENT REQUIREMENTS

The ordinance requires that any person wanting to remove, destroy, relocate or otherwise damage a tree of the oak genus, being eight inches in diameter or more as measured four and one half feet above natural grade, must first obtain an Oak Tree Permit. The application for a permit includes not only ownership information, but also an Oak Tree Report.

The Oak Tree report forms the basis for determining whether a permit will be issued by the Department of Regional Planning. It includes detailed information on the condition, location, species and size of each tree. The proposed development is evaluated for its potential impact upon each tree shown on the site plan. Also, a map of the subject property, drawn to scale showing each oak tree, is submitted in the report. Each tree must be identified by number on the map and in the field by a permanent identification tag. Additional comments such as crown diameter, lean and other factors are often presented, although they are not required.

The Department of Forester and Fire Warden reviews the Oak Tree Report for accuracy and reports their findings to the Department of Regional Planning. They often suggest alternatives to the planned development when such alternatives are not cost prohibitive and a reasonable and an efficient use of the land. All Oak Tree Permits are either approved or denied by the Director of Regional Planning.

[1]Presented at the symposium on "Multiple-Use Management of California's Hardwood Resources" held in California, November 12-14, 1986 at Cal Poly, San Luis Obispo.

[2]Senior Deputy Forester, Forestry Division, East Management Section, Department of Forester; Fire Warden, County of Los Angeles.

PROBLEMS

The portion of the ordinance requiring removed trees to be replaced is ineffective. Replacement trees are being planted, but not maintained for a sufficient period of time to insure their survival.

Additionally, replacement trees are required to be either 5 or 15-gallon in size. They are, therefore, less than eight inches in diameter and not covered by the ordinance. Some developers have removed these small trees as additional areas have been developed.

Developers must replace removed trees on a 2 for 1 or 6 for 1 basis depending upon the replacement tree size regardless of the removed trees condition. A small tree that is in poor health is given the same status as a tree that may have been hundreds of years old, very large, in excellent condition and of exceptional value to the community.

REVISION BEGAN

To bring about a desirable change in the ordinance, it was felt that a basic philosophy change was needed.

Beginning in February of 1986, the Planning and Advisory Committee (PAC) for the Santa Clarita Valley was presented with an alternative to the existing ordinance by the County Forester. It was based on a modified version of the International Society of Arboricultures', "Guide to Establishing the Value of Trees and Shrubs". This guide provides a framework to create an Oak Tree Resource Recovery Fund. The fund would be included as part of an overall plan that would meet the following goals:

1. Favor retention of high quality oak trees;
2. Encourage developers to remove poor or otherwise hazardous trees of little value and retain the better and larger trees;
3. Provide a source of funds for establishment and preservation of the oak genus when development makes it necessary to remove a tree and replacement on site is impractical;
4. Provide an incentive for good tree maintenance; and,
5. Minimize the need for intensive field verification of the Oak Tree Report filed by the Oak Tree Permit applicant.

An additional step would thus be added to the Oak Tree Report. Each tree's value would be determined and become part of the report. This information would then be used to determine whether a financial penalty would be assessed against a developer. This method of appraisal is based on each trees species, size, physical condition and location. It is an unemotional method that will give the tree equal status to man-made improvements. A modified form of this method of appraisal has been successfully used in Cincinnati, Ohio, for street trees (Sandfort & Runch, 1986).

– The basic formula for determining a tree's value is the tree's basic value or the cross sectional area taken at breast height times the current $22 per cross sectional square inch. This is equal to the approximate production cost by nurseries. The resulting figure is then multiplied by the condition, species and location factors which are each reported as a percent of 100 (Neeley, 1979).

The species factor relates the growing conditions, life span and other elements of a particular plant species to its ideal growing conditions. Although oaks are native to Los Angeles County, especially the Coastal Live Oak (Quercus agrifolia), and Valley Oak (Quercus lobata), little or no reproduction is taking place, air quality is poor in comparison to the past and water tables have fallen. These conditions have resulted in increased stress upon native oak trees and set up the conditions ideal for insects and disease. Due to these changes, site quality has been reduced thus the 80 percent minimun rating for the species factor.

The location factor relates the place a plant is growing to the optimum of 100 percent. The highest rating is given for a plant or plants of historical significance while the low end of the scale is applied to wildland plants. The minimum 40 percent figure is a compromise between wildlands and residential growing sites.

As an example, let us assume that an historical 10-inch diameter native oak in excellent condition is to be removed. Its value would be:

Where $22 is the cost of growing a tree per square inch, 78.5 is the number of square inches in a 10-inch diameter tree, 100 percent is the trees condition factor, 80 percent is the species factor and 40 percent is the trees location factor.

Table 1–Oak Tree Resource Recovery Fund Worksheet

1. Net Value of Oak Tree on Property ________________
   (As determined by Oak Tree Report)
2. Value of Trees Rated Less Than 40 pct . . . . . .$________
3. Value to be Managed (line 1-2) . . . .$________
4. Credits:
   A. Value of Oak Trees Retained . . . .$____[1]____
   B. Value of Oak Trees Maintained. . . . .$____[2]____
   C. Value of Oak Trees Planted . . . .$____[3]____
   D. Value of Oak Tree Report . . . .$____[4]____
5. . . . . .TOTAL CREDIT . . . . .$________
6. Subtotal (lines 3-5) . . . .$________
7. Permit Fee Paid. . . . .$____[5]____
8. TOTAL DUE. . . . .$________

[1] Trees rated 40% or higher in condition
[2] Pre-construction (in the past 5 years) and post-construction maintenance on the retained trees (submit receipts)
[3] See Figure 3 – total number
[4] See Figure 4
[5] See Figure 2

Tables 1-4 show an Oak Tree Resource Recovery Fund Worksheet, variable permit fee, credits for oak trees planted and the Oak Tree Report respectively.

Table 2–Permit fees determined by the number of trees involved in the project. Fees based on actual costs to County associated with this ordinance.

	Number of Trees					
	1-3	4-9	10-24	25-99	100-499	500+
Basic Charge	0	25	150	380	875	1,380
Plus	+	+	+	+	+	+
$/Tree	50	35	20	10	5	4

Examples: 20 trees = 150 + (20 x 20) = $550
5 trees = 25 = (5 x 35) = $200

To better understand the recovery fund, the following example of an inventory is provided. The trees shown represent the first 10 trees of a larger inventory composed of 72 trees. This inventory was reported in an Oak Tree Report in 1983 taken in Calabasas.

Tree Number	Diameter (inches)	Condition	Location	Species	Net Value
1.	16	35	40	80	$ 495
2.	30	30	"	"	1,493
3.	36	30	"	"	2,150
4.	18	30	"	"	537
5.	16	15	"	"	212
6.	19	70	"	"	1,397
7.	19	10	"	"	200
8.	35	90	"	"	6,096
9.	16	80	"	"	1,132
10.	21	70	"	"	1,707
				TOTAL =	$15,419

Table 3–Oak Tree Planting Credit for each size tree planted. Developer must insure tree survival for a period of 2 years.

1	5-gallon	Oak	=	$ 30
1	15-gallon	Oak	=	$ 100
1	24" box	Oak	=	$ 350
1	48" box or Larger	Oak	=	$ 1,000

Table 4–Oak Tree Report Credit

	Number of Trees					
	1-3	4-9	10-24	25-99	100-499	500+
Basic Charge	25	75	150	250	470	1,454
Plus	+	+	+	+	+	+
$/Tree	40	20	12	8	6	4.50

Credit = Basic charge plus $/Tree x No. of trees

Example: 50 trees = 250 + (8 x 50) or $650
200 trees = 455 + (200 x 6) or $1,655

With the above information and using the Oak Tree Resource Recovery Fund Worksheet, serveral management alternatives follow with corresponding financial penalties imposed.

Alternative	Management
1	Retain all trees over, or equal to, 60 percent in condition and 20 inches in diameter; no replacement trees and hazard maintenance of the retained trees.
2	Remove all trees; no replacements or maintenance.
3	Retain all trees rated 40 percent or more in condition; no replacement trees and hazard maintenance of those trees retained.

The following completed worksheet is provided for Alternative 1 based on the 10 tree inventory. For Alternatives 2 and 3, a short statement and total is provided:

Alternative 1:

OAK TREE RESOURCE RECOVERY FUND WORKSHEET

1. Net Value of Oak Tree on Property . . . .$ 15,419
   (As determined by Oak Tree Report)
2. Value of Trees Rated Less Than 40 pct. . . . . . .$ 5,087
3. Value to be Managed (line 1-2) . . . .$ 10,332
4. Credits:
   A. Value of Oak Trees Retained . . . .$ 7,803
   B. Value of Oak Trees Maintained. . . . .$ 400
   C. Value of Oak Trees Planted . . . .$ 0
   D. Value of Oak Tree Report . . . .$ 270
5. . . . . .TOTAL CREDIT . . . . .$ 8,473
6. Subtotal (lines 3-5) . . . .$ 1,859
7. Permit Fee Paid. . . . .$ 370
8. TOTAL DUE. . . . .$ 1,489

Only 4 trees will remain following construction. Tree Maintenance cost is estimated.

Alternative 2; Results in a penalty of $9,692. All Trees would be removed in this case.

Alternative 3; Resulted in no penalty. All the better trees were saved or a total of 4 trees.

Although space does not allow for displaying the worksheet of the entire 72-tree report, the results can be shown. The entire property had an oak tree resource valued at $105,457. If the same alternatives were chosen as those used above, the results would be as follows:

Alternative	Financial Penalty
1	$12,330
2	$77,925
3	$ 0

TARGET MET

The five desired goals of the County Forester are met. Trees of high quality are favored for retention over poorer quality trees of lesser value. Funds for tree preservation would be provided from financial penalties imposed upon developers who reduced the value of the resource. Tree maintenance was encouraged both prior to development and after a project completed. Replacement trees must survive for a minimum of two years. Since the authenticity of an Oak Tree Report must be verified in the field, the County Forester would now put more emphasis upon the higher value trees.

CONCLUSIONS

The use of tree value alone will not create the conditions favorable for native plant perpetuation. Only when it is reinforced by sound construction and maintenance practices, such as fencing at the drip line to protect feeder roots and providing conditons that will not set up circumstances that will favor insects and disease (Hunt, 1982), will native species be protected.

The high values that will be generated by this method may cause a developer to relocate or alter a project when cost benefit analysis and engineering alternatives are considered (Standfort & Runck, 1986). Developers will further consider tree value as a component of total land value.

In June, 1986, PAC unanimously passed a recommendation that favored the basic philosophy change presented in this paper. As of the writing of this paper, the ordinance study committee and the County Planning Commission are reviewing PAC's recommendation. From a historical need to perpetuate the species and an aesthetic need to maintain natural surroundings, this management alternative proposes the best solution between the development minded public and preservationists.

REFERENCES

Hunt, R.H. et al. Guideline for Developing Ordinances in Urban Forests. University of California, Cooperative Extension. 1982. 7 p.

Los Angeles County Code (Oak Tree Permits). Seattle, Washington. Book Publishing Company. Part 16; Section 22.56.2050 – 22.56.2260: 1982: 214-228.

Neely, Dr. Dan. Guide to Establishing Values of Trees and Other Plants. International Society of Arboriculture. Urbana, Illinois. 1979. 42 p.

Sandfort, S.; Runck, R. C. III. Trees Need Respect Too. Journal of Arboriculture, Vol. 12: (6) :141-145. 1986 June.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Tree Hazard Assessment Program in San Francisco[1]

Stephen G. Smith[2]

Abstract: In 1982, San Francisco instituted a Tree Assessment Program for the systematic evaluation of the trees in various parks throughout the City. Many of the City's trees were reaching maturity, and their hazard potential had to be determined. The assessor maps the park and gathers 85 pieces of information on each tree that is assessed. A computer generates reports on the age and vigor of the park, as well as a listing of trees in order of their hazard potential. Trees with high hazard control numbers are transferred to the Municipal Arborist for immediate hazard reduction work. Over time, trends can be analyzed regarding the individual park's health, the maintenance requirements of individual tree species, and the need for additional staff for reducing tree hazards or implementing reforestation procedures. The documented tree work and a detailed historical file will be of significant value in reducing litigation costs.

Like it or not, San Francisco is in the hardwood business. As a matter of fact, 31 percent of San Francisco's urban forest is blue gum eucalyptus (McBride 1978). In December 1982, a terrible windstorm blasted down hundreds of eucalypts in one park and killed a gardener. Sigmund Stern Grove became a log deck and 12,000 cu ft of hardwoods were put up for the City's first major log sale.

In response to this catastrophe our fledging Tree Assessment Program became permanent within the Urban Forestry Division of the San Francisco Recreation and Park Department. The department has 3,000 acres of parkland, over 300,000 trees, an annual budget of $50 million and 1,200 employees. The Urban Forestry Division provides system-wide forest services including reforestation, tree pruning and removals, erosion control, insect and disease detection, and habitat enhancement for wildlife.

The Urban Forestry Division is divided into three sections: (1) The Reforestation Section is responsible for the continual replacement of San Francisco's aging forest; (2) the Arboricultural Section is responsible for all tree pruning and removals; and (3) the Tree Assessment Section collects information to assist both divisions.

Golden Gate Park is not monitored or assessed using the individual tree method employed in the other 200 neighborhood parks, squares and golf courses. Golden Gate Park's interior forest is managed on an age rotation (Smith 1980). This forest replacement program methodically removes all old trees over a specific time period and replants. This method of forest replacement keeps the forest healthy and safe but is not practical in a small park with relatively few trees of great esthetic value.

The Hazard Assessment was specifically designed for the Arboricultural Section to use in areas outside Golden Gate Park. Since the late 1970's we were experiencing increasing tree and limb failures in these high use areas. San Francisco's urban (planted) forests are the oldest on the west coast and we, as foresters, must expect failures to increase as trees age. Although all standing trees represent some degree of hazard, some failures are predictable and it is our foremost responsibility to provide a reasonably safe environment for the public and our employees. We also have a legal responsibility; having a professional and systematic assessment process in place can protect the City from claims of negligence. A secondary benefit is that the Assessment system allows us to quantify arboricultural needs and provides us with a mechanism to rationally allocate the arboricultural staff's time. This same mechanism helps us to develop adequate budgets.

The continuous inventory and physiological condition data collected by the assessors is valuable to the Reforestation Section. From the data, they can identify decadent stands and plan for and provide replacement trees before the planted park forests slowly disappear.

Our assessment of a park unit provides us with a site-and tree-specific map. We also gather forest data such as numbers of trees, tree species, forest health, specific hazards and a tree hazard rating. With these in hand, the rest of the Forestry Division, the Park Division (Maintenance, Claims and Planning) and the Fiscal Division can allocate resources to address the park unit's forestry and land use problems.

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[1]Presented at the Symposium on Multiple Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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With over 200 parks covering 3,000 acres, the first step was a simple prioritization of the Parks (or unit) by degree of potential hazard to users. A numerical rating system was developed using three categories:

Each category has an assigned value between 1 and 3, and all three categories are added up for the unit's priority rating, and e.g., a high priority would be 9, a very low priority would be 3.

	Number of large trees
0-10	= 1 point
10-50	= 2 points
Over 50	= 3 points
	Degree of use
Low	= 1 point
Med.	= 2 points
High	= 3 points
	Overall tree condition
Good	= 1 point
Fair	= 2 points
Poor	= 3 points

Every park must have a map, and every tree is accurately placed and numbered. Although this is time consuming, subsequent tree work and forest and park planning are efficiently done with this map making investment.

The actual inventory and assessment phase evaluates each tree over 6 inches in diameter and 20 feet in height. Each tree is marked with a numbered aluminum tag.

Approximately 85 physiological and structural characteristics are examined to determine the hazard potential of each tree.

SCIENTIFIC BASIS

The scientific basis for our final hazard determination for a tree comes from research performed at the Pacific Southwest Forest and Range Experiment Station of the forest Service, U.S. Department of Agriculture, Berkeley, California (Paine 1971, 1978). The guiding philosophy was the assumption that all trees in the vertical position are potentially hazardous. All the physical and structural attributes of the tree distill down to a hazard rating formula made of four components: (1) Probability of Strike [P(s)], (2) Probability of Failure [P(f)], (3) Probability of Damage [P(d)], and (4) Target Value [T.V.].

P(f), Probability of Failure, is the estimate of the trained assessor that the tree or its parts will fail during a predetermined time period. The City's formal reassessment period is 5 years. The assessor estimates the percent chance of failure after examining and noting specific attributes of the tree, the soil, the environment and modified by the assessor's experience with the species.

P(s), Probability of striking a target, if a failure occurs, is the most important aspect to any tree hazard assessment program. There must be a target to qualify a tree as a hazard, i.e., if a tree falls in the middle of the forest - no one cares; but if it falls on your home, you have problems. The probability of strike is the evaluation of probable targets that lay in the path of a potential failure. This is expressed as a percentage. Our parks are used, in many cases, 24 hours a day. The potential to strike a "recreationist" is sometimes difficult to determine.

P(d), damage potential, is based on actual scientific data (Paine 1978). Damage potential is a function of tree form and size. Paine documented over 20,000 actual tree failures and created (Pd) tables based on tree species, diameter and the portion of the tree where the probable failure is expected to occur (roots, lower bole, upper bole, or branches). The University of California (Davis, CA) and the Cooperative Extension Service are collecting data on actual failures and can update these tables.

T.V., Target Value is the value of what would be hit if the tree failed. Our value of a recreationist (person) is $10,000, based on insurance industry payouts nationwide. The current value of a particular type of structure has been determined by our Park Structural Maintenance Division, the Pacific Gas and Electric Company or the Municipal Transit Authority, where applicable.

These four values are multiplied together to project a hazard rating: P(f) x P(s) x P(d) x T.V. = $ Value or Hazard Control Number (HCN). The level of hazard at which we have the resources to take control action, with our existing arboricultural staff and equipment, is a HCN of 200 or higher. If we had more resources, we might be able to lower that HCN to 100. If our budget was cut severely, the HCN might have to be raised to perhaps 500 or more.

TREE INVENTORY DATA SHEET

Our data sheet labeled "Tree Inventory Data Sheet" (fig. 1) is filled out on each assessed tree. The form is in three sections. At the top the tree is identified and located, the crew is identified and the map used is noted.

Immediately below the identification data is the "Condition Class." Here is where we collect physiological data to determine the vigor of a tree. This can be important for us on an individual tree basis or for determining the overall health of a particular forest stand or a species in a stand (or park). This information is important to the Reforestation Section in determining future needs for replacement trees for a particular park.

The bottom half of the form and the majority of the information gathered is labeled "Tree Characteristics." This looks at the tree purely as a structural organism. There are various kinds of physically observable defects that can be noted. Each defect has a standardized method of measurement and rating determination listed in the "Glossary" (training manual) of the "Tree Identification Data Sheet." There are four areas of each tree that are examined for structural defects: roots, lower bole, upper bole and branches. After compiling all observable defects of each area, the assessor determines P(f) and P(s), and then a hazard rating.

Roots

Potential root hazards are particularly important because if roots fail, the whole tree fails. The roots have several important functions: they anchor the tree in the soil, they absorb water and mineral elements from the soil, and they store food in the form of starch. Root defects can adversely affect these functions by weakening the vigor and stability of a tree. We often use vigor and evidence of past stability to evaluate the potential for root failure (since the roots are not visible)! We also include the root crown (2 inches above the soil level) as part of the observable root system. We may even excavate around the roots to carefully evaluate potential rot or loss on a valuable tree.

An example of a potential root defect is a leaning tree. It's possible for a tree to grow in that position, and if so, it could be quite stable. In most cases, a leaning tree has a suspected root problem and one showing more than one movement is highly suspect. With many of the observable defects, using a scale of 1-5 allows the examiner to weigh the defects from highly improbable to imminent potential to fail.

After the root section is completed, the overall potential for the roots to fail is estimated by the assessor and (Ps), P(d) and T.V. are determined.

The Bole of the tree is defined as the stem or trunk of the tree. The bole may extend to the top of the tree, as with conifers (which display an excurrent growth habit) or it may be lost in the ramification of the crown, as in hardwoods (which display a deliquescent growth habit).

Lower Bole

Lower bole is defined as the lower 20 feet of the tree beginning at the root crown. The lower 6 feet is also called the butt. Its function is to support the entire tree and is important in tree evaluation.

Upper Bole

Upper bole is defined as the main stem of the tree from the top of the lower bole to the live crown. The function of the upper bole is to support the main laterals. In deliquescent trees, especially smaller ones, there may not be an upper bole.

Branches

Branches are where most failures occur. A limb fails when a combination of forces exceed the strength of the limb at its weakest point. Those forces include weight of the limb, weight of rain, wind, decay, insects, splits/cracks, branch development and spacing. Other factors to consider are angles of attachment, any atypical development, and the diameter of the limb in relation to trunk diameter.

Insects and Disease determination and problem severity help the Reforestation Section determine the appropriate species to replant.

Control Recommended is the bottom line of the hazard reduction program. The assessor's determination of type of pruning or removal is cross-checked by the arborist supervisor before work is scheduled. Most trees under the HCN of 200 will not be worked on in the first 5-year interval.

All the Tree Inventory Data Sheets for a park are entered into a computer, which produces several kinds of reports:

Age distribution reports can project necessary replacement time.

Vigor reports can pinpoint declining areas or species and spot possible disease infestation sites.

Species distribution reports tell us which species are performing well or poorly, and where they are located.

A report listing trees by descending hazard control numbers (HCN) for a particular park or for the entire city.

A report on the pruning history of a tree/trees in a park or for the city for a year.

The report on the condition of a particular tree species in certain parks is used by the Reforestation Section to determine future park planting needs or to determine the biological life span of a favorite species.

The municipal arborist uses the HCN report to prioritize other job requirements and allocates work crews to the highest hazard areas. Equipment and personnel budgets are justified by specific tree numbers.

The San Francisco Zoo is having many of its trees removed due to hazard. It also has many trees in poor health. With reports in hand and the obvious need of the trees for a windbreak, funding for a zoo reforestation program is easily justified.

Other reports can be developed to address the use of hardwoods in the urban areas. Hardwoods make up one-third of our park forests and nearly 80 percent of our street and parkway landscapes. Easily made reports from our data base could tell:

Which hardwood, city-wide, would be most desirable to plant based on health or hazard.

Which hardwood has the highest potential to fail; by parts, compared with other tree species.

Which hardwood would grow in a particular foggy San Francisco park under an existing eucalyptus stand, on an irrigated soil.

Programming for these reports is "almost" available. This information has a high priority in our system because of the potential liability represented by trees, hardwoods in particular, and their potential loss in the park environment if we don't replace them. Training park horticultural staff to program computers takes time and high motivation on the part of the trainees.

SUMMARY

To sum up the process briefly, a Park unit is assessed, each tree is mapped, evaluated and marked with an aluminum tag, the data is entered into the computer and reports produced, work is completed and reentered into the computer. Every year a nontechnical reassessment takes place. Every 5 years a complete reassessment and inventory is undertaken. Tree failures and predicted potential failures are evaluated and the P(d) table is updated.

Every tree is potentially hazardous unless removed. As professionals we need to make responsible decisions and perform proper control work to enhance our environment with the beauty of trees, yet keep it reasonably safe.

REFERENCES

McBride, Joe R., 1978. The Structure and Condition of Over Mature Forests in Parks and Open Spaces of San Francisco, CA. Berkeley Department of Forestry and Resource Management, University of California; 32p.

Smith, S. G., 1980. Golden Gate Park Forest Management Plan. Sacramento, California Department of Forestry Resources Agency; 158p.

Paine, Lee A., 1971. Accident Hazard; Evaluation and Control Decisions on Forested Recreation Sites. Gen. Tech. Rep. PSW-68. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 10p.

Paine, Lee A., 1979. Coding Hazardous Tree Failures for a Data Management System. Gen. Tech. Rep. PSW-29. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 108p.

TREE INVENTORY DATA SHEET

LOCATION CODE:_______ LOC:_______________________ SPECIES:_______________
TREE NUMBER:_______ MAP NUMBER_______________________ SPECIES CODE:_______________
D.B.H.: ___ STEMS:___ HEIGHT:_______________ ft. CROWN SPREAD: N S E W ft.
CREW:____ ____ ____ AGE CLASS:_______________ DEAD TREE: Y N

CONDITION CLASS

LIVE CROWN RATIO:_____ % RECENTLY PRUNED: Y N PRUNING CODES: ___ ___ ___
CROWN CLASS POINTS:_____ HEAVY FRUITING: Y N
COLOR CLASS POINTS:_____ STAND: Y N
GROWTH CLASS POINTS:_____ - (EST. BY: ____ SHOOT _____ DIAMETER _____ TWIG _____ CALLUS)
REMARKS:____

TREE CHARACTERISTICS

ALTERED STAND STRUCTURE:____

****

ROOTS: ____ % CHANCE OF FAILURE SITE CODES: ____ ____ ____ ____
P(S) PERSON: ____ P(S) PROPERTY: ____

LEAN: ____ ° GREW IN THAT POSITION: Y N MORE THAN ONE MOVEMENT: Y N
DECAY: ____ % CIR. DECAY IN PLANE OF LEAN: Y N
LOSS: ____ % CIR. OTHER DAMAGE:_______________________

MOUNDING/SOIL MOVE: 1 2 3 4 5 0 ROOT DISEASE 1 2 3 4 5 0 PAVEMENT LIFTED: 1 2 3 4 5 0
FILL OR OVERLAY : 1 2 3 4 5 0 PAVED AROUND: Y N GIRDLING ROOTS : 1 2 3 4 5 0
EXCAVATION/EROSION: 1 2 3 4 5 0 OTHER:_______________________

****

LOWER BOLE: ____ % CHANCE OF FAILURE SITE CODES: ____ ____ ____ ____
P(S) PERSON: ____ P(S) PROPERTY: ____

DECAY: ____ % VOL 1 2 3 4 5 0 EXPOSED WOOD: ____ % CIR. LOOSE BARK: ____ % CIR.
CROOK/SWEEP: ____ ° RESIN: 1 2 3 4 5 0 TWIN BOLE/BASAL FORK: 1 2 3 4 5 0
CRACKS/SPLITS: 1 2 3 4 5 0 SEAMS: 1 2 3 4 5 0 CANKER(S) : ____ % CIR.
D.B.H. HAZARDOUS STEM: _____ OTHER:_______________________

****

UPPER BOLE: ____ % CHANCE OF FAILURE SITE CODES: ____ ____ ____ ____
P(S) PERSON: ____ P(S) PROPERTY: ____

DECAY: ____ % CIR. EXPOSED WOOD: ____ % CIR. CANKER(S): ____ % CIR.
CROOK/SWEEP: CRACKS/SPLIT: 1 2 3 4 5 0 TWIN BOLE: 1 2 3 4 5 0
OTHER:____

****

BRANCHES: ____ % CHANCE OF FAILURE SITE CODES: ____ ____ ____ ____
P(S) PERSON: ____ P(S) PROPERTY: ____

FORK/MULTI TOP: 1 2 3 4 5 0 # OF HANGERS/HANGUPS: ____ HANGER HAZARD: 1 2 3 4 5 0
CRACKS/SPLITS: 1 2 3 4 5 0 POOR ANGLE OF ATTACHMENT: $< 15°$ $> 90°$
OBSTRUCTION: 1 2 3 4 5 0 CROWN UNEVEN: 1 2 3 4 5 0 # HEAVY LATERAL LIMBS:____
OTHER:____

****

INSECTS/DISEASE: _____ _____ _____ _____ _____

GENERAL COMMENTS:____

CONTROL RECOMMENDED:_____ _____ _____ _______________________

Figure 1--"Tree Inventory Data Sheet" has three sections. The data at the top of the sheet is for inventory purposes, the next section is for collecting data on vigor, and the bottom is for collecting information on the tree structure.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Value of Oaks in Rural Subdivisions[1]

Richard B. Standiford, Nancy Diamond, Peter C. Passof, and John LeBlanc[2]

Abstract: The relationship between blue oak crown canopy and property value for rural subdivision was investigated. Photographs were taken of blue oak stands with 0, 40, 100, 200, 300, and 460 trees per acre, and a hypothetical property description was prepared. Thirty rural realtors/appraisers were interviewed in Ukiah and Santa Rosa and asked for their estimate of unimproved property values. Bare land values in Ukiah were $5100 per acre, and $24,000 in Santa Rosa. Areas with 40 trees per acre were worth $6500 per acre in Ukiah (a 27 percent increase over bare land), and $29,000 per acre in Santa Rosa (a 21 percent increase over bare land). There was little change in property value between 40 and 460 trees per acre in Ukiah, and a trend of a slight decrease in property value in Santa Rosa as tree density increased. Ranchers who may subdivide their hardwood rangeland should maintain some tree cover. In high density blue oak stands, thinning to 40 trees per acre will not decrease, and may possibly increase property value.

INTRODUCTION

Over the last decade, the hardwood rangelands of California have become subject to increasing pressure to provide housing in rural areas. With many of the prime agricultural and commercial forest sites in the state falling into protective zoning ordinances such as the Williamson Act and Timber Production Zone, counties with rapid population increases have in many cases concentrated new subdivisions in the hardwood range areas. Often, these subdivisions have resulted in varying degrees of tree removal, ranging from complete to selective. Prior to actually subdividing, the landowner may be driven by a number of economic factors to harvest trees on their hardwood rangelands. Economic factors include the increasing demand for oak firewood for home heating and for other biomass products, as well as tree removal to increase forage production for livestock production. Additional harvesting of the tree cover on these lands is often carried out as a part of the construction of residences and supporting road systems once the land has been subdivided. Doak and Stewart (1986) in a recent report have identified large-scale subdivision as a primary reason for a loss in hardwoods rangelands in the state.

Widescale hardwood removal due to subdivision is of concern in the state for a variety of reasons. There is some evidence to suggest that certain species, especially those in the white oak group, are not adequately regenerating, and any removal creates concern about conservation of the species (Muick and Bartoleme, 1986). Trees on the hardwood rangeland areas in the state also have an important aesthetic appeal to the state's residents. Another important amenity value provided by hardwood trees, is food and cover for wildlife species. Hardwoods also provide visual screening, privacy, and protection from the wind for people who establish residences in these rural subdivisions. It is not clear, however, whether these aesthetic and amenity values of trees on these hardwood rangelands are reflected in the market value of subdivided land.

Previous studies have determined that individual trees and stands of trees can increase the market value of a property. Literature on the valuation of individual trees on urban and suburban property includes work by Neely (1979) and Chadwick (1980). A study in Colorado found that trees and groups of trees in Estes Park, Colorado influence property value and that property value was maximized at 120 to 140 healthy trees per acre (Walsh et al, 1981). This study also found that property value at 275 trees per acre was approximately equal to property value for 10 trees per acre if all other site conditions were held equal. Payne (1973) showed photographs of wooded and open land in Amherst, Massachusetts to real estate appraisers and found that trees increased the appraised value of unimproved land in a suburban setting by 27 percent. For half-acre

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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lots with houses, maximum property values were obtained with a tree density of 30 trees per acre. In a later study, Payne and Strom (1975) photographed simulated landscapes of different tree density and spatial arrangements. With a property description and map of an actual site, appraisers in Massachusetts and New Jersey were asked to estimate the market value of lots which were identical in all ways except tree arrangement and density. They found that the presence of trees did increase property value, and that scattered trees were preferred to more concentrated arrangements.

Although it is widely believed that trees on hardwood rangelands, predominantly oaks, follow the same trend observed in these studies and add to the market value of a property, little empirical data has been obtained to support this assertion in California. The objective of this study was to determine the market value which the aesthetic and amenity values of trees on hardwood rangelands contribute to the value of unimproved rural property. This information would help landowners to assess the value of residual hardwood trees in areas where subdivision will be occurring, and assist them in making decisions about tree harvesting.

METHODS

As a preliminary step in asessing the value of trees on hardwood rangelands undergoing subdivision, this study was confined to blue oak (Quercus douglasii Hook and Arn.) woodlands. These areas represent the largest acreage in the hardwood range region in the state. Furthermore, the study was restricted to the Sonoma and Mendocino county region of the state, to minimize the cost of data collection.

In July of 1986, a series of photographs was taken of several blue oak stands at the Briones Regional Park in Contra Costa County. The areas were photographed to make the trees, grass and slope appear consistent in all photographs. Vistas, steep draws, streams and large-crowned "trophy trees" were intentionally avoided. Tree density as the only variation between the five photographs, and included of blue oak stands with 0, 40, 200, 300 and 460 trees per acre. Complete stand data was collected for each photographed area, including the number of trees per acre, percent crown cover, volume per acre, and basal area per acre and is presented in Table 1. A sixth photograph of similar appearance where the blue oak stand had been thinned to approximately 100 trees per acre was added from the collection of Pamela Muick, Department of Forestry and Resource Management at U.C. Berkeley.

A single hypothetical property description was prepared to accompany the six photographs to give unifying assumptions on parcel size, the availability of water and utilities, soils, topography, zoning, access, and several other features. These assumptions were pretested in both the Mendocino and Sonoma county areas, and modified to fit with realistic local conditions for hardwood range subdivision properties. These assumptions are shown below in Table 2.

Table 1. Data from the 5 sample blue oak stands at Briones Regional Park, Contra Costa County, California.

Stand #	Trees per Acre	Basal Area per Acre (sq. ft.)	Volume per Acre (cu. ft.)	Crown Cover (percent)
1	0	0	0	0
2	40	52	2258	20
3	200	206	5590	50
4	300	123	1324	40
5	460	223	3872	70

Table 2. Hypothetical property description data for blue oak rural subdivision acreage in Ukiah and Santa Rosa, California.

CITY: Ukiah and Santa Rosa
COUNTY: Mendocino and Sonoma
LOT SIZE: Ukiah--10-acre unimproved square lot
Santa Rosa-- 3-acre unimproved square lot
ROADS: No on-site roads, faces county road
SEWERS: None
WATER: City water unavailable, Must dig 100' well
ELEC. & GAS: Public utility
TELEPHONE: Service available, None now
STRUCTURES: None
NATURAL FEATURES: No streams present, landscape is blue oak woodland
TOPSOIL: Stable for construction, rangeland suitability, no grapes
SLOPE: Gentle, 5 - 10 %
DRAINAGE: Good EASEMENTS: None
DEED RESTRICTIONS: None
ZONING: Single-family residential, adjacent areas similarly zoned, Property and adjacent areas not in Timber Production Zone or under Williamson Act
ACCESS & TRANSPORTATION: Good access to downtown, shopping, schools (5 miles), no public transportation

In order to ascertain the value of the hypothetical rural subvision properties, 15 individuals including both realtors and appraisers were interviewed in Ukiah and another 15 in Santa Rosa. The selection of interviewees was made in two ways. In the smaller rural area of Ukiah, a list of 30 real estate agents and appraisers was found in the classified section of the telephone directory. The Mendocino Board of Realtors was consulted and indicated that all real estate agents and appraisers listed worked with rural properties. A random selection of 15 was drawn from this population. In the more heavily populated Santa Rosa area, there were approximately 260 realtors and appraisers in the telephone directory. The chair of the Sonoma County Board of Realtors Farm and Land Committee was consulted to determine those realtors specializing in rural acreage sales. A random selection of 15 interviewees was made from this abbreviated list.

Each realtor was interviewed in-person in their office, and were given a brief explanation of the study and its objectives. The interviewees were told to treat each photograph they were shown as a separate piece of property, and to apply the same property description to each area. In this manner, all conditions were presented as the same for each photographed stand with the exception of density of tree cover. They were then handed 8 inch by 10 inch glossy color photographs in a random order. All photographs could be inspected before they were asked to estimate the market value for the entire property. The term "market value" as used in this study refers to the "highest price in terms of money which a property will bring in a competitive and open market under all conditions requisite to a fair sale, the buyer and seller each acting prudently, knowledgeably and assuming the price is not affected by undue stimulus" (Boyce, 1975).

RESULTS

Mean property values were calculated for each stand and expressed on a per acre value for both Ukiah and Santa Rosa. Outlying observations were deleted if they were greater or less than four times the standard error from the mean value for the stand. Tables 3 and 4 below shows the mean market value of the six different stand structures shown in the photographs for Ukiah and Santa Rosa respectively. Figures 1 and 2 show these results graphically. The mean values are bracketed by plus and minus one standard error (SE) of the mean. Bare rangeland value was worth $5100 per acre in Ukiah, and $24,000 per acre in Santa Rosa for an unimproved subdivision lot. In contrast, stands with as few as 40 trees per acre, were worth $6500 per acre in Ukiah, a 27 percent increase over bare land value, and $29,000 per acre in Santa Rosa, a 21 percent increase over bare land value. These property values were significantly different from the bare land value at the 5 percent level.

Referring back to Table 1, and assuming that there are 85 cubic feet of firewood in a cord, then the stand with 40 trees per acre has almost 27 cords of firewood in it. If a landowner who saw an opportunity for subdivision were to clear the blue oak trees prior to selling the subdivision acreage, then they would be giving up $1400 per acre in the more rural Ukiah area, and $5000 per acre in the more densely populated Santa Rosa area. This means that the sale of firewood would have to generate a stumpage value (standing tree value net of harvesting, processing and transportation costs) of $52 per cord in Ukiah, and $185 per cord in Santa Rosa. Both of these are well above the reported statewide average stumpage value for hardwood firewood of $15 per cord (State Board of Equalization, 1986). Thus, it appears that the market value for the amenities associated with the blue oak trees on hardwood rangelands exceeds the value which can realistically be obtained for firewood stumpage at this time.

Table 3 shows that for the more rural Ukiah location, that there was no statistically significant difference in the per acre property value between 40 and 460 trees per acre. Table 4 also shows no significant difference in property value in the Santa Rosa location between 40 and 460 trees per acre. However, a trend of decreasing property value can be seen in the Santa Rosa location as oak density increases from 40 to 460 trees per acre ($29,000 per acre at 40 trees per acre, versus $26,300 per acre at 460 trees per acre). Further study is needed to see if this trend holds up. However, it can be hypothesized that with the smaller parcel size in the more urbanized Santa Rosa setting (3 acres versus 10 acres for the Ukiah sample), dense tree cover actually represents an increased cost to subdivision. On these smaller parcels, there would

Table 3. Mean property value per acre for 10 acre lots of unimproved blue oak stands, 5 miles outside of Ukiah, California.

# Trees per Acre	$ per Acre
0	$5118 b
40	$6514 a
100	$6255 a
200	$6573 a
300	$6482 a
460	$6395 a

Note: Means followed with different letters are significantly different at the .05 level using Duncan's Multiple Range Test.

Table 4. Mean property value per acre for 10 acre lots of unimproved blue oak stands, 5 miles outside of Santa Rosa, California.

# Trees per Acre	$ per Acre
0	$23,820 b
40	$29,097 a
100	$26,972 ab
200	$27,445 a
300	$26,639 ab
460	$26,333 ab

Note: Means followed with different letters are significantly different at the .05 level using Duncan's Multiple Range Test.

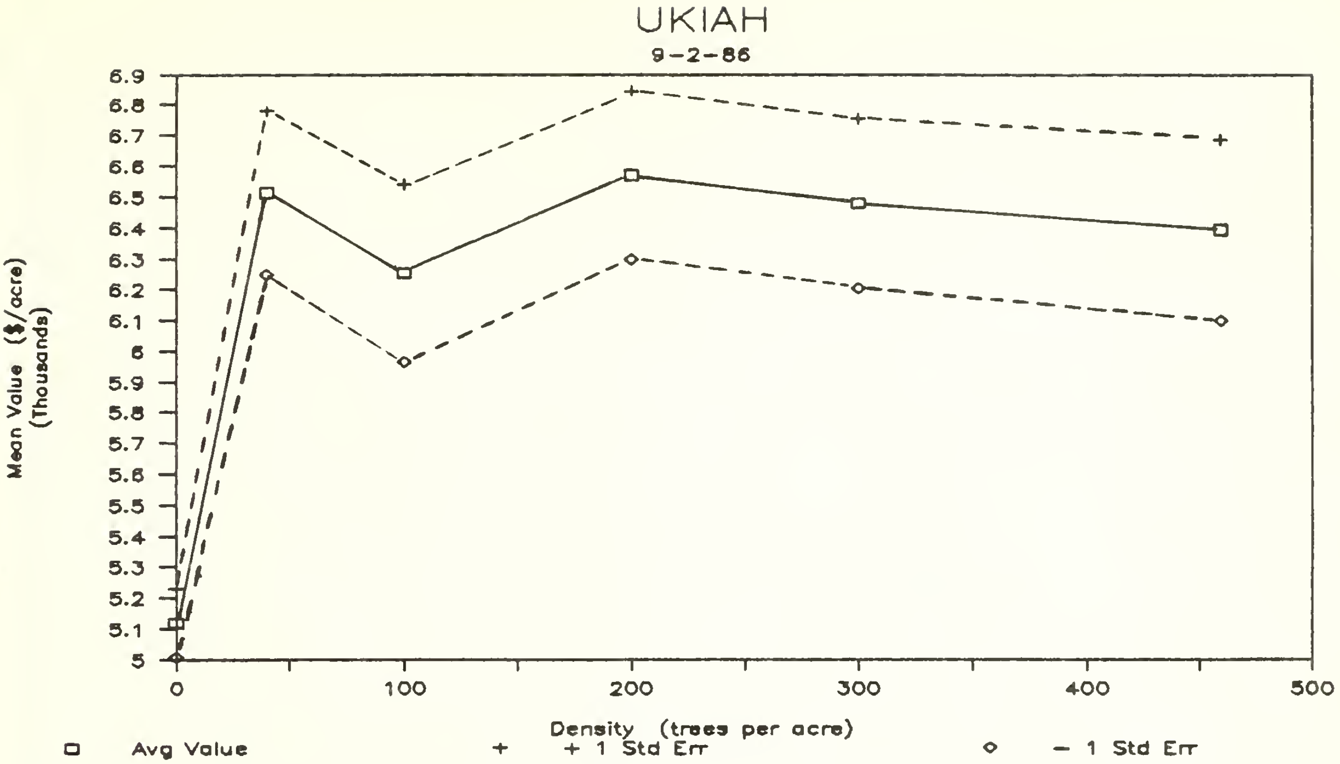

Figure 1--Property value per acre for 10 acre lots of unimproved blue oak stands 5 miles outside Ukiah, California for different trees per acre.

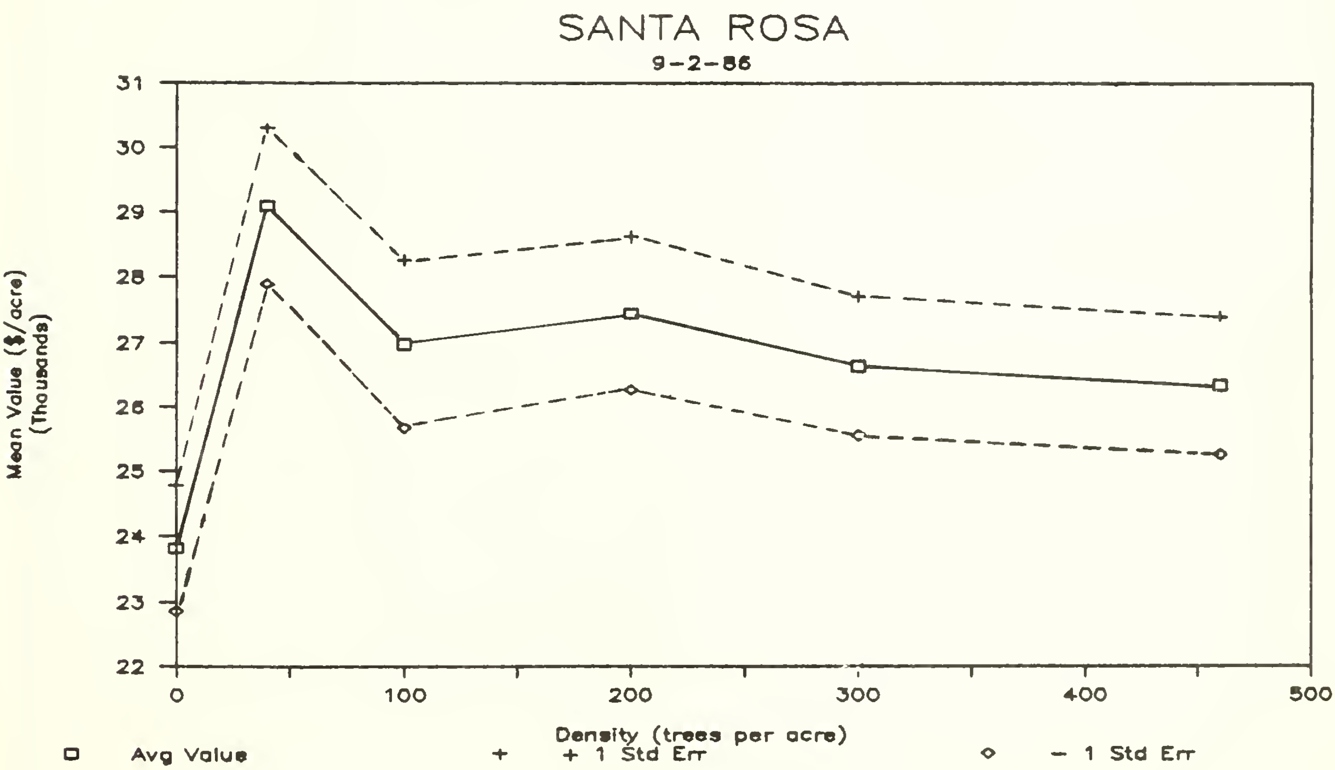

Figure 2--Property values per acre for 3 acre lots of unimproved blue oak stands 5 miles outside Santa Rosa, California for different trees per acre.

actually be less room to place a home on the subdivision acreage and hence, property values would be expected to decrease at high tree densities.

DISCUSSION

This study was an initial attempt to quantify the value of oaks on hardwood rangelands where rural subdivision will be occurring. The results suggest that landowners who are interested in receiving the maximum value for parcels they sell, should not clear all the oaks prior to subdivision. The aesthetic and amenity values from 40 blue oak stems per acre contributed a 21 to 27 percent increase in land value when compared to acreage with no trees present. The lack of a statistical difference in property value between 40 and 460 stems per acre suggests that a landowner could very likely selectively thin their stand and not decrease, and possibly increase property value for subdivision.

This study needs to be expanded to include other areas of the state where subdivision pressure in hardwood rangelands poses serious concerns about loss of hardwood species. However, these preliminary results do suggest that an understanding of market values for hardwoods by landowners may provide adequate protection of the hardwood cover in the event of subdivision. Maintenance of a hardwood tree cover alone does not ensure that other concerns about subdivision will be alleviated, such as the impact on wildlife species. Nonetheless, attention to spatial arrangement of subdivision lots and minimum lot size by county planning departments working with wildlife biologists, coupled with market driven values for oak stands in rural subdivisions, can help to minimize future concerns.

LITERATURE CITED

Boyce, B.N. Real estate appraisal terminology. Cambridge, MA: Ballinger Publishing Co; 1975. 137 p.

Chadwick, L.C. Review of guide for establishing values of trees and other plants. Journal of Arboriculture 6(2):48-50; 1980

Colorado State Forest Service/Colorado State University. n.d. Dollars and sense about your trees. Colorado State Forest Service. 17 p.

Doak, S; Stewart, W. A model of economic forces affecting California's hardwood resource: monitoring and policy implications. Berkeley, CA: U.C. Dept. of Forestry and Res. Mgt. Report Submitted to California Department of Forestry; 1986; 148 p.

Muick; Bartolome. Statewide oak regeneration survey. Berkeley, CA: University of California; 1986.

Neely, D. Guide for establishing values of trees and other plants. Urbala, IL: International Society of Arboriculture; 1979.

Payne, B.R. The twenty-nine tree home improvement plan. Natural History 82(9):74-75; 1973.

Payne, B.R; Strom, S. The contribution of trees to the appraised value of unimproved residential land. ASA Valuation (Oct.-Nov.):36-45; 1975.

State Board of Equilization. Timber harvest value schedule. Sacramento, CA: State Board of Equalization; 1986; 26 p.

Walsh, R.G; Keleta, G; Olienyk, J.P; Waples, E.O. Appraised market value of trees on residential property with mountain pine beetle and spruce budworm damage in the Colorado front range. Fort Collins, CO: Department of Economics, Colorado State University (Unpublished Report); 1981; 87 p.

Wildlife

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

The Importance of Hardwood Habitats for Wildlife in California[1]

Jared Verner[2]

Recent analyses of the variety of wildlife species that find optimum or suitable conditions for breeding in different habitat types in California show that hardwood types rank among the most important in the State. For example, Ohmann and Mayer (1987) report that more terrestrial vertebrate species in California breed in conifer and hardwood habitats than in any other types. These two general habitat types support breeding by approximately equal numbers of amphibians, reptiles, and mammals, but the hardwood types have more breeding birds than any other general habitat. Similarly, Verner (in press) showed that "oak woodlands rank among the top three habitat types in the number of bird species for which they provide primary breeding habitat." In a recent search of the Statewide file on Wildlife-Habitat Relationships managed by the California Department of Fish and Game, Mayer (1986) found that 13 species--1 amphibian, 4 mammals, and 8 birds--find conditions suitable for reproduction only in hardwood-dominated ecosystems, including riparian types. These patterns are even more significant when combined with the fact that approximately 20 percent of California's land base supports hardwoods.

Given the knowledge of the need for hardwood habitats by wildlife, one must wonder why the critical needs of wildlife species using these habitats have been so little studied. For example, what are specific dependencies of most species of wildlife on hardwoods? Many species consume mast when available, and many nest in cavities in the trees, but would these species be threatened by the loss of the hardwoods? Managers have no reasonable guidelines for retention of hardwoods for most wildlife species, in terms of tree size or age, basal area, canopy cover, or dispersion. And what are normal, annual fluctuations in abundance for any terrestrial vertebrate that breeds regularly in hardwood habitats in California?

The following are among the more critical research needs: (1) standardized methods for studying the habitat relationships of wildlife, particularly for distinguishing among habitat use, preference, and need; (2) implementation of standardized monitoring programs to measure trends in wildlife populations; (3) better Habitat Suitability Index (HSI) models as used in the Habitat Evaluation Procedures (U.S. Dept. Int., Fish and Wildlife Serv. 1980), including verification for specific localities; (4) more accurate Wildlife-Habitat Relationships (WHR) models of the sort used by the USDA Forest Service (Verner and Boss 1980); (5) better models of plant succession for predicting changes in plant species composition over time; and (6) an understanding of the effects of habitat fragmentation on wildlife species, particularly the mosaic of different habitat types as embodied in the new and growing discipline of landscape ecology (e.g., Picket and White 1985).

This section of the proceedings on wildlife will not go far in answering the needs identified above, but it will provide some direction. In addition, several studies currently underway promise, within the next 5 years, major advances in understanding of several aspects of the habitat relationships of wildlife in hardwoods. Finally, I see additional reason for optimism in the growing awareness among managers of the need to include wildlife considerations when planning for the future of California's hardwood resources.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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REFERENCES

U.S. Department of the Interior, Fish and Wildlife Service. Habitat evaluation procedures (HEP). Ecological Services Manual 102. Washington, DC: Division of Ecological Services; 1980. 84 p.

Mayer, Kenneth E. Wildlife and Range Ecologist, California Department of Forestry, Sacramento. [Personal conversation]. 19 September 1986.

Ohmann, Janet L.; Mayer, Kenneth E. Wildlife habitats of California's hardwood forests--linking extensive inventory data with habitat models. 1987 [These proceedings].

Pickett, S. T. A.; White, P. S. The ecology of natural disturbance and patch dynamics. New York: Academic Press; 1985. 472 p.

Verner, Jared; Boss, Allan S., tech. coords. California wildlife and their habitats: western Sierra Nevada. Gen. Tech. Rep. PSW-37. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 439 p.

Verner, Jared. In press. Significance of oak woodlands in maintaining the richness of California' avifauna. In: Brown, Stacy; Bowler, Peter A., eds. Proceedings of the California Oak Heritage Conservation Conference, 1983 March 11-12; Irvine, CA.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Conceptual Framework and Ecological Considerations for the Study of Birds in Oak Woodlands[1]

William M. Block and Michael L. Morrison[2]

Abstract: The distributions and abundances of birds within oak woodland communities of California are the results of geologic events leading to the formation of the Mediterranean-type ecosystem, and of more recent anthropogenic impacts that have altered the landscape. These human-wrought disturbances to oak woodlands likely are affecting population parameters and distributions of birds throughout California. Because little is known of bird-habitat relationships in oak communities, however, the actual effects of these land-use practices on birds are unknown. Here we present a framework for the study of birds in the oak woodlands of California. The principal objective of this framework is to outline aspects of bird biology, ecology and behavior that must be addressed before assessments of habitat quality can be made. Assessments of habitat quality require that population numbers, reproduction rates, and survival rates be monitored. Further, bird habitats must be studied to determine site characteristics of areas that birds actually use within oak woodlands. Determination of specific patterns of resource use entails intensive study of bird activities. Collection of all of these data requires extensive field work to determine temporal and spatial patterns of habitat and resource use. There are no shortcuts for obtaining this information.

The distributions, abundances, and habitat-use patterns of birds in oak habitats are influenced by numerous factors. Avian settlement patterns and processes of speciation can be traced to the Tertiary and Quaternary periods. During these periods climatic changes, mountain building, and glaciation resulted in the present distributions of hardwoods throughout the state of California, which have in turn strongly influenced the distributions of birds (Hubbard 1973, Axelrod 1977). Proximate and ultimate factors, biotic and abiotic processes, temporal and spatial patterns, and various innate and learned behaviors interacted to shape the patterns of habitat use evident in modern species. Recent anthropogenic pressures have reshaped the landscape and have altered the environments available to birds. These changes have most likely altered the historic habitat-use patterns of birds.

Unfortunately, little is known of bird-habitat relationships in oak woodlands. Early naturalists (e.g., Grinnell and Miller 1944, Leopold 1951, Miller 1951) provided valuable species accounts based on their observations. The information presented by these naturalists was generally in the form of qualitative descriptions of species' distributions and habitat associations. These data are of insufficient detail, however, to allow resource managers to assess habitat quality or to predict the effects of environmental change on bird population parameters. Further, Muick and Bartolome (1985) found few recent studies of bird-habitat relationships in oak woodlands. Consequently, a research program is required to study bird-habitat relationships in oak woodlands that provides information in sufficient detail to allow assessments of habitat quality and predictions of the effects of habitat change on birds.

The purpose of this paper is to present a general framework for the study of birds in oak woodlands. Our primary objective is to outline aspects of bird biology and ecology that researchers must study to provide the baseline information required by managers to determine habitat quality for birds. We begin this framework by suggesting a scenario to describe distributional patterns of birds within oak woodlands. We use the discussion as a basis for explaining ecological and behavioral relationships of birds to their environments, and we conclude by presenting a methodology for the study of birds in oak woodlands.

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DISTRIBUTIONAL PATTERNS

Geologic Evolution of Oak Woodland Ecosystems

The evolution of the contemporary Mediterranean ecosystem and associated oak woodlands consisted of an ever-changing environment that enabled biotic speciation to occur. Changing climatic conditions during the Tertiary, and periods of extensive glaciation and mountain building during the Quaternary, strongly influenced patterns of extinction and speciation of both plant and animal life. Axelrod (1973, 1977) developed a theory for the evolution of oak communities based on paleobotanical evidence. That theory suggested that oak diversity decreased as the geographic range of oaks constricted with time from the Miocene through the Pleistocene. Axelrod's theory appears to be consistent with those of avian speciation presented by Rand (1948), Selander (1965), Mengel (1970), and Hubbard (1973). Changing landscapes during the Tertiary and Quaternary periods likely resulted in varying environmental conditions (e.g., temperature, moisture) for different species of birds. As the total area occupied by oaks decreased with time, less habitat was available for many birds. Further, decreases in floristic and structural diversity probably led to a decrease in bird species diversity. Previous studies (MacArthur and MacArthur 1961, Cody 1974, Tomoff 1974) demonstrated that bird species diversity was positively associated with structural vegetative diversity. Others (Robinson and Holmes 1984, Rotenberry 1985) noted that many birds appeared to selectively use plant species. Consequently, as plant species diversity decreased with time, a concomitant decrease in bird species diversity likely occurred.

These influences and the selective processes of isolation and restricted gene flow during Pleistocene periods of glaciation were largely responsible for extinctions and speciations of birds (Rand 1948, Selander 1965, Hubbard 1973, Diamond 1984). Selander (1965) noted that about 30 percent of the species that occurred during the Pleistocene are now extinct. Although most of the evolutionary processes leading to existing taxa of birds probably occurred during the Miocene and Pliocene (Wetmore 1951), evolution during the Pleistocene continued to differentiate species on subspecific and semi-specific levels (Rand 1948, Selander 1965). Hubbard (1973) traced speciation within the genera *Pipilo* (towhees), *Toxostoma* (thrashers), *Callipepla* (quail), and others as having occurred during the glacial periods of the Pleistocene. He further postulated that many of the species that arose during the Pleistocene had a tendency towards sedentariness. Given this limited motility, these species may be the ones least likely to escape the effects of environmental change.

Human Impact on Oak Woodlands

The evolution of oak-woodland communities occurred over millions of years. More recently, humans have exerted artificial, selective forces that have further altered distributional patterns of oaks. Prior to European settlement, aborigines burned the understory of oak woodlands. These periodic burns influenced the population structure of oaks, and consequently the structure and floristic composition of the stands (Jepson 1910, Rossi 1980). Since European settlement of western North America, changes to oak communities by humans have been more dramatic. Early Spanish settlers cleared expanses of oaks for livestock and agriculture. Increased grazing pressures with the introduction of domestic livestock probably further altered the population structure of oak stands because of the consumption of acorns and seedlings by sheep and cattle. The introduction of livestock also indirectly changed the composition of the understory as many exotic annual grasses displaced natural perennials. Recent fire-suppression programs have allowed conifers to displace oaks as Bonnicksen and Stone (1982) noted for the Sierra Nevada. Bartolome (pers. commun.) speculated that oaks in California are becoming less diverse and proportionally more sclerophyllous owing to historical grazing and cutting practices. He attributed this trend to the tendency of live oaks to sprout after being cut, and to the resistance of live oaks to browsing. In contrast, many of the white oaks [e.g., valley oak (*Quercus lobata*), blue oak (*Q. douglasii*), and Engelmann oak (*Q. engelmannii*)] are not regenerating well, and seedlings and saplings are more heavily impacted by browsing. Thus, the trend described by Bartolome has led to a decrease in white oak populations whereas live oak populations have remained relatively stable.

The cumulative impact of these disturbances has resulted in younger, smaller stands with altered age structures and species compositions. The effects of such large-scale habitat modifications on birds are not well known. However, birds that require extensive stands of large trees or birds that rely on blue, valley or Engelmann oak might be affected adversely by these changes in age and stand structure. Consequently, it is imperative that a protocol be established for the study of birds in oak woodlands. Only through detailed study of these relationships will there be sufficient information to assess environmental impacts on the avifauna of the California oaks and to develop methods to retard or mitigate these losses if judged unacceptable.

STUDY OF ECOLOGICAL RELATIONSHIPS OF BIRDS

Before questions regarding the effects of oak management practices on birds can be addressed, it is necessary to understand the basic biologies, ecologies, and behaviors of birds found in oak woodlands. Whether or not a bird "selects" a given habitat is attributable to a number of proximate and ultimate factors (Hildén 1965, Cody 1985). Proximate factors are cues that induce a bird to settle in a certain area. Examples of proximate factors are song posts, nest sites, and the composition and structure of vegetation. Ultimate factors are those that provide conditions for reproduction and survival. As such, ultimate factors are adaptations resulting from the processes of natural selection. Thus, the study of bird-habitat relationships in oak woodlands is essentially the study of proximate and ultimate factors that allow birds to settle, reproduce, and survive within oak habitats.

Because habitat selection by birds is largely behavioral (Morse 1980), investigators often take indirect approaches to discern patterns of habitat and resource use. These approaches include monitoring population parameters, characteristics of bird habitats, and resource abundances. Measures of population parameters are required to understand the viability of species in relation to habitat conditions (Van Horne 1983). Detailed quantitative descriptions of macro- and microhabitats of species are needed by resource managers to determine habitat quality (Capen 1981). It is also necessary to measure resource abundance--in particular prey abundance--and relate these measures to bird population parameters to more fully understand the extrinsic factors that regulate bird distributions and abundances. We detail below parameters that should be included in the study of birds in oak woodlands.

Study Areas

In our discussion we present examples from the Tejon Ranch, Kern County, California and Blodgett Forest Research Station (University of California, Berkeley), El Dorado County, California. The Tejon Ranch is a 100,000-ha corporate landholding in the Tehachapi Mountains. Approximately 35,000 ha of the Ranch are oak woodlands dominated by blue oak, valley oak, and California black oak (*Quercus kelloggii*), with lesser amounts of canyon live oak (*Q. chrysolepis*), interior live oak (*Q. wizlisneii*), and Brewer's oak (*Q. garryana* var. *brewerii*). The Ranch is managed for multiple uses including livestock production, firewood cutting, and game hunting. Cutting of oaks is restricted to selected stands of blue, valley, and black oaks, leaving large areas of the Ranch uncut. Elevation on the Ranch ranges from 1,000 to 1,700 m, and aspects include all directions. Because of the variety of land-use practices that occur on the Ranch, it provides an excellent opportunity for study of the effects of oak removal and livestock grazing on bird habitat.

Blodgett Forest Research Station is located in the central Sierra Nevada at an elevation of 1300 m. Vegetation of the forest is characteristic of mixed-conifer forests of the Sierra Nevada, and is dominated by white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), incense-cedar (*Calocedrus decurrens*), and California black oak. Tanoak (*Lithocarpus densiflorus*), Pacific madrone (*Arbutus menziesii*), and golden chinquapin (*Castanopsis chysophylla*) are major hardwood components of the subcanopy. The 1,200-ha forest is divided into compartments 5-35 ha in size. Compartments have been subjected to various forest management practices. Thus, Blodgett affords an opportunity to study the use of hardwoods by birds within a managed mixed-conifer forest.

Methods

Monitoring Populations

Although monitoring population parameters of species is time- and labor-intensive, these data are integral to understanding bird-habitat relationships in oak woodlands. Commonly, only species abundances are measured by researchers. Van Horne (1983) discussed the shortcomings of this approach and showed that population abundance alone may be an inadequate measure of habitat quality. Whether or not a habitat is suitable for a species depends largely on the species' ability to survive and/or reproduce there. Thus a population-monitoring program should not only be directed at estimating abundances, but it should also attempt to estimate rates of survival and reproduction.

Numerous techniques are used to measure the numbers of birds (Ralph and Scott 1981, Verner 1985). No technique, however, has been shown to yield accurate estimates of bird numbers, as all techniques contain inherent biases. Counting birds can provide measures of absolute abundance or indexes of relative abundance. We will not review the advantages and disadvantages of the various techniques because these have been reviewed amply elsewhere (Ralph and Scott 1981, Verner 1985, Verner and Ritter 1985). It is important to note, however, that the choice of counting technique depends on several factors and should not be haphazard. Further, comparisons of abundances using most methods should be restricted to the same species, location, and season (J. Verner, pers. commun.).

We used the variable-radius circular plot method (Reynolds and others 1980, Verner and Ritter 1985) to estimate numbers of birds at the Tejon Ranch. Eighty points were placed at 300-m intervals using a systematic-random sampling design. We chose 300-m intervals to ensure sampling independence among points. Censusing was done by only one observer to remove observer differences. The observer remained at the point for 5 min and recorded all birds detected by sight or sound. Counts were replicated at each point three times. Censuses were done between 05:30 and 09:30 from 29 May to 24 June 1986. We used a Fourier series estimator from the computer program TRANSECT to calculate density estimates (Laake and others 1979). We calculated densities only for species for which we accumulated >40 detections. Density estimates ranged from 4.8/40 ha (Nuttall's woodpecker), to 47.2/40 ha (plain titmouse) (table 1). Coefficients of variation ranged from 3.8 percent (acorn woodpecker) to 20.9 percent (northern flicker) (table 1). Although we cannot evaluate the accuracy of these density estimates, the shapes of the probability density functions met the shape criterion of Burnham and others (1980), and the coefficients of variation for most of the density estimates were less than 20 percent, suggesting that the estimates were within ranges of precision generally accepted by wildlife biologists.

Estimates of bird numbers generally have been restricted to the breeding season under the assumption that the breeding season is the most important in a bird's life history. The breeding season is not the only time of the year when oaks are used by birds, however. Many species are year-long residents, and others may use an area during nonbreeding periods as short-term migrants or as wintering birds. If birds change their patterns of resource use, then studies restricted to the summer may not detect shifts in some critical aspects of resource use. Consequently, use of oaks by nonbreeding birds might be as important for their ultimate survival as the oaks are for the survival of breeding birds. Lack (1954) and Wiens (1977) noted that the nonbreeding season might be the most critical period of a bird's annual cycle. Consequently, it is critical that bird numbers are monitored throughout the year and not only during the breeding season.

As an example of the temporal variation in avifaunal composition, we recorded the species present in the oak woodlands of the Tejon Ranch from 14 to 20 April 1986 and from 18 May to 20 June 1986. Although there was extensive overlap of the species present during both periods, we recorded 13 species during April that were not present during May and June, and 9 species detected during May and June were not detected during April (table 1). Most of the species detected only during April were probably migrants (with exception of California condor) which used Tejon Ranch woodlands as foraging and resting sites. The species detected in May-June but not during April were probably late-arriving breeding birds. Thus, if surveys or censuses were restricted to only one of these periods, many species would have gone undetected. These data are only preliminary, but they serve as examples of the dilemma faced by resource managers attempting to construct bird-habitat models: different sets of species use a particular area during different seasons. Further, if habitat-use patterns by birds change over time, then changes to the environment might differentially affect the species present during different times. An increasing body of literature indicates that different tree species are differentially preferred by birds based on the season (Travis 1977, Conner 1980, Hutto 1981, Morrison and others 1985). In New Hampshire, for example, Kilham (1970) showed that in winter downy woodpeckers (<u>Picoides pubescens</u>) were attracted to birches (<u>Betula papyifera</u>) that were infested with a scale insect. Therefore, managers must provide adequate habitat for a variety of situations.

Many studies of bird populations are restricted to estimating densities during a single year. Wiens (1981), however, cautioned against single-sample surveys because the numbers estimated during any one year may not be representative of long-term population trends. Fretwell and Lucus (1970) and Van Horne (1983) noted that once the preferred habitat of a species becomes saturated, the surplus population will occupy marginal habitats. Theoretically, the relative densities of the species in marginal habitats may exceed the numbers found in superior habitats, leading to erroneous conclusions if population densities alone are used to index habitat quality. A more appropriate method for monitoring habitat quality must include estimates of reproduction and survival rates for species found in the oak woodlands, as well as numbers. Further, the monitoring program should occur over a timeframe encompassing temporal variations in population parameters in response to various biotic and abiotic factors.

Study of Habitats

Descriptions of bird habitats are central to the study of birds in oak woodlands. The study of habitats involves two major steps. The first step is to associate birds with macrohabitats such as blue-oak savanna or canyon-live-oak woodlands. These general associations have been provided by early naturalists (e.g., Grinnell and Miller 1944, Leopold 1951, Miller 1951); Verner (1980) summarized regional associations. These descriptions provide useful summaries and serve to narrow the range of possible hardwood communities where a species might be found. Much of the information provided by these naturalists is used to construct models of wildlife-habitat relationships. These wildlife-habitat models are matrices that qualitatively rate the suitability of various seral stages of common vegetation types for selected species of wildlife. Because these models are based mostly on general descriptions, many existing models of wildlife-habitat relationship have been found to be inaccurate when tested with empirical data (Dedon and others 1986). Further, the descriptions of habitats and distributions provided by these models are only very general in nature. For instance, a blue oak stand may exhibit certain structural or floristic characteristics that are used disproportionately

Table 1. Species of birds present within the oak woodlands of the Tejon Ranch during the 1986 breeding season. Estimates of the densities (#/40 ha) given for common species.

Species	Presence Status[1]	Density[2] n	D	pct CV
California condor (*Gymnogyps californianus*)	1			
Cooper's hawk (*Accipiter cooperii*)	3			
Red-tailed hawk (*Buteo jamaicensis*)	3	45	7.7	18.5
Golden eagle (*Aquila chrysaetos*)	3			
American kestrel (*Falco sparverius*)	3	9		
California quail (*Callipepla californica*)	3	38		
Mountain quail (*Oreortyx pictus*)	3	10		
Band-tailed pigeon (*Columba fasciata*)	3			
Mourning dove (*Zenaida macroura*)	3	263	20.1	7.5
Western screech owl (*Otus kennicottii*)	3			
Great-horned owl (*Bubo virginianus*)	3			
Northern Pygmy-owl (*Glaucidium gnoma*)	3	1		
Long-eared owl (*Asio otus*)	3	1		
Anna's hummingbird (*Calypte anna*)	3	26		
Acorn woodpecker (*Melanerpes formicivorus*)	3	1120	39.6	3.8
Lewis' woodpecker (*Melanerpes lewis*)	1			
Nuttall's woodpecker (*Picoides nuttallii*)	3	55	4.8	15.3
Hairy woodpecker (*Picoides villosus*)	2	4		
Northern flicker (*Colaptes auratus*)	3	49	11.7	20.9
Olive-sided flycatcher (*Contopus borealis*)	2	1		
Western wood-peewee (*Contopus sordidulus*)	2	111	13.8	10.3
Dusky flycatcher (*Empidonax oberholseri*)	1			
Black phoebe (*Sayornis nigricans*)	2			
Say's phoebe (*Sayornis saya*)	1			
Ash-throated flycatcher (*Myiarchus cinerascens*)	3	244	30.3	11.0
Western kingbird (*Tyrannus verticalis*)	3	11		
Purple marten (*Progne subis*)	2	1		
Violet-green swallow (*Tachycineta thalassina*)	3	226	33.6	8.6
Stellar's jay (*Cyanocitta cristata*)	3			

Table 1. Continued.

Species	Presence Status[1]	Density[2] n	D	pct CV
Scrub jay (*Aphelocoma coerulescens*)	3	195	22.4	11.4
Common raven (*Corvus corax*)	3	5		
Plain titmouse (*Parus inornatus*)	3	346	47.2	8.6
Bushtit (*Psaltriparus minimus*)	3	5		
White-breasted nuthatch (*Sitta carolinensis*)	3	174	28.0	8.3
Brown creeper (*Certhia americana*)	2	1		
Bewick's wren (*Thryomanes bewickii*)	1			
House wren (*Troglodytes aedon*)	3	348	44.2	8.3
Blue-gray gnatcatcher (*Polioptila caerulea*)	3	8		
Western bluebird (*Sialia mexicana*)	3	34		
American robin (*Turdus migratorius*)	3	25		
Phainopepla (*Phainopepla nitens*)	2	1		
Loggerhead shrike (*Lanius ludovicianus*)	1			
European starling (*Sturnus vulgaris*)	3	46	18.5	19.1
Hutton's vireo (*Vireo huttoni*)	1			
Warbling vireo (*Vireo gilvus*)	1			
Yellow-rumped warbler (*Dendroica coronata*)	3	3		
Townsend's warbler (*Dendroica townsendi*)	1			
Hermit warbler (*Dendroica occidentalis*)	1			
Western tanager (*Piranga ludoviciana*)	2	1		
Black-headed grosbeak (*Pheucticus melanocephalus*)	3	130	19.9	13.6
Rufous-sided towhee (*Pipilo erythrophthalmus*)	3	7		
Brown towhee (*Pipilo fuscus*)	3	99	24.7	14.9
Chipping sparrow (*Spizella passerina*)	3	10		
Lark sparrow (*Chondestes grammacus*)	3	2		
Golden-crowned sparrow (*Zonotrichia atricapilla*)	1			
White-crowned sparrow (*Zonotrichia leucophrys*)	1			
Dark-eyed junco (*Junco hyemalis*)	3	1		
Red-winged blackbird (*Agelarus phoenueus*)	3	5		

Table 1. Continued.

Species	Presence Status[1]	Density[2] n	D	pct CV
Western meadowlark (*Sturnella neglecta*)	3	22		
Brewer's blackbird (*Euphagus cyanocephalus*)	3	11		
Brown-headed cowbird (*Molothrus ater*)	3	8		
Northern oriole (*Icterus galbula*)	3	221	35.1	8.2
Purple finch (*Carpodacus purpureus*)	1			
House finch (*Carpodacus mexicanus*)	3	76	15.8	15.5
Lesser goldfinch (*Carduelis psaltria*)	3			
Lawrence's goldfinch (*Carduelis lawrencei*)	2	147	27.7	18.0

[1] 1-detected only between 14 and 20 April; 2-detected only between 18 May and 20 June; 3-detected both between 14-20 April period and 18 May-20 June.

[2] n = number of detections; D = density (#/40 ha) estimates; pct CV = percent coefficient of variation. All densities calculated using Fourier series estimator from the computer program TRANSECT.

by a species. Thus it is instructive to examine in more detail aspects of the areas a species actually uses (i.e., microhabitat) within the macrohabitat where it is found. Microhabitat includes the size and shape of leaves, branches, bark, and other subtle features of the vegetation present in the macrohabitat. These features vary with the size and age of the tree, for example. Thus, the density--or even mere presence--of a bird may be related not only to the plant species present, but their size, shape, and vigor. The failure of existing wildlife-habitat models to incorporate these fine-scaled aspects of species' microhabitats may be one reason why the models perform poorly.

Two primary techniques are used to describe the microhabitats of species. One method correlates the abundance of a species to combinations of physiognomic and floristic characteristics. This method entails estimating relative or absolute numbers of a species at a set of fixed census points and correlating these abundances to physiognomic and floristic characteristics measured at the points. Morrison and others (1987) used stepwise multiple regression (Draper and Smith 1981) to relate relative abundances of species to habitat characteristics. They used fixed-radius circular plots to obtain indexes of relative abundance, and measured habitat characteristics within the radius of the census plot. Thus, if a species is strongly associated with certain habitat features and those features are measured by the investigator, this method is potentially effective. Other investigators use variable-radius circular plots to census birds. However, the area over which these birds are recorded can be greater than the area within a fixed-radius plot, and thus may contain greater habitat heterogeneity. Thus using regression techniques to discern relationships between a species and habitat components might yield weaker associations than using fixed-radius plots because the species might not be closely associated with the location where the habitat measurements were taken.

An alternative method of quantifying habitats is to center habitat plots at the locations where birds are found. Larson and Bock (1986) found that organism-centered plots provided better descriptions of a species' habitat than using the regression techniques described above. There could be little question as to whether or not the bird was associated with the habitat, because by definition habitat is where the organism is found. There is a risk, however, that only the more conspicuous members of a population will be sampled by this method. This effect might be lessened if the observer moves slowly through the area, using care not to disrupt bird activity patterns. Separate plots could be centered at locations used for perching, singing, foraging or nesting. Collins (1981) showed that the characteristics of areas used by a species for different purposes (e.g., nest sites vs. perch sites) may differ. The strength of this type of analysis is that an investigator could more accurately predict habitat components of areas used for specific functions by a species.

Measuring habitat plots can be accomplished in many different ways. Considerations include plot shape and size, and the techniques used to measure them. James and Shugart [1970; see also James (1971)] presented a methodology commonly used in eastern deciduous forests; this was refined by Noon (1981). Whether or not the James and Shugart method is appropriate for western oak woodlands is unknown. Plot size can vary with the habitat and the activity range of the species studied. The objective of plot size is to include a representative sample of the variation found within the habitat of a species. James and Shugart's (1971) plots were 0.04 ha in size, whereas Gutiérrez (1980) found that 0.02 ha plots were sufficient for describing mountain quail habitat in the sclerophyllous oak woodlands of the central California Coast Range. Morrison and Meslow (1983) used 0.01-ha plots to describe the habitats of brush-inhabiting birds in clearcut Douglas-fir habitats of the Oregon Coast Range.

Plot size will likely vary with the species studied and with the type of vegetation present. Pilot studies should be done to determine appropriate plot sizes for different birds and vegetation types.

The choice of habitat characteristics to be measured and the techniques used to measure them are integral to describing the habitat of a species. An investigator must have some prior knowledge of the biology and habitat-use patterns of the bird. James (1971) used the term "niche gestalt" to refer to how an organism perceived the environment, but a more appropriate explanation of this concept is that the "niche gestalt" is how an investigator perceives the species' environment. The closer the investigator's gestalt is in accord with how the organism perceives the environment, the more accurate the description of the habitat. Unfortunately, data on the biology and "niche gestalt" of many species are lacking; thus the investigator must rely on her or his field expertise to determine which components of the environment should be studied. Various techniques are used to quantify these habitat characteristics. These techniques range from ocular estimates to rather meticulous and often labor-intensive measurements. Each technique contains certain inherent biases and different techniques vary with regards to accuracy. Block and others (in press) compared habitat measurements with ocular estimates of the same characteristics and found that measurements provided more accurate estimates with greater precision than ocular estimates. Moreover, measurements tended to vary less among observers than did estimates. Consequently, actual measurements would be expected to yield a more accurate estimate of a species' niche gestalt than values obtained by estimation (i.e., "guessing").

Study of Bird Activity Patterns

To understand the modes of resource use by birds in greater detail, it is useful to measure activities of birds (Holmes 1981). Quantifying foraging activity has been the object of many studies. From a theoretical standpoint, this seems appropriate because food availability is generally acknowledged as a key factor in whether a bird survives and/or reproduces. In a more practical sense, foraging involves a large proportion of a bird's activity time, thus making it easier for an observer to obtain adequate numbers of samples. This does not negate the importance of other aspects of bird activity, since most bird activity is likely adaptive and certainly merits study. Studies should be flexible and designed to collect data measuring all aspects of bird behavior. Unfortunately, the costs of a study to determine all aspects of bird activity probably exceed the budgets of most projects, because adequate samples for many bird activities are precluded by the infrequency or secrecy of the activity.

Birds forage throughout the year, although the prey and methods used to capture prey vary across both time and space. Spatial and temporal variations might be attributed to differences in the phenologies of vegetation and of the prey available to birds. Consequently, studies should sample behavior across a range of conditions and times. The types of information that should be collected include general characteristics of the plant or object where foraging occurred, details of the perch and foraging substrates, and the foraging maneuver. These types of data provide detailed information about modes of resource use by species. Further, the patterns of microhabitat use by birds can be used by resource managers to determine how even fine-scale habitat alterations will affect selected species.

We observed activity locations and foraging behaviors of birds at the Tejon Ranch from 15 May to 20 June 1986. A bird was observed from 10-30 sec while foraging. We recorded the characteristics of the tree (when applicable) where the bird foraged (species, height, diameter, and vigor of the tree), characteristics of the foraging and perch substrates, and the foraging maneuver. Simple analyses of these data suggested that some birds used certain tree species with greater frequency than others (table 2). For example, northern orioles were observed using valley oak with greater frequency than other oak species, whereas Nuttall's woodpeckers, plain titmice, and white-breasted nuthatches used blue oak with greater frequency (table 2). In contrast, black-headed grosbeaks rarely were observed foraging on oaks and appeared to use California buckeye (*Aesculus californicus*) more frequently than any other foraging substrate (table 2).

The use of oaks and other hardwoods by birds is not restricted to oak woodlands. We used the same general methods as those used at the Tejon Ranch to study activity patterns of birds found in the mixed-conifer habitats of Blodgett Forest. All species studied used California black oaks for part of their foraging activities, with the Nashville warbler making heavy use of oak (table 3). The red-breasted sapsucker, pileated woodpecker, solitary vireo, warbling vireo, and black-headed grosbeak used hardwood species for at least 20 percent of their foraging activities; the Nashville warbler did so for almost 50 percent of its activities. Thus, alteration of the hardwood resource in the mixed-conifer zone may affect adversely some or all of these species.

Intensive observations of bird activities are therefore critical to understanding actual modes of habitat use by species. These data allow managers to more specifically assess tree species and substrate preferences by the birds. For example, a species might use a plant species in

Table 2. Relative frequency (percent) of use of foraging substrates by birds within oak woodlands at the Tejon Ranch, Kern County, California during the 1986 breeding season.

Species	n	Blue oak	Valley oak	California black oak	Canyon live oak	Interior live oak	California buckeye	Other plants	Ground	Air
Nuttall's woodpecker	39	61.9	17.9	5.3	5.3	5.3	5.3			
Acorn woodpecker	22	18.2	31.8	18.2	4.5		4.5			22.7
White-breasted nuthatch	57	56.1	26.3	8.8	7.0	3.5		1.8	1.8	
Plain titmouse	81	57.3	9.7	4.9	2.4	9.8	7.3	3.7	4.9	
House Wren	22	13.6	31.8	4.5				13.6	37.5	
Ash-throated flycatcher	23	21.7	21.7			4.3		4.3	17.4	30.4
Black-headed grosbeak	29		13.7		6.9	10.3	31.0	17.2	13.7	6.9
Northern oriole	46	11.4	50.0	13.6	4.5	6.8	11.4		11.4	

Table 3. Tree species used (pct) by foraging birds at Blodgett Forest Research Station, El Dorado County, California during spring-summer 1983-85[1].

Species	N[2]	Black oak	Tan oak	Other hardwood[3]	Coniferous[4]
Red-breasted sapsucker (*Sphyrapicus ruber*)	91	15	1	7	76
Hairy woodpecker	89	14	0	3	81
Pileated woodpecker (*Dryocopus pileatus*)	48	23	0	1	76
Dusky flycatcher	45	16	4	5	72
Mountain chickadee (*Parus gambeli*)	62	8	3	2	87
Chestnut-backed chickadee (*P. rufescens*)	129	13	0	1	84
Brown creeper	124	10	2	-	86
Red-breasted nuthatch (*Sitta canadensis*)	126	14	0	1	84
Solitary vireo (*Vireo solitarius*)	79	23	0	1	77
Warbling vireo	50	26	0	6	68
Nashville warbler (*Vermivora ruficapilla*)	98	38	1	8	48
Yellow-rumped warbler	84	11	1	2	84
Black-headed grosbeak	86	19	0	7	71

[1]Percentages do not total 100 percent because not all foraging substrates are given.

[2]Number of individuals observed; sexes combined.

[3]Primarily madrone, chiquapin, and white alder (*Alnus rhombifolia*).

[4]Douglas-fir, white fir, incense cedar, and ponderosa and sugar pine.

much greater frequency than it occurs in the macrohabitat. Detailed observations may indicate, however, that the bird concentrates foraging activities on stems of a certain size or exhibiting a certain vigor (e.g., live, dying, dead). These types of data are critical for the formulation of species-specific management plans, as they indicate the species and relative vigor of trees and substrates used by birds.

CONCLUSIONS

The study of birds within any habitat requires first a conceptual understanding of the processes that influenced their distributions, and second, intensive field research to determine viability and patterns of resource use of the species. Much research is restricted to a single season or within a particular site. Although this approach provides useful information, the results of such study may be valid only for the place and time the data were collected. More extensive data are required to determine year-round patterns of habitat and resource use by birds. There are no shortcuts for obtaining the information.

Determining population parameters, habitat quality, and resource-use patterns of species are both time- and labor-intensive. These data are essential for the development of species-specific models to assess habitat quality and to predict the effects of various land-use practices on the viability of oak woodland birds. These models must be based on empirical field data that include characteristics of the habitat thought to be critical to the survival of the species. Once developed, these models must be scrutinized to determine their temporal and spatial applications through rigorous testing and refinement. Only through such integrated study of avian-habitat-resource relationships will researchers begin to understand the processes that underlie bird distributions and abundances, and to provide managers a basis from which positive management approaches can be advanced.

Acknowledgments: We thank Donald Geivet and Russell Mohr for providing access and logistical assistance at the Tejon Ranch. Robert Heald and the staff of Blodgett Forest helped facilitate study there. Reviews by Martin G. Raphael, William Laudenslayer, and Jared Verner improved this paper. Special thanks to Lorraine Merkle for technical assistance.

References

Axelrod, Daniel I. History of the Mediterranean ecosystem in California. In: di Castri, Francesco; Mooney, Harold A., eds. Mediterranean type ecosystems: origin and structure. New York: Springer-Verlag; 1973:225-277.

Axelrod, Daniel I. Outline history of California vegetation. In: Barbour, Michael G.; Major, Jack, eds. Terrestrial vegetation of California. New York: John Wiley & Sons; 1977:139-193.

Block, William M.; With, Kimberly A.; Morrison, Michael L. On measuring bird habitat: influence of observer variability and sample size. Condor, in press.

Bonnicksen, Thomas M.; Stone, Edward C. Reconstruction of a presettlement giant sequoia-mixed conifer forest community using the aggregation approach. Ecology 63(4):1134-1148; 1982.

Burnham, Kenneth P.; Anderson, David R.; Laake, Jeffrey L. Estimation of density from line transect sampling of biological populations. Wildl. Monogr. 72:1-202; 1980.

Capen, David E., ed. The use of multivariate statistics in studies of wildlife habitat. Gen. Tech. Rep. RM-87. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1981. 241 p.

Cody, Martin L. Competition and the structure of bird communities. Princeton, NJ: Princeton Univ. Press; 1974. 318 p.

Cody, Martin L., ed. Habitat selection in birds. New York: Academic Press; 1985. 558 p.

Collins, Scott L. A comparison of nest-site and perch-site vegetation structure for seven species of warbler. Wilson Bull. 93(4):542-547; 1981.

Conner, Richard N. Foraging habitats of woodpeckers in southwestern Virginia. J. Field Ornithol. 51(2):119-127; 1980.

Dedon, Mark F.; Laymon, Stephen A.; Barrett, Reginald H. Evaluating models of wildlife-habitat relationships of birds in black oak and mixed-conifer habitats. In: Verner, Jared; Morrison, Michael L.; Ralph, C. John, eds. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. Madison, WI: Univ. of Wisconsin Press, 1986;115-119.

Diamond, Jared M. "Normal" extinctions of isolated populations. In: Nitecki, Matthew H., ed. Extinctions. Chicago, IL: Univ. of Chicago Press; 1984:191-246.

Draper, Norman; Smith, Harry. Applied regression analysis. 2nd ed. New York: John Wiley and Sons; 1981. 709 p.

Fretwell, Stephen D.; Lucas, H. L. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. Acta Biotheoretica 19(1):16-36; 1970.

Grinnell, Joseph; Miller, Alden H. The distribution of the birds of California. Pacific Coast Avifauna 27; 1944. 608 p.

Gutiérrez, R. J. Comparative ecology of mountain and California quails in the Carmel Valley, California. Living Bird 18:73-91; 1980.

Hildén, Olavi. Habitat selection in birds: a review. Ann. Zool. Fenn. 2(1):53-75; 1965.

Holmes, Richard T. Theoretical aspects of habitat use by birds. In: Capen, David E., ed. The use of multivariate statistics in studies of wildlife habitat. Gen. Tech. Rep. RM-87. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1981:33-37.

Hubbard, John P. Avian evolution in the aridlands of North America. Living Bird 12:155-196; 1973.

Hutto, Richard L. Seasonal variation in the foraging behavior of some migratory western wood warblers. Auk 98(4):765-777; 1981.

James, Frances C. Ordinations of habitat relationships among breeding birds. Wilson Bull. 83(3):215-236; 1971.

James, Frances C.; Shugart, Herman H. Jr. A quantitative method of habitat description. Audubon Field Notes 24:727-736; 1970.

Jepson, Willis L. The silva of California. Berkeley, CA: Univ. of California Press; 1910. 480 p.

Kilham, Lawrence. Feeding behavior of downy woodpeckers. I. Preferences for paper birches and sexual differences. Auk 87(3):544-556; 1970.

Laake, Jeffrey L.; Burnham, Kenneth P.; Anderson, David R. User's manual for the program TRANSECT. Logan, UT: Utah State University Press; 1979. 26 p.

Lack, David. The natural regulation of animal numbers. Oxford; 1954. 343 p.

Larson, Diane L.; Bock, Carl E. Determining avian habitat preference by bird-centered vegetation sampling. In: Verner, Jared; Morrison, Michael L.; Ralph, C. John, eds. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. Madison, WI: Univ. of Wisconsin Press; 1986:37-43.

Leopold, A. Starker. Wildlife of Mexico. Berkeley, CA: Univ. of Calif. Press; 1951. 608 p.

MacArthur, Robert H.; MacArthur, John W. On bird species diversity. Ecology 42(3):594-598; 1961.

Mengel, Robert M. The North American central plains as an isolating agent in bird speciation. In: Dort, W., Jr.; Jones, J. K., Jr., eds. Pleistocene and recent environments of the central Great Plains. Lawrence, KS: University of Kansas Press; 1970:279-340.

Miller, Alden H. An analysis of the distribution of the birds of California. Univ. of Calif. Publ. in Zool. 50:531-644; 1951.

Morrison, Michael L.; Meslow, E. Charles. Bird community structure and early growth clearcuts in western Oregon. Am. Midland Nat. 111(1):129-137; 1983.

Morrison, Michael L.; Timossi, Irene C.; With, Kimberly A.; Manley, Patricia N. Use of tree species by forest birds during winter and summer. J. Wildl. Manage. 49(4):1098-1102; 1985.

Morrison, Michael L., Timossi, Irene C.; With, Kimberly A. Development and testing of linear regression models predicting bird-habitat relationships. J. Wildl. Manage. 51(1):247-253; 1987.

Morse, Douglas H. Behavioral mechanisms in ecology. Cambridge, MS: Harvard University Press; 1980. 383 p.

Muick, Pamela C.; Bartolome, James W. Research studies in California related to oaks. Wildland Research Center Report No. 7. Berkeley, CA: Div. of Agric. and Nat. Resources, University of California; 1985. 37 p.

Noon, Barry R. Techniques for sampling avian habitats. In: Capen, David E., ed. The use of multivariate statistics in studies of wildlife habitat. Gen. Tech. Rep. RM-87. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1981:42-52.

Ralph, C. John, Scott, J. Michael, eds. Estimating numbers of terrestrial birds. Studies in Avian Biol. 6; 1981. 630 p.

Rand, A. L. Glaciation, an isolating factor in speciation. Evolution 2(4):314-321; 1948.

Reynolds, Richard T.; Scott, J. Michael; Nussbaum, Ronald A. A variable circular-plot method for estimating bird numbers. Condor 82(3):309-313; 1980.

Robinson, Scott K.; Holmes, Richard T. Effects of plant species and foliage structure on foraging behavior of forest birds. Auk 101(4):672-684; 1984.

Rossi, Randall S. History of cultural influences on the distribution and reproduction of oaks in California. In: Plumb, Timothy R., tech. coord. Proceedings, Ecology, management, and utilization of California oaks; 1979 June 26-28, Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station. Forest Service, U.S. Department of Agriculture; 1980:7-18.

Rotenberry, John T. The role of habitat in avian community composition: physiognomy or floristics? Oecologia 67(2):213-217; 1985.

Selander, Robert K. Avian speciation in the Quaternary. In: Wright H. E., Jr.; Frey, David G., eds. The Quaternary of the United States. Princeton, NJ: Princeton Univ. Press; 1965:527-542.

Tomoff, Carl S. Avian species diversity in desert scrub. Ecology 55(2):396-403; 1974.

Travis, Joseph. Seasonal foraging in a downy woodpecker population. Condor 79(3):371-375; 1977.

Van Horne, Beatrice. Density as a misleading indicator of habitat quality. J. Wildl. Manage. 47(4):893-901; 1983.

Verner, Jared. Birds of California oak habitats--management implications. In: Plumb, Timothy R., tech. coord. Proceedings, Ecology, management, and utilization of California oaks; 1979 June 26-28, Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station. Forest Service, U.S. Department of Agriculture; 1980:246-264.

Verner, Jared. Assessment of counting techniques. In: Johnston, Richard F., ed. Current ornithology. Volume 2. New York: Plenum Press; 1985;247-302.

Verner, Jared; Ritter, Lyman V. A comparison of transects and point counts in oak-pine woodlands of California. Condor 87(1):47-68; 1985.

Wetmore, A. Recent additions to our knowledge of prehistoric birds, 1933-1949. X Intern. Ornith. Congr.; 1951:51-74.

Wiens, John A. On competition and variable environments. Am. Scientist 65(5):588-597; 1977.

Wiens, John A. Single-sample surveys of communities: Are the revealed patterns real? Am. Nat. 117(1):90-98; 1981.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Wildlife Habitats of California's Hardwood Forests—Linking Extensive Inventory Data With Habitat Models[1]

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Abstract: An approach for inventorying and assessing California's wildlife habitats is presented. It links data from an extensive, sample-based inventory with models developed by the California Wildlife Habitat Relationships Program to assess current and future habitat capability. Over 300 wildlife species find hardwood habitats optimum or suitable for reproduction. The approach to habitat evaluations is demonstrated for two of these species. In California, hardwood-dominated habitats occupy 7,170,000 acres (2,868,000 ha) of forest lands outside National Forests, parks, and wildernesses. Most of the area (89 percent) is privately owned. Eighty three percent of the hardwood area occurs on woodlands; 17 percent is on timberland. Most of the area of hardwood habitats (81 percent) consists of stands in the pole/small tree size class. The area is almost equally divided between stands of sparse and dense canopy closure.

BACKGROUND AND INFORMATION NEEDS

Interest in California's hardwoods has grown markedly over the past few years, witnessed by the recent increase in oak-related research (Muick and Bartolome 1985), the formation of a Hardwood Task Force by the California Board of Forestry, and the holding of symposia such as this. The importance of hardwoods to wildlife is one of the major hardwood-related issues that has emerged.

California's tremendous ecological diversity offers many opportunites for wildlife; about 600 terrestrial vertebrates are native to the State (Laudenslayer and Grenfell 1983). The data base of current knowledge about these species, compiled by the California Wildlife Habitat Relationships Program (WHR),[3] indicates that more than half of the wildlife species find hardwood-dominated habitats optimum or suitable for reproduction--more than any other broad vegetation type. Of the six broad vegetation types, hardwoods rank third in numbers of wildlife species that depend solely on that type for habitat for reproduction (table 1).

In the last two decades, concerns for wildlife have been addressed to a greater degree in allocating natural resources, developing land use plans, and formulating forest regulations. Nevertheless, forest planners and policymakers have been limited in their ability to account for wildlife in their decisions by the lack of basic information about the resource, and by the lack of analytical tools. To date, no statewide inventory or assessment of California's wildlife habitats has been conducted. State- and regional-level planning for wildlife requires current data on the extent and characteristics of vegetation--primary determinants of habitat conditions on forest land. Models for translating these data into information on wildlife habitat and populations are also needed.

These ingredients of a habitat assessment have recently become available. However, producing a statewide assessment is an enormous and complex task presenting unique challenges. Information must be provided for a great diversity of vegetation types and wildlife species, in a format that is useful for meeting a variety of planning and management objectives. The various State and Federal agencies entrusted with managing California's wildlife are concerned with maintaining species diversity and exploitable populations of commercial and game species. In this paper we introduce a strategy for broad-scale assessment of California's wildlife habitats. Using the State's hardwood habitats as a case study, we demonstrate how State- or regional-level information for wildlife planning can be developed. Our approach is based on the assumption that qualitative habitat assessments, based on level-one models of wildlife-habitat relationships (Nelson and Salwasser 1982, Mayer 1983), are acceptable for broad-scale planning. Level-one models provide data for wildlife species that indicate relative suitability of a habitat for reproduction, foraging, and cover. Models of this level of resolution cannot be used to predict actual animal abundance. In demonstrating our approach, we also provide useful information for addressing some of the current issues related to California's hardwood habitats.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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[3]California wildlife-habitat relationships data base--1986, on file with the California Department of Fish and Game, Sacramento, California.

Table 1--Number of wildlife species using broad vegetation types for reproduction

Broad vegetation type and wildlife species group	Type provides optimum or suitable habitat	Type is only source of optimum or suitable habitat
	Number of species	
Hardwood-dominated		
Herpetofauna	58	1
Birds	168	12
Mammals	105	7
All species	331	20
Conifer-dominated		
Herpetofauna	55	1
Birds	148	13
Mammals	108	4
All species	311	18
Shrub-dominated		
Herpetofauna	62	0
Birds	85	5
Mammals	102	6
All species	249	11
Desert types		
Herpetofauna	58	8
Birds	98	15
Mammals	74	8
All species	230	31
Wetland types		
Herpetofauna	27	6
Birds	89	30
Mammals	53	1
All species	169	37
Grassland types		
Herpetofauna	32	0
Birds	56	5
Mammals	77	5
All species	165	10

AN APPROACH FOR ASSESSING CALIFORNIA'S WILDLIFE HABITATS

The Approach

The challenge of assessing California's forest and rangeland resources has recently brought together departments of two resource agencies: the Forest and Rangeland Resources Assessment Program (FRRAP) of the California Department of Forestry, and the Forest Inventory and Analysis Research Unit (FIA) of the USDA Forest Service, Pacific Northwest Research Station. These two groups have cooperated for more than 6 years to complete a statewide assessment of the State's forest and rangeland resources. An evaluation of the effects of land management and ownership change on wildlife is part of this assessment.

We met this challenge by developing an approach for assessing wildlife habitat that links data from FIA's statewide, sample-based inventory of forest lands with models developed as part of the California WHR Program. We first classify each FIA field plot according to the type of vegetation (i.e. wildlife habitat) present. Plot data are then expanded using FIA's double sample design to estimate area by wildlife habitat in various regions of the State (fig. 1). Finally, using models of wildlife-habitat relationships available in the WHR data base, we translate the area estimates into information on current availability of suitable habitat for selected wildlife species. By projecting future forest conditions, we can also evaluate future habitat capability under alternative scenarios of land ownership, use, and management.

The California Wildlife Habitat Relationships Program--a Source of Analytical Models

The WHR Program in California was initiated by the USDA Forest Service and the California Department of Fish and Game, in cooperation with the California Interagency Wildlife Task Group. A primary goal of the Program is to provide users a credible and more efficient mechanism for evaluating the consequences of land management

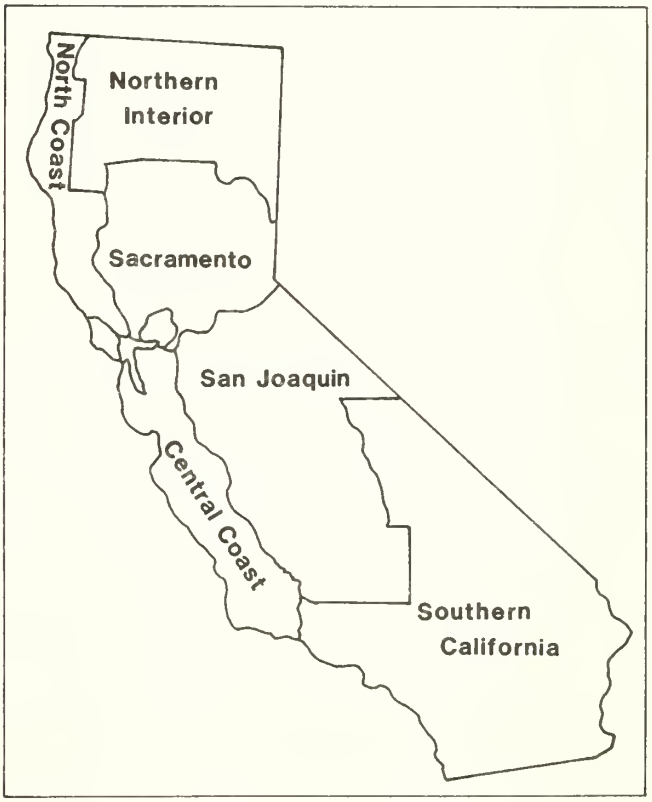

Figure 1--Resource areas in California

alternatives on wildlife. Another Program goal is to improve standardization and uniformity in habitat inventory, classification, and evaluation through increased communication and coordination among agencies and individuals (Grenfell and others 1982).

The core of the WHR Program is a systematically organized, computer-accessible data base of current knowledge about the life history characteristics of more than 600 terrestrial vertebrates, and about the relative capability of different environments to support them. Two features of the data base make it well suited to using data from an extensive inventory such as FIA's: it applies to a wide geographic area and a broad array of wildlife species, and it uses a single, uniform habitat classification system.

The FIA Inventory--a Source of Habitat Data

The concept of using data gathered from a sample-based inventory to assess habitat conditions over extensive areas is relatively new. The FIA inventory, in fact, offers several advantages as a framework for such an effort: (1) an established grid of permanent plots across all lands except National Forests, parks, and wildernesses; (2) an existing land classification system in use across the United States; (3) a design that provides confidence intervals for estimated variables; (4) periodic measurement data; and (5) multiresource data from the same sample plots, providing capability for assessing resource interactions. While early inventory efforts by FIA concentrated on timber resources, several changes to the inventory design were made for the recent survey of California. For the first time, tree and stand measurements were taken in the State's extensive oak woodlands (Bolsinger in press; McKay 1987). In addition, new procedures were incorporated for collecting the kinds of information important for evaluating wildlife habitat (Ohmann 1983).

The FIA sample design and data are discussed in detail in another paper in these proceedings (McKay 1987). Briefly, the sample design approximates Cochran's (1977) double sampling for stratification. The primary sample consists of a systematic grid of about 80,000 randomized photo points, with an average interval of 0.85 miles (1.37 km). During photo interpretation, each point was classified by broad ownership class, land class[4] (timberland, other forest, or nonforest), and other attributes.

The secondary sample consists of every 16th photo point, with a grid interval of 3.4 miles (5.4 km). At each grid point in timberland, field crews established or remeasured a permanent inventory plot consisting of five sample points distributed over about 5 acres (2 ha), and recorded detailed site and vegetation data. In other forest, which includes the hardwood woodlands, ground plots were established at every other grid point (about 6.8 miles (10.8 km) apart). Each timberland plot represents an average of 7,400 acres (2,960 ha); plots in other forest represent about 29,600 acres (11,840 ha). About 1,000 timberland and 400 other forest plots were established and measured from 1981 to 1984.

AN INVENTORY OF CURRENT HABITAT CONDITIONS

Vegetation Types

There are over 30 species of hardwoods in California, which have varying relationships with wildlife. Hardwoods are found growing in pure stands or mixed with conifers on productive timberland, in woodlands, as scattered trees in the vast foothill savannas, and in riparian strips at all elevations. Many systems for classifying this diverse vegetation have been developed. In this analysis we consider only those lands meeting the FIA definition of forest land. In describing the vegetation of these areas, we use the habitat classification system of the California WHR Program.[5] The WHR habitats are identified by the composition ("vegetation type") and structure (size and canopy closure class, or "stage") of vegetation currently dominating the site. Of the 25 tree vegetation types recognized by WHR, we focus on the eight hardwood habitats sampled by FIA field plots in this analysis. Descriptive information about the composition and structure of vegetation in these habitats is contained in the WHR habitat guide (Mayer and Laudenslayer in press).

In classifying FIA field plots, vegetation type was usually determined by translating the field-recorded CALVEG[6] series into the

[4]Forest land is land that is capable of 10 percent stocking of trees and is not developed for nonforest use. Timberland is forest land capable of producing 20 cubic feet or more per acre per year of industrial wood. Other forest is forest land that cannot produce successive crops of trees suitable for industrial roundwood.

[5]Salwasser, Hal; Laudenslayer, William F., Jr. California Wildlife and Fish Habitat Relationships (WFHR) System: products and standards for wildlife. Unpublished document on file with the U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, San Francisco, California; California; 1982. 25 p. and appendices.

[6]Parker, Ike; Matyas, Wendy. CALVEG--a classification of California vegetation. Unpublished document on file with the U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, San Francisco, California; 1979. 159 p.

Table 2--Area of unreserved forest land outside National Forests by broad vegetation type, land class, and ownership class, California, January 1, 1985[1]

Broad vegetation type	Timberland: Privately owned	Timberland: Publicly owned	Timberland: All ownerships	Other Forest: Privately owned	Other Forest: Publicly owned	Other Forest: All ownerships	Total
	Thousand acres						
Tree types:							
Hardwoods	1,086	132	1,218	5,265	688	5,952	7,170
Conifers	6,170	374	6,544	655	844	1,498	8,042
All trees	7,255	506	7,762	5,920	1,531	7,451	15,212
Shrub types	190	10	200	3,321	1,215	4,535	4,736
Herbaceous types	18	--	18	--	--	--	18
Unclassified	--	--	--	55	31	86	86
Total	7,464	516	7,980	9,295	2,777	12,072	20,052

[1]Totals may be inexact due to rounding.

Table 3--Area of unreserved forest land outside National Forests by hardwood vegetation type, resource area, and land class, California, January 1, 1985[1]

Resource area and land class	Coastal oak woodland	Valley oak woodland	Blue oak woodland	Blue oak-Digger pine	Montane hardwood	Montane hardwood-conifer	Valley-foothill riparian	Eucalyptus	All hardwood vegetation types
	Thousand acres								
North coast:									
Timberland	14	8	8	--	593	147	7	--	778
Other forest	126	84	--	--	293	--	--	--	503
Total	140	92	8	--	886	147	7	--	1,281
Northern interior:									
Timberland	--	--	--	--	79	49	--	--	127
Other forest	--	--	109	137	192	124	--	--	562
Total	--	--	109	137	270	173	--	--	689
Sacramento:									
Timberland	--	--	--	8	113	48	--	--	170
Other forest	--	--	525	730	205	--	33	--	1,492
Total	--	--	525	738	318	48	33	--	1,662
Central coast:									
Timberland	25	--	--	--	33	8	--	--	66
Other forest	673	90	135	359	45	--	--	45	1,346
Total	698	90	135	359	78	8	--	45	1,412
San Joaquin and southern Calif.:									
Timberland	--	--	--	7	55	15	--	--	77
Other forest	105	--	782	918	189	19	--	36	2,049
Total	105	--	782	925	244	34	--	36	2,126
All resource areas	943	182	1,559	2,159	1,796	410	40	80	7,170

[1]Totals may be inexact due to rounding.

corresponding WHR vegetation type. CALVEG series consist of general dominance types that are based on existing overstory vegetation. Tables 2-4 present information on current area of the WHR vegetation types. The tables include only those forest lands that are outside National Forests, parks (including national, State, county, and municipal), and wilderness areas.

Table 4--Area of unreserved forest land outside National Forests by hardwood vegetation type and ownership class, California, January 1, 1985[1]

Hardwood vegetation type	Ownership class: Private	Public	All owners
	Thousand acres		
Coastal oak woodland	863	80	943
Valley oak woodland	140	42	182
Blue oak woodland	1,392	168	1,559
Blue oak-Digger pine	1,891	268	2,159
Montane hardwood	1,595	201	1,796
Montane hardwood-conifer	350	60	410
Valley-foothill riparian	40	--	40
Eucalyptus	80	--	80
All hardwood types	6,351	820	7,170

[1]Totals may be inexact due to rounding.

Size and Canopy Closure Classes

The vegetation structure of the WHR habitats is defined by size class and canopy closure class. Size classes of tree vegetation types are defined by the size of the dominant vegetation present. For FIA field plots in hardwood types, we classified size class based on the quadratic mean diameter of hardwood trees in the stand. Because of the broad-scale, planning-level nature of our habitat assessment, we grouped the WHR size classes into three categories: seedling/sapling (0-6.0 inches d.b.h.), pole/small tree (6.1-24.0 inches d.b.h.), and medium/large tree (>24.0 inches d.b.h.).

The WHR habitat classification system recognizes four broad canopy closure classes for tree vegetation types, which we grouped into two for our analysis: sparse (0-39 percent canopy closure) and dense (40-100 percent canopy closure). To classify canopy closure classes of FIA field plots, we used information on the height and canopy closure of vegetation recorded on a 16-foot (5-m) fixed-radius, 0.02-acre (0.01-ha) plot centered on each of the five sample points. Tables 5 and 6 present information on current size and canopy closure classes of the hardwood vegetation types.

Table 5--Area of unreserved forest land outside National Forests by hardwood vegetation type, size and canopy closure classes, California, January 1, 1985[1]

Size and canopy closure classes	Hardwood vegetation type: Coastal oak woodland	Valley oak woodland	Blue oak woodland	Blue oak-Digger pine	Montane hardwood	Montane hardwood-conifer	Valley-foothill riparian	Eucalyptus	All hardwood vegetation types
	Thousand acres								
0 6 inches d.b.h.:									
0-39 pct cover	36	--	202	360	154	118	--	--	869
40-100 pct cover	--	--	27	101	127	100	--	--	355
Total	36	--	229	461	281	218	--	--	1,225
6.1-24 inches d.b.h.:									
0-39 pct cover	381	129	945	1,083	286	99	40	36	2,997
40-100 pct cover	527	53	353	555	1,223	74	--	45	2,830
Total	908	182	1,298	1,638	1,509	173	40	80	5,827
>24 inches d.b.h.:									
0-39 pct cover	--	--	33	60	--	19	--	--	112
40-100 pct cover	--	--	--	--	6	--	--	--	6
Total	--	--	33	60	6	19	--	--	118
All classes:									
0-39 pct cover	417	129	1,180	1,503	440	236	40	36	3,978
40-100 pct cover	527	53	380	656	1,356	174	--	45	3,191
Total	943	182	1,559	2,159	1,796	410	40	80	7,170

[1]Totals may be inexact due to rounding.

Table 6--Area of hardwood vegetation types on unreserved forest land outside National Forests by ownership, land and size classes, California, January 1, 1986[1]

Land class and size class (inches d.b.h.)	Public	Forest industry	Other private	All owners
	Thousand acres			
Timberland:				
0-6.0	11	78	164	253
6.1-24.0	116	153	691	959
>24.0	6	--	--	6
Total	132	231	855	1,218
Other forest:				
0-6.0	140	--	832	972
6.1-24.0	547	75	4,246	4,868
>24.0	--	--	112	112
Total	688	75	5,190	5,952
All classes	820	306	6,045	7,170

[1]Totals may be inexact due to rounding.

EVALUATING HABITAT CAPABILITY

WHR's level-one models of wildlife-habitat relationships represent a major advancement in analytical tools for predicting the effects of habitat alterations on wildlife. For each wildlife species, the models provide data that indicate the relative suitability (optimum, suitable, or marginal) of each habitat for reproduction, foraging, and cover. The models do not provide data for predicting animal abundance. They do, however, allow the analyst to evaluate wildlife habitat qualitatively--an acceptable level of analysis for many broad-scale, planning-level applications.

In applying the models, the analyst must compare the amounts of suitable habitat before and after a management action. Changes in habitat area can be actual changes detected by inventorying or monitoring, or potential changes as portrayed through habitat projection or simulation. If a particular habitat is essential to a species' survival, then an increase or decrease in the area of that habitat has a corresponding effect on the species' ability to survive. For example, if a wildlife species is restricted to one or two size or canopy closure classes for reproduction, and the area of these stages is reduced by 50 percent over a given period of time, one would expect a decline in animal abundance.

For our examples of how habitat capability can be evaluated using FIA data and the level-one models, we chose two wildlife species found in California's valley-foothill hardwoods.[7] The gray fox (Urocyon cinereoargenteus) prefers early-successional stages as habitat, and the plain titmouse (Parus inornatus) uses later stages. For this analysis, we translated the qualitative ratings of habitat suitability into numerical ratings of probability of occurrence (presence or absence). For each life requisite (breeding, feeding, and resting), vegetation types and stages not used by the wildlife species received a rating of zero. Marginal habitats received a rating of 0.3, suitable 0.6, and optimum 1.0. For each habitat stage, the ratings for the three life requisites were then averaged to derive the composite ratings, or habitat suitability index (HSI), shown in figure 2.

Available habitat units can be calculated for a given point in time by multiplying the area in each stage (fig. 3) by the corresponding rating (fig. 2), and then summing across all stages in the vegetation types. Future habitat units are calculated based on a projected inventory of available vegetation types and stages. In our hypothetical example, we show how habitat availability would be affected if the total area of valley-foothill hardwoods in the Sacramento and San Joaquin resource areas were to decrease by about 175,000 acres (70,000 ha) over the next decade (figs. 4 and 5). The proportion of the remaining area that is comprised of late-successional stands would also decrease. Under these conditions, the plain titmouse would have greater difficulty finding adequate habitat; available habitat units would decrease by about 8 percent. Suitable habitat for the gray fox would decrease to a lesser degree (by about 4 percent) (fig.

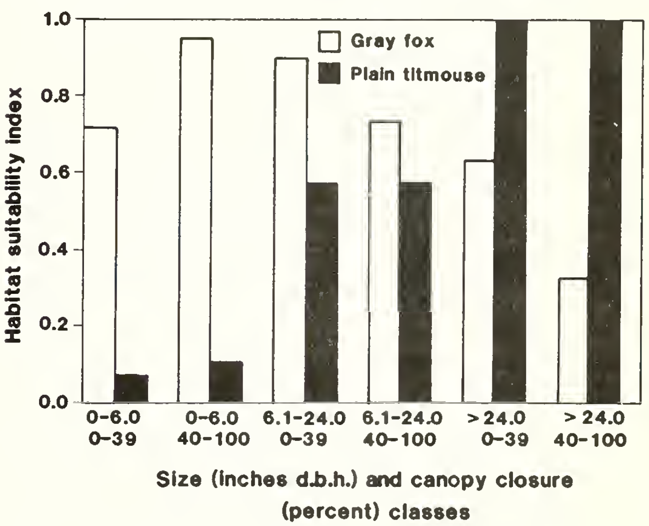

Figure 2--Habitat suitability indices for the valley-foothill hardwoods, California

[7]Valley-foothill hardwoods include blue oak woodland, blue oak-Digger pine, valley oak woodland, and coastal oak woodland.

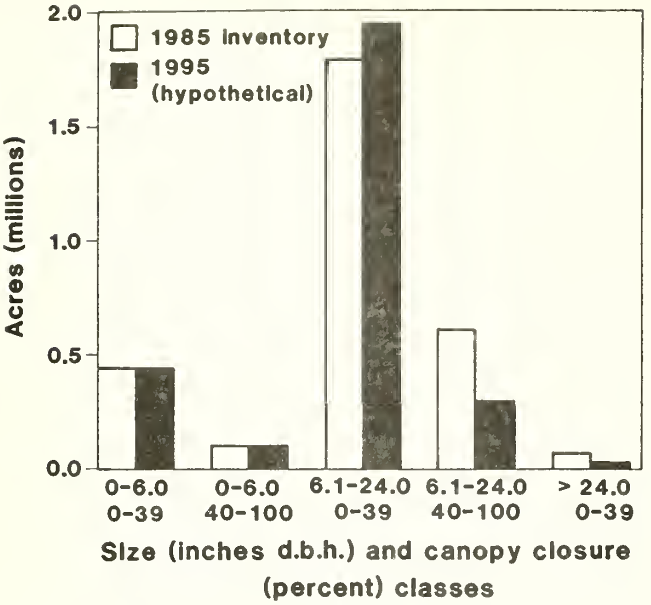

Figure 3--Area of valley-foothill hardwoods in the Sacramento and San Joaquin resource areas, California

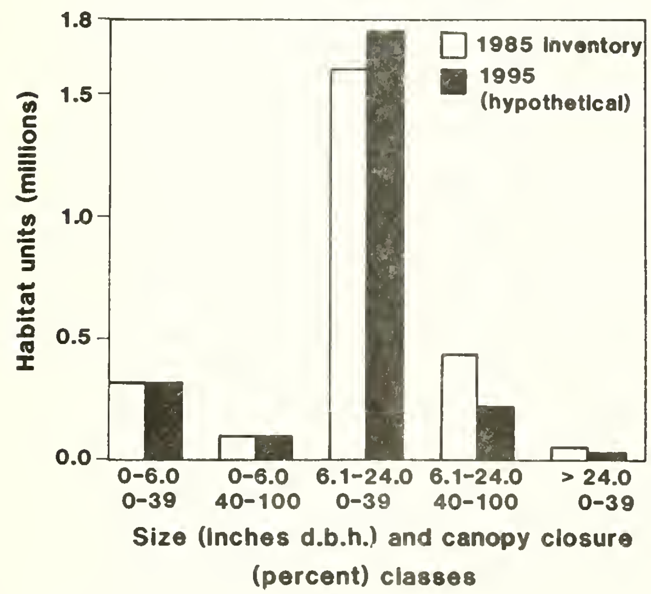

Figure 4--Available habitat units for the gray fox in valley-foothill hardwoods, Sacramento and San Joaquin resource areas, California

Given this kind of information, planners can compare projected habitat units achieved under alternative scenarios and select the one that most closely meets objectives. The magnitude of potential adverse situations can also be determined. Specific measures aimed at avoiding problems can be taken following further research into the nature of the problem, how it varies by locality, and available alternatives for mitigating negative impacts.

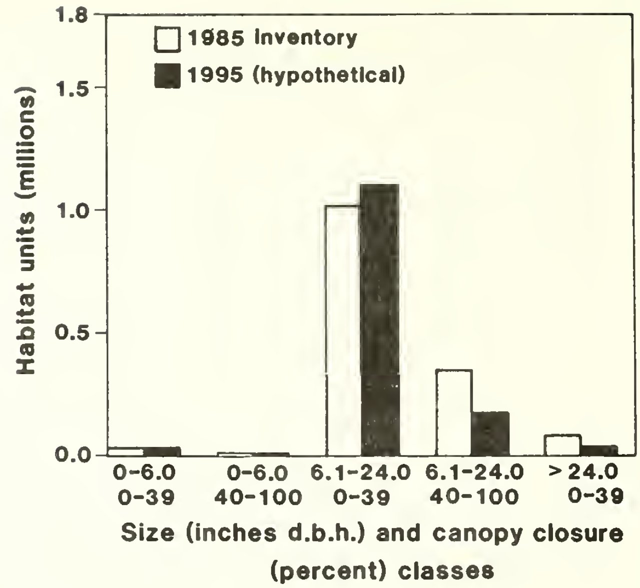

Figure 5--Available habitat units for the plain titmouse in valley-foothill hardwoods, Sacramento and San Joaquin resource areas, California

INTERPRETING AND APPLYING THE HABITAT INFORMATION

Several things must be considered when interpreting or applying the estimates of habitat area. First, the estimates are subject to sampling error (see discussion in McKay 1987). However, because the information is intended to be used at the planning level, a greater level of sampling error is acceptable than for making on-the-ground management decisions. The estimates of habitat area may also include nonsampling kinds of error, but these have been minimized through careful quality control and the standardization of field and analytical procedures. Furthermore, the WHR habitats define very general kinds of vegetation, overriding the need for highly precise input data.

Our estimates of habitat area may differ from other published estimates of area by forest or vegetation type, as a result of differing definitions and/or sampling procedures. In particular, estimates of area by hardwood forest types reported by Bolsinger (in press) may appear to conflict with our estimates of WHR vegetation types. However, direct comparisons of area estimates using the two classification systems are impossible, because the forest types and the WHR types do not correspond exactly. Furthermore, Bolsinger's forest types are assigned based on the tree species with the plurality of basal area, as determined from the tree tally. The WHR types are based on an assessment of overall conditions in the general 5-acre (2-ha) plot area.

Users of our habitat data should also remember that they indicate existing, not potential, vegetation. In addition, we classified plots using a "top-down" approach. Any stand with at least 10 percent canopy closure of trees is

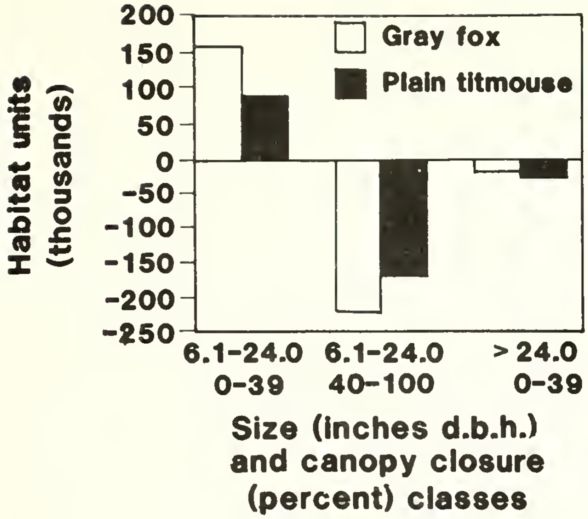

Figure 6--Change in available habitat units in valley-foothill hardwoods, Sacramento and San Joaquin resource areas, California

considered a tree habitat regardless of understory, which may vary greatly. Heavily disturbed timberland or woodland sites with less than 10 percent canopy closure of trees are considered shrub or nonforest habitats and are not included in the hardwood area. Furthermore, some conifer WHR types commonly support hardwood vegetation in their early successional stages. These stands are included in the tables presented here. For example, hundreds of thousands of acres in the North Coast that were formerly conifer-dominated forests now support tanoak (Lithocarpus densiflorus (Hook. & Arn.) Rehd.) and Pacific madrone (Arbutus menziesii Pursh). These stands are classified here as montane hardwood.

A drawback of using sample-based inventory data for assessing habitat relates to the lack of spatial information. Although we can describe individual stands in great detail, we lack information on surrounding forest conditions, and on the area covered by individual stands. The FIA inventory data could be augmented with such information in the future if the need arises. For the time being, this limitation can be minimized through careful selection of wildlife species for evaluation. The suitability of habitat for wildlife species that are highly dependent on "edge," or on a certain juxtaposition or interspersion of habitats and stages within their home range or territory, should not be evaluated using FIA plot data alone. Wildlife species that require stands of large area are also poor choices for habitat evaluation.

Finally, how closely our inventory of suitable habitat reflects the real world is directly related to how well the level-one WHR models reflect wildlife preference for habitats. As the models are validated, or more sophisticated ones developed, we can improve predictions of habitat suitability made with FIA inventory data.

A LOOK TO THE FUTURE

Clearly, providing information on habitat conditions on forest lands inventoried by FIA completes only one piece of the total resource picture. Future work should be undertaken to obtain compatible habitat data for all lands in the State, including National Forests, reserved areas, and nonforest lands.

Future evaluations of wildlife habitat using FIA data can be improved by applying additional information from the FIA inventory and other sources. The FIA data base contains a vast amount of data not accommodated by level-one WHR models. Many of the FIA data relate to habitat elements such as understory vegetation and snags. This kind of information, which can be used to supplement habitat evaluations based on level-one models, may be summarized in future publications. The FIA habitat data may also be used to produce maps. By plotting FIA sample locations on map overlays, we can display the habitat data in a form suitable for discerning general patterns across the landscape.

Future wildlife assessments by FRRAP will incorporate a "value ranking" (Ogle 1981) in the evaluation process. The ranking is used to adjust habitat units upward or downward according to the perceived value of the habitat to wildlife. Loss of a vegetation type or successional stage that is uncommon, or that is used by a large number of wildlife species, is perceived as more critical than loss of more common or less used habitats. In a regional analysis such as that described in this paper, changes affecting critical habitats may be obscured because inventory estimates consist of large acreages. Changes in habitat area may appear small when expressed as a proportion of the total, even though the actual number of acres affected may be substantial.

Producing a statewide inventory of current, and potential future, wildlife habitats represents a critical first step towards ensuring the long-term survival of California's wildlife. Once the magnitude of potential impacts on selected indicator species of wildlife have been identified using the approach described in this paper, research may be done to learn more about the nature and location of any problems. Given similar resource data from future FIA inventories, actual changes in the amount and suitability of wildlife habitat on private lands can be monitored. The effectiveness of mitigation efforts can also be evaluated in this way. Documented information on trends in the resource will prove essential to sound multiresource planning for wildlife in California's forests.

ACKNOWLEDGEMENTS

We thank William Laudenslayer, USDA Forest Service, and Ellen Yeoman, Pacific Gas & Electric, for their timely and helpful technical reviews of the manuscript. Irene Timossi, University of

California, Berkeley, developed the habitat suitability indices and provided computer support in accessing the WHR data base. Katharine McDuffie, USDA Forest Service, wrote computer programs for screening the FIA field plot data. Finally, we thank the many individuals in the FIA research unit involved in collecting data and compiling the findings of the California inventory.

LITERATURE CITED

Bolsinger, Charles L. An assessment of the hardwoods of California timberlands, woodlands, and savannas. Resour. Bull. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; [in press].

Cochran, William G. Sampling techniques, 3rd edition. New York, NY: John Wiley & Sons, Inc.; 1977. 428 p.

Grenfell, William E., Jr.; Salwasser, Hal; Laudenslayer, William F., Jr. The California Wildlife/Fish Habitat Relationships System. Cal-Neva Wildlife Transactions. 1982: 27-33; 1982.

Laudenslayer, William F., Jr.; Grenfell, William E., Jr. A list of amphibians, reptiles, birds and mammals of California. Outdoor California 44(1): 5-14; 1983.

McKay, Neil. How the statewide forest inventory was conducted. 1987 [These proceedings].

Mayer, Kenneth E. A review of selected remote sensing and computer technologies applied to wildlife habitat inventories. Calif. Fish and Game 70(2): 102-112; 1984.

Mayer, Kenneth E.; Laudenslayer, William F., Jr.; eds. A guide to wildlife habitats of California. Sacramento, CA: State of California; [in press].

Muick, Pamela C.; Bartolome, James W. Research studies in California related to oaks. Berkeley, CA: University of California Wildland Resources Center; 1985; Report No. 7. 37 p.

Nelson, Robert D.; Salwasser, Hal. The Forest Service Wildlife and Fish Habitat Relationships Program. In: Transactions of the North American wildlife and natural resources conference 47. Washington, DC: Wildlife Management Institute; 1982.

Ogle, C.C. The ranking of wildlife habitats. New Zealand Journal of Ecology 4: 115-123; 1981.

Ohmann, Janet L. Evaluating wildlife habitat as part of a continuing, extensive forest inventory. In: Proceedings: Renewable resource inventories for monitoring changes and trends; 1983 August 15-19; Corvallis, OR. Corvallis, OR: Oregon State University; 1983: 623-627.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Wildlife-Tanoak Associations in Douglas-fir Forests of Northwestern California[1]

Martin G. Raphael[2]

Abstract: I sampled characteristics of vegetation and estimated abundances of 61 vertebrate species on 166 sites representing early clearcut through mature seral stages of Douglas-fir forests in northwestern California. Tanoak was present in most stands and increased in canopy volume as stand age increased. The abundances of 12 bird species, 7 mammal species, and 5 salamander species were greatest in stands with greater tanoak canopy volume, suggesting that tanoak may be an important habitat component for these species. Capture rates of small mammals on clearcuts with and without tanoak, and among forested sites with varying tanoak volume, showed that some species, especially northern flying squirrel, Allen's chipmunk, and dusky-footed woodrat were very closely tied to tanoak, which provided mast and nesting cover. Management practices that eliminate tanoak are probably detrimental to these and possibly other species of wildlife in Douglas-fir forests.

Tanoak (Lithocarpus densiflorus) is the most abundant hardwood tree species in Douglas-fir (Pseudotsuga menziesii) forests of northwestern California. It often dominates the subcanopy layer at heights <35 m. Following fire or logging, tanoak regenerates by sprouting and can form a nearly solid canopy depending on previous stand conditions and on available soil moisture (Thornburgh 1982, Raphael in press, a). Because such dense regrowth can suppress regeneration of conifers for many years, tanoak has been considered a pest species and is the target of intensive suppression efforts (King and Radosevich 1980).

Tanoak contributes about 30 percent of the total cubic-foot volume of all hardwoods in California (Bolsinger 1980). Commercial use of tanoak has been low, but is increasing in northwestern California primarily to meet demands for pulpwood and fuelwood (Stine 1980). Because (1) the harvest rate of tanoak is likely to increase, and (2) removal of tanoak regeneration to reduce competition with conifers will continue, tanoak volume may decline in managed stands of the northwest. If so, how will this affect wildlife? To begin answering this question, I sampled wildlife populations and vegetation cover on a large number of sites and compared the abundances of wildlife species to the amount of tanoak at each site.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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METHODS

Study Area

Study sites were located on the Six Rivers, Trinity, and Klamath National Forests of northwestern California. Forest cover is dominated by Douglas-fir in association with an understory of tanoak, Pacific madrone (Arbutus menziesii), and a large variety of other tree and shrub species, depending on site conditions. Elevations of study sites varied from 427 to 1220 m, averaging 838 m.

Study Design

Extensive Survey

This study involved two complementary approaches. The first was an extensive 3-year survey of late-seral stands that varied from about 50 to >350 years old. For this survey, 136 sites were selected using Forest Service timber type maps, aerial photographs, and ground examinations. Each site was an area of about 10 ha, bounded by a circle with a 180-m radius and centered on a point that was marked on the ground. Terrestrial vertebrates were sampled on each site using four primary methods described by Raphael (1984).

Variable-Radius Circular Plots--A team of four trained biologists counted birds and squirrels from the center of each site during 12 10-min periods each spring and winter, 1981-83. Distances were estimated to each animal, permitting calculation of estimated density using the computer program TRANSECT (Laake and others 1979, Raphael in press, b).

Pitfall Traps--Pitfall traps were used to capture small mammals, amphibians, and reptiles. Arrays consisted of 10 2-gallon plastic buckets arranged in a 2x5 grid with 20-m spacing, buried flush with the ground surface and covered with plywood lids. One such array was placed at the center of each site. Each bucket was checked at weekly to monthly intervals from December 1981 through October 1983. For this study, I calculated the total captures of each species over the entire sampling period and the total number of trapnights for each site; capture rate was then expressed as the number of captures/1000 trapnights.

Drift Fence Arrays--Primarily to capture snakes, the sampling team installed a drift fence array on a randomly selected subset of 30 sites. An array consisted of two 5-gallon buckets placed 7.6 m apart and connected by an aluminum fence 7.6 m long by 50 cm tall, with a 20x76-cm funnel trap placed on each side of the center of the fence. Each array was in place from May to October, 1983. Captures from these arrays, and associated trapnights, were pooled with results of the pitfall arrays.

Track Stations--The team recorded tracks of squirrels and carnivores on each site using a smoked aluminum plate baited with tuna pet food (Barrett 1983, Raphael and others 1986). Each station was monitored for 8 consecutive days in August, 1981-83. A species was recorded as present on a site if it was recorded any time during these 3 years.

Vegetation Sampling--Characteristics of vegetation structure and composition were estimated from three randomly located, 0.04-ha circular plots located within 60 m of the center of each of the 136 sites. A sampling team measured characteristics of each live tree and snag >2 m tall within each circular plot. Canopy volume was computed for each tree using a modified version of the program HTVOL (Mawson and others 1976); tree volumes were summed for each species on each site. Stand age was estimated from the diameter-distribution of all conifers (Raphael 1984). Slope and aspect were measured at each site and were used to calculate an index of total yearly solar radiation (Frank and Lee 1966).

Data Analysis--I computed Pearson correlation coefficients between estimated abundance of each vertebrate species (except those too rare for valid analysis) and canopy volume of tanoak for all 136 sites. Because the correlations can be confounded by other habitat gradients, especially stand age, elevation, and solar radiation, I used partial correlation analyses to examine the correlation of tanoak volume and abundance with the effects of the other three gradients removed. All statistical analyses were conducted using the SPSS program package.

Intensive Sampling

Surface Search--To better capture salamanders, the sampling team conducted time- and area-constrained searches (Bury and Raphael 1983, Welsh, these proceedings) on a randomly selected subset of 87 sites from the extensive sample, plus an additional 60 sites representing early seral stages. A two-person team searched under all movable objects and within all logs on three randomly located 0.04-ha subplots (fall 1981, 1982) or within a 1-ha area for four person-hours (spring 1983). Results were expressed as mean captures/site; analyses included only those sites sampled in this manner.

For each capture, the observer recorded the species of salamander and its location, including the substrate where it was found, substrate size (and species, if appropriate) and its location relative to water. In addition, the observer recorded the size and species of all substrates examined where salamanders were not found in 1982. The latter data allowed an estimate of substrate availability.

Livetrap Grids--To estimate abundance and habitat associations of small mammals in more detail than possible with the extensive survey, the observers established livetrap grids on a subset of 27 sites representing both early and late seral stages. Each grid consisted of 100 25-cm Sherman live traps arranged in a 10x10 grid with 20-m spacing. Traps were checked once daily for 5 days during July, 1982-83. Capture rates were expressed as total captures/500 trapnights after adjusting for closed or damaged traps.

Observers also recorded vegetation characteristics within a 25-m^2 quadrat surrounding each trap. Percent cover was estimated for (1) bare ground and rocks; (2) litter; (3) logs >8 cm diameter and 1 m long; (4) understory cover (plants <2 m tall) of Douglas-fir, tanoak, Pacific madrone, and other species; and (5) overstory cover (vegetation >2 m tall) of Douglas-fir, tanoak, Pacific madrone, oak species, and other species, and total cover.

I used discriminant analysis to test for habitat differences between trap sites where animals were captured versus where they were not. For each trapsite, I counted the number of individuals of each mammal species captured at that site. For each discriminant analysis, the capture sites were weighted by the number of individuals of the species being considered. For example, if 50 of 100 traps captured 75 different deer mice, the discriminant analysis would be based on 50 noncapture versus 75 capture sites. Those sites with two captures would be represented twice in the analysis. Up to four individuals of a species were captured at each site, but multiple captures greater than two were rare.

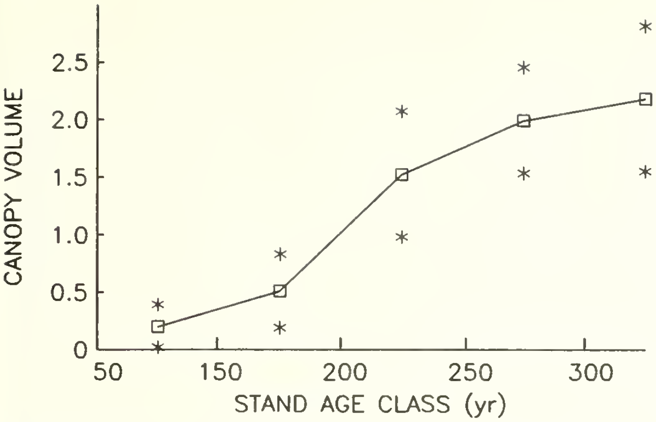

Figure 1--Canopy volume (m^3/m^2 of ground area) of tanoak in relation to stand age class in Douglas-fir forests of northwestern California. Asterisks indicate 95 percent confidence intervals.

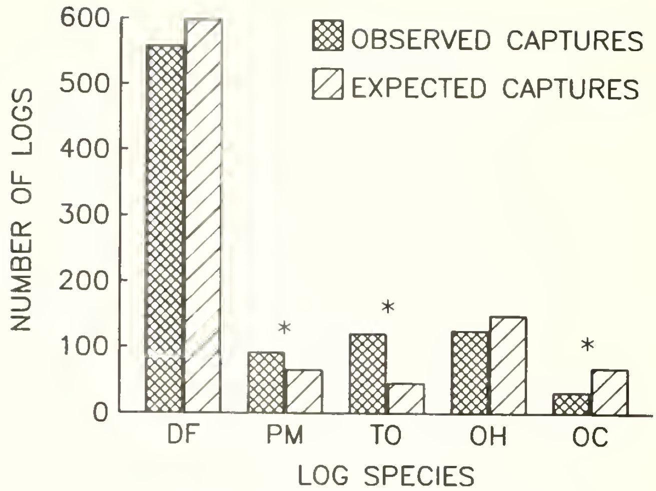

Figure 2--Frequency of salamander captures in logs of various species compared to expected captures based on numbers of logs searched. Log species codes are: DF, Douglas-fir, PM, Pacific madrone; TO, tanoak; OH, other hardwoods; OC, other conifers. Asterisks indicate significant differences between used and expected frequencies of use (binomial test, $P < 0.05$).

RESULTS

Tanoak Occurrence

Tanoak occurred on 115 of the 136 sites, and increased in canopy volume as stand age increased (ANOVA, test for linear trend, P = 0.000, fig. 1). Total canopy volume ranged from 0 to 5.4 m^3/m^2 ground surface and averaged 1.3 ± 0.1 m^3/m^2 over all sites. Tanoak volume increased with increasing basal area of Douglas-fir (r = 0.47, P = 0.001) and higher elevation (r = 0.20, P = 0.019), and it decreased with higher solar radiation (r = -0.37, P = 0.001). Thus, canopy volume of tanoak was greatest in older, higher elevation stands on north-facing slopes.

Vertebrate Associations

Extensive Survey

The extensive survey yielded estimates of relative abundance for 61 species of amphibians, reptiles, mammals, and birds. The abundance of 24 of these species (5 salamanders, 7 mammals, and 12 birds) increased significantly ($P < 0.10$) as tanoak canopy volume increased (table 1). These correlations, although significant statistically, were rather weak (all $r < 0.50$), which was not surprising given the variability associated with this type of sampling. Separating the effects of solar radiation, stand age, and elevation reduced the number of species with significant correlations to 12 (3 salamanders, 3 mammals, and 6 birds; table 1).

Intensive Samples

Salamander Habitat Use--Observers recorded 1,631 salamander locations during three seasons of searches, and also recorded characteristics of 4,482 substrates where no salamanders were found. Most salamanders were found in association with logs (63 percent of locations); 13 percent of these were tanoak, whereas only 5 percent of searched logs were tanoak. Compared to available (searched) substrates, tanoak and Pacific madrone logs were used more often than expected from their availability (fig. 2); tanoak was the most highly preferred log substrate used by Del Norte salamander, ensatina, black salamander, and clouded salamander.

Small Mammal Captures--Observers recorded 1,029 captures of 513 individual small mammals in 1982 and 1,978 captures of 928 individuals in 1983 from 2,638 trap locations. Among the four most abundant species, capture rates were correlated with understory tanoak cover for all species except pinyon mouse (*Peromyscus truei*, table 2), which was apparently responding to cover of other shrubs (primarily *Quercus chrysolepis*).

Mean cover of shrubs (mostly tanoak), computed for each of six generalized seral stages, was greatest in the late clearcut (shrub/sapling) stage and lowest in the pole stage (fig. 3); relative abundance of the four common mammals followed a similar pattern (table 3).

I used discriminant analysis to evaluate whether mammals used particular microhabitats within plots. For each of the four most abundant mammals, I compared capture and noncapture trapsites using mean cover values for seven variables measured around each trap location. In each case, differences between capture and noncapture sites were statistically significant,

Table 1--Simple and partial correlations[1] of relative abundance of vertebrate species with canopy volume of tanoak among 136 late-seral sites in northwestern California.

Species	Simple Correlation	Partial correlation[2]
Salamanders		
Pacific giant salamander (Dicamptodon ensatus)	0.21*	0.10
Del Norte salamander (Plethodon elongatus)	0.47***	0.38**
Ensatina (Ensatina eschscholtzi)	0.45***	0.43***
Black salamander (Aneides flavipunctatus)	0.38**	0.27*
Clouded salamander (Aneides ferreus)	0.33**	0.16
Mammals		
Pacific shrew (Sorex pacificus)	0.17*	0.03
Allen's chipmunk (Tamias senex)	0.21*	0.03
Douglas' squirrel (Tamiasciurus douglasii)	0.15*	0.02
Northern flying squirrel (Glaucomys sabrinus)	0.28***	0.30***
Deer mouse (Peromyscus maniculatus)	0.18*	0.02
Black bear (Ursus americanus)	0.15*	0.16*
Fisher (Martes pennanti)	0.24**	0.23**
Birds		
Spotted owl (Strix occidentalis)	0.15*	0.00
Acorn woodpecker[3] (Melanerpes formicivorus)	0.16*	0.13
Red-breasted sapsucker (Sphyrapicus ruber)	0.17*	0.04
Olive-sided flycatcher (Contopus sordidulus)	0.23**	0.17*
Western flycatcher (Empidonax difficilis)	0.39***	0.32***
Hermit thrush (Catharus guttatus)	0.34***	0.13
Varied thrush[3] (Ixoreus naevius)	0.33***	0.35***
Hutton's vireo (Vireo huttoni)	0.19*	0.30***
Warbling vireo (Vireo gilvus)	0.38***	0.28***
Hermit warbler (Dendroica occidentalis)	0.15*	0.04
Wilson's warbler (Wilsonia pusilla)	0.23**	0.08
Purple finch (Carpodacus purpureus)	0.21*	0.25**

[1] Asterisks indicate level of significance: * = P<0.10, ** = P<0.01, *** = P<0.001, blanks = not significant (P>0.10).
[2] Partial correlation after controlling for stand age, elevation, solar radiation.
[3] Winter populations.

Table 2--Correlation of capture rate (numbers of individuals per 500 trapnights) and mean cover of selected characteristics computed for 27 study sites. Only significant correlations (P < 0.05) are reported.

Characteristic	Species[1]			
	PEMA	PETR	NEFU	TASE
Litter	-0.48			-0.72
Logs				
Bare ground	0.57			0.61
Ground vegetation	0.40			0.42
Tanoak <2 m	0.53		0.52	0.69
Other <2 m		0.33		0.43
Total >2 m	-0.60			-0.69

[1] PEMA = deer mouse, PETR = pinyon mouse, NEFU = dusky-footed woodrat, TASE = Allen's chipmunk.

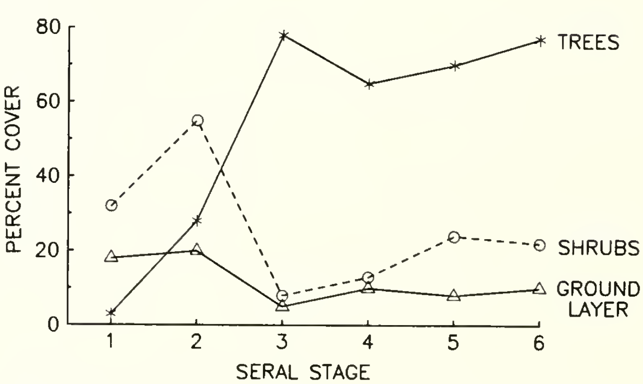

Figure 3--Percent ground cover of vegetation in three height strata among six seral stages of Douglas-fir forests. Values are averages from 300, 300, 500, 472, and 566 quadrats (25 m^2) in stages 1-6, respectively. See Table 3 for a description of seral stages.

Table 3--Average capture rates (animals/500 trapnights) of common mammals among seral stages of Douglas-fir forest in northwestern California.

Species	Seral stage[1]					
	1	2	3	4	5	6
Allen's chipmunk	8.7	27.3	0.3	1.0	3.8	3.4
Deer mouse	58.7	59.0	23.7	13.2	58.8	36.4
Pinyon mouse	2.7	15.0	4.7	12.6	4.6	1.6
Dusky-footed woodrat	1.7	3.0	0.3	0.8	5.4	3.8
Totals	71.8	104.3	29.0	27.6	72.6	45.2

[1] 1 = early clearcut (N = 3), 2 = late clearcut (N = 3), 3 = Pole (< 100 years, N = 3), 4 = sawtimber (100-150 years, N = 5), 5 = mature (150-250 years, N = 7), 6 = old growth (> 250 years, N = 6).

although the differences were weak (R^2 varied from 3 to 7 percent, table 4). Results generally paralleled those derived from the correlations reported earlier (table 2). Understory tanoak cover was the most consistently important variable. Except for pinyon mice, these animals had a tendency to enter traps surrounded by a higher than average amount of tanoak. Pinyon mice, in contrast, were most often captured in drier, rocky sites dominated by canyon live oak. In addition to having greater tanoak cover, Allen's chipmunk capture sites had much lower litter and higher log cover than noncapture sites (table 4). Although log cover varied little among the plots and was not correlated with chipmunk abundance among plots (table 2), the large F-ratio and high correlations with the discriminant function (table 4) indicated that log cover may be an important habitat characteristic for chipmunks.

DISCUSSION

This study provides strong circumstantial evidence that tanoak is an important habitat component for at least 16 of the 61 vertebrate species I sampled in Douglas-fir forests of northwestern California. For birds and larger mammals (nine species, table 1), evidence for this association was based strictly on the correlation between abundance of each species with canopy volume. Some of these correlations may be spurious because of confounding with other habitat characteristics (even though I controlled for other major habitat gradients) and because of the ever-present risk that even random data will yield statistically significant correlations some of the time. However, it is very unlikely that all of these correlations were spurious. For example, 24 of the 61 simple correlations were significant at the 10 percent level or better (table 1), whereas only three significant positive correlations would be expected by chance alone.

Further evidence that these correlations are not spurious is found in Verner's (1980) review of breeding bird associations with oaks (Quercus spp). For 8 of the 12 species of birds whose abundance was correlated with tanoak, Verner presented documented use of oaks for nesting and feeding. Considering only those six species with significant partial correlations between abundance and tanoak volume, only one (varied thrush) was not documented as using tanoak by Verner, but this species, which occurred only in winter in my study area, was not included in Verner's list because he considered only breeding birds.

Evidence based upon the intensive salamander searches and mammal livetraps is stronger because it shows either actual use of tanoak or at least consistent presence of tanoak in close proximity with the animal. These data reinforced correlational results for three species (ensatina, Del Norte salamander, and black salamander) and provided evidence for considering four additional species as tanoak associates (clouded salamander, deer mouse, Allen's chipmunk, and dusky-footed woodrat).

These wildlife species use tanoak in a variety of ways. Salamanders use tanoak logs for resting or hiding cover and perhaps nesting. Mammals feed on tanoak mast (e.g., black bear, northern flying squirrel), use it for nesting (e.g., dusky-footed woodrat), feed on prey associated with tanoak (e.g., fisher), or use cover provided by dense tanoak in the understory (e.g., Allen's chipmunk and deer mouse). Use of tanoak by birds can include all of the above examples.

The relative dependence of these species of wildlife on tanoak remains an open question. Although these species were more abundant in stands with higher tanoak volume, some may have been using tanoak opportunistically. Well-designed experiments, involving demographic studies of species before and after removal of tanoak, will be necessary to establish causal links between these wildlife populations and the volume of tanoak.

Until such studies are completed, I believe the available evidence is sufficient to recommend maintaining mature tanoak in forest stands, and maintaining some proportion of cutover forest in a tanoak-dominated, brushy condition. Mature

Table 4--Summary of discriminant analyses comparing habitat characteristics between capture and noncapture trapsites of 4 mammal species on 21 study grids (clearcut plots excluded) in 1982.

Characteristic[1]	Deer Mouse (N = 387)		Pinyon Mouse (N = 136)		Dusky-footed woodrat (N = 60)		Allen's Chipmunk (N = 193)	
	F	Corr.	F	Corr.	F	Corr.	F	Corr.
Bare Ground[2]	6.5	0.20	11.8***	0.46	2.1	0.17	0.6	0.06
Litter	40.2***	-0.51	0.5	-0.09	2.0	-0.16	82.8***	0.71
Logs[3]	24.3***	0.39	3.5	-0.25	2.7	0.19	69.1***	0.65
Herbs, grasses, low shrubs	36.2***	0.48	2.2	0.20	5.6*	0.28	0.0	0.00
Tanoak $\leq$2 m	87.2***	0.75	6.5*	0.34	38.8***	0.73	44.8***	0.52
Other $\leq$2 m	0.8	0.07	36.9***	0.81	15.4***	0.46	7.0**	0.21
Total $\geq$2 m	4.8*	-0.18	3.6	-0.25	1.8	-0.16	12.3***	0.27

[1] Percent cover of each category, estimated within a 25-m^2 quadrat around a trap.
[2] Includes rocks and area occupied by tree stems.
[3] Downed wood > 8 cm diameter.

forest stands and old, brushy clearcuts seem to be particularly important seral stages for wildlife. Brushy clearcuts dominated by tanoak provide nesting substrate, mast, and hiding cover for small mammals and probably birds. Mature stands with tanoak understories provide foraging habitat for birds and produce logs that are used by amphibians (and probably small mammals). Such stands have the multilayered structure that produces the microclimate required by spotted owls (Barrows 1981) and other birds.

ACKNOWLEDGMENTS

These studies were funded by the Pacific Southwest Region and the Pacific Southwest Forest and Range Experiment Station of the USDA Forest Service. The University of California (AES Project 3501 MS) also provided support. I am indebted to many field assistants, in particular John Brack, Cathy Taylor, and Kenneth Rosenberg who also helped analyze data. I thank Kenneth Rosenberg and William Block for comments on an earlier draft of this paper.

REFERENCES

Barrett, Reginald H. Smoked aluminimum track plots for determining furbearer distribution and relative abundance. Calif. Fish and Game 69: 188-190; 1983.

Barrows, Cameron W. Roost selection by spotted owls: an adaption to heat stress. Condor 83: 302-309; 1981.

Bolsinger, Charles L. Oaks in California's commercial forests--volume, stand structure, and defect characteristics. In: Plumb, Timothy R., tech. coord. Proceedings of the symposium on ecology, management and utilization of California oaks, 1979 June 26-28, Claremont, California. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980; 101-106.

Bury, R. Bruce; Raphael, Martin G. Inventory methods for amphibians and reptiles. In: Bell, John F.; Atterbury, Toby, editors. SAF 83-14. Renewable resource inventories for monitoring changes and trends. Proceedings of an international conference; 1983 August 15-19; Corvallis, OR. Corvallis: College of Forestry, Oregon State University; 1983; 416-419.

Frank, Ernest C.; Lee, Richard. Potential solar beam irradiation on slopes. Res. Paper RM-18. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1966. 114 p.

King, M. G.: Radosevich, S. R. Tanoak (Lithocarpus densiflorus) leaf surface characteristics. In: Plumb, Timothy R., tech. coord. Proceedngs of the symposium on the ecology, management, and utilization of California oaks, 1979 June 26-28, Claremont, California. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980; 36-42.

Laake, Jeffrey L.; Burnham, Kenneth P.; Anderson David R. Users manual for program TRANSECT. Logan: Utah State University Press; 1979. 26 p.

Mawson, Joseph C.; Thomas, Jack Ward; DeGraaf, Richard M. Program HTVOL--the determination of tree crown volume by layers. Res. Paper NE-354. Upper Darby, PA: Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, 1976. 9 p.

Raphael, Martin G. Douglas-fir (DFR). In: Mayer, Kenneth E.; Laudenslayer, William F., Jr.; eds. A guide to wildlife habitats of California. Sacramento, CA: California State Department of Forestry; in press, a.

Raphael, Martin G. Estimating relative abundance of forest birds: simple versus adjusted counts. Wilson Bulletin; in press, b.

Raphael, Martin G. Wildlife populations in relation to stand age and area in Douglas-fir forests of northwestern California. In: Meehan, William R.; Merrell, Theodore R., Jr.: Hanley, Thomas A., editors. Proceedings of the symposium on fish and wildlife relationships in old-growth forests; 1982 April 12-15; Juneau, AK. American Institute of Fishery Research Biologist; 1984; 259-274.

Raphael, Martin G.; Taylor, Cathy A.; Barrett, Reginald H. Smoked aluminum track stations record flying squirrel occurrence. Res. Note PSW-384. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1986 3 p.

Rapahel, Martin G.; Rosenberg, Kenneth V.; Marcot, Bruce G. Large-scale changes in bird populations of Douglas-fir forests, northwestern California. Bird Conservation 3: In press.

Stine, Raymond. Economics of utilizing oak for energy. In: Plumb, Timothy R., tech coord. Proceedings of the symposium on ecology management, and utilization of California oaks, 1979 June 26-28, Claremont, California. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980; 345-353.

Thornburgh, Dale A. Succession in the mixed evergreen forests of northwestern California. In: Means, J. E., ed. Proceedings of symposium on forest succession and stand development research in the northwest, March, 1981, Corvallis, OR. Oregon State University, Corvallis; 1982; 87-91.

Verner, Jared. Birds in California oak habitats-management implications, In: Plumb, Timothy R., tech. coord. Proceedings of the symposium on the ecology, management, and utilization of California oaks. 1979 June 26-28, Claremont, California. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980; 246-264.

Welsh, Hartwell H. Monitoring herpetofauna in woodland habitats of northwestern California and southwestern Oregon: a comprehensive strategy (These proceedings).

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Preserving Oak Woodland Bird Species Richness: Suggested Guidelines from Geographical Ecology[1]

R. Chad Roberts[2]

Abstract: Recommendations are given for preserving the richness of oak woodland bird communities, based on a theory of "geographical ecology." The theory is tested with preliminary data along a geographical gradient in northwestern California. Results of the test are consistent with the theory, suggesting that it may be useful for predicting effects of habitat fragmentation.

This symposium asks us to consider the effects upon wildlife of human use of oak woodlands. This is similar to questions asked of conservation biologists in designing "nature reserves" to maximize species preservation with a land base shrinking due to human modifications (Whitcomb and others 1981, Harris 1984). An important theoretical framework for nature reserve design has been contributed by students of biogeographic phenomena, in a subject area appropriately termed "geographical ecology." Recently the term "landscape ecology" (Forman and Godron 1986) has been applied to this body of theory.

The theory of "island biogeography" (MacArthur and Wilson 1967) predicts that the species richness of a mainland will be greater than that of a nearby island, and that as the distance of the island from the mainland increases, the richness will decline further. Taking a series of islands of about the same size and with similar habitats, but differing in distance from the mainland species "source pool," the theory predicts a characteristic declining species richness curve as distance increases.

The "Foothill Woodland" (Munz and Keck 1973) habitat type occupies a significant area around California's central valley (the approximate areal distribution may be determined by superimposing the ranges of valley oak and blue oak [scientific names of oaks in table 1] from Griffin and Critchfield 1976). This physiognomically-designated habitat varies somewhat throughout the state, but the avifauna is relatively constant throughout. The breeding species I observed in Yolo County also were described by Verner and Ritter (1985) from Fresno County.

In this paper, I assume that this expanse of Foothill Woodland may be treated as a "mainland," with a species pool that acts as a source of colonists for outlying "islands" of similar habitat. These islands are oak woodland patches within a matrix of different habitats, located in a transect toward the northwest (see fig. 1). The theory predicts that the fraction of the species present at each site that are also found in the mainland pool will decrease with increasing distance of the site from the mainland. However, if any isolated patch is connected to a less isolated patch by a corridor of suitable habitat, then the species richness of the two patches should be similar, and the isolation effect should be less significant.

In this paper I apply geographical ecological theory and preliminary field survey results to examine a pattern of distribution in the breeding avifauna of oak woodlands in northwestern California. My objectives are: (i) to describe the avifaunal similarity among the study sites, (ii) to apply the similarity calculations to test a prediction derived from geographical ecology, and (iii) to explore the application of geographical ecology to the conservation of biological diversity in California's oak woodlands. The theory may be useful in defining the parameters of "nature reserves" in oak-dominated landscapes, or in guiding research efforts aimed at determining the effects of oak woodland fragmentation.

METHODS

Study Sites

The site selected to represent conditions in Foothill Woodland is in western Yolo County, near the end of County Road 29 (see fig. 1), described in Roberts (1976) and hereafter called the Road 29 site. The approximate northwestern limit of Foothill Woodland in the study area is the headwaters of the main and east forks of the Russian River (fig. 1). Foothill Woodland (represented here by the Road 29 data) is the biogeographic "mainland" for this analysis.

The remaining sites discussed in this analysis were selected according to map location and gross habitat conformation. For the study to be meaningful, the habitats being contrasted must be generally similar, and consequently I selected woodland patches dominated by deciduous oak species with little conifer canopy. (The quantitative similarity of the sites and its effect on the birds will be reported in a subsequent paper; as an indication of similarity, oak species present at each site are listed in table 1.) Sites were not selected by "island" size, although the minimum size accepted was 10 hectares (200 meters by 500 meters).

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[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, California Polytechnic State University, San Luis Obispo, California.

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Table 1--Oak species found at study sites referred to in this report.

SPECIES	LOCATION						
	Road 29	Round Valley	Eel River Canyon	Kekawaka Creek	Olsen Creek	Madden Creek	Bald Hills
Valley Oak (*Quercus lobata*)	x	x					
Blue Oak (*Quercus douglasii*)	x	x					
Interior Live Oak (*Quercus wizlezenii*)	x		x	x			
Black Oak (*Quercus kelloggii*)		x	x	x	x	x	
Garry Oak (*Quercus garryana*)			x	x	x	x	x

Adequate spacing along the geographical gradient was required. This was accomplished by fixing the northwestern end of the transect at a known woodland site (the Bald Hills), and locating a second site (Madden Creek) with appropriate size and habitat conformation along the geographical transect. These two sites established an approximate intersite distance of 30 kilometers as the appropriate spacing.

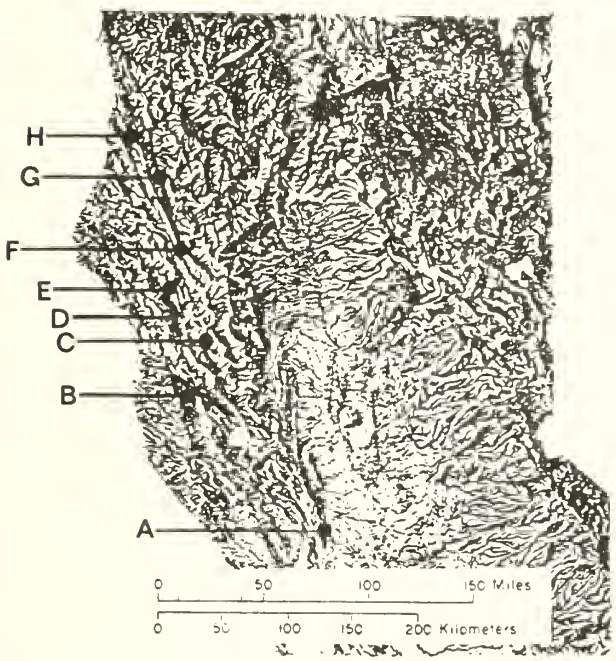


Figure 1--Sites referred to in this report are: A - Road 29, Yolo Co. (Sacramento River drainage); B - headwaters of the Russian River (approximate limit of Foothill Woodland), Mendocino Co.; C - Round Valley, Mendocino Co. (Middle Fork Eel River); D - Eel River canyon, Mendocino and Trinity Cos.; E - Kekawaka Creek, Trinity Co. (mainstem Eel River); F - Olsen Creek, Trinity Co. (Mad River); G - Madden Creek, Humboldt Co. (Trinity River); and H - Bald Hills, Humboldt Co. (Redwood Creek). Note northwest-trending mountains and river drainages, which act as movement corridors for wildlife. Map courtesy of U.S. Geological Survey; reproduced from Griffin and Critchfield (1976).

I required the transect to pass through the mainstream Eel River valley, and include Round Valley, which is slightly upstream on the Middle Fork. Sites there and at Kekawaka Creek are approximately at opposite ends of an essentially continuous oak woodland corridor through the Eel River canyon. The final site (Olsen Creek) was selected as an appropriately configured woodland patch that lay within a map circle between the two adjacent sites.

The oak woodland corridor along the mainstream Eel River was sampled by automobile where accessible, and by boat in the area downstream of Dos Rios (confluence of the mainstream and Middle Fork). Most of this river reach is inaccessible by automobile.

Bird Species Richness

Bird species richness as used here is the number of species believed to be breeding at each site. I assumed that the habitat conformation at each site is close enough to the "niche gestalt" (James 1971) of each species to be acceptable habitat, and that each species is experiencing adequate reproduction to maintain breeding populations in northwestern California. "Breeding" is defined here as being present for one month or longer during the period March through July, being observed defending a territory, or being observed with young. This definition purposely avoided the time-consuming process of locating nests, allowing species to be included on the basis of behavior that generally accompanies breeding. Examples of such behavior include territorial advertisement (especially regular singing), countersinging, conspecific chasing, carrying nesting material, and frequent foraging forays with food ferried back to near the starting point. Many species observed on the study sites were excluded from this analysis because they did not meet any of the criteria for inclusion.

The species richness for Road 29 is based upon a spot-map breeding survey conducted in the spring of 1978; all breeding species present were identified.[3]

The Kekawaka Creek data were derived from an intensive 2-day (12-hr) survey conducted in September 1982. An irregular transect 14.8 kilometers long was walked, in which all bird species present were recorded. The assignment of breeding status to a subset of the observed species (table 2) was based on the following criteria: (i) species that are widespread breeders in northwestern California, (ii) species that are resident (i.e., nonmigratory) in the region, and (iii) species that I have observed breeding in other oak-dominated sites in the Eel River basin (see discussion).

Quantitative data for Round Valley were derived from one preliminary survey conducted outside the breeding season in August 1986. A 1-km survey transect was walked (both directions); additional spot surveys extended the survey length to approximately 2.5 km. All observed bird species were listed, although the primary focus was scansorial species (see below). I used the same criteria that were used for Kekawaka Creek to assign breeding status.

Bird species occurring in oak stands within the Eel River canyon were recorded during three canoe trips (1983, 1984, and 1985), and supplemented with additional data from the part of the canyon accessible by automobile. The canoe trips were conducted in May and June, when nearly all bird species encountered are breeding. Notes were made of all bird species seen or heard in oaks along the river. In addition, variable circular-plot counts (see below) were conducted at several locations.

Data for the other three locations (Bald Hills, Madden Creek, and Olsen Creek) were derived from variable circular-plot surveys (VCP; Reynolds and others 1980), done in conjunction with walkthrough surveys used to identify all species present at each site (see table 3). Additional data for the Bald Hills site came from Davenport (1982). VCP surveys were conducted between 08:00 and noon during the breeding seasons of 1985 and 1986. Sampling periods were standardized at 8 minutes each. Because I was the sole observer, variability in observer sensitivity should be minimized.

VCP count points were not permanently marked. Repeat counts at each of the three sites were conducted from approximately the same points (differing by a few meters between counts) on different visits. Similarly, the walkthrough surveys covered approximately the same zigzag route during sequential visits to a site.

The preliminary species richness data for these sites clearly only approximate the breeding avifauna of each site (see discussion). To strengthen hypothesis testing described here, I took special care to identify scansorial species (which forage partly or entirely on or beneath the bark on trunks, branches, and limbs of the oaks) present at each site. These species are essentially resident (i.e., occur all year) in the woodlands. If geographic trends for the scansorial guild are similar to the trends for all species, then interpretations for the entire avifauna can be made with greater confidence.

[3] Roberts, data on file, Eureka, California.

RESULTS AND DISCUSSION

Biogeography

Few species occurred along the entire gradient. Most species found breeding in northwestern California oak woodland patches did not breed at Road 29, and vice versa (table 2). Using the Road 29 site as a standard for the breeding avifauna of the "mainland," the relative dominance of the mainland species at each of the other sites can be expressed as a ratio according to the formula:

$$D = B/T,$$

where: D = the index of relative dominance,

B = the number of species that bred both at Road 29 and at the site being compared with Road 29, and

T = the total number of species that bred at the site being compared with Road 29.

The descending curve obtaining by plotting the index of relative dominance against site (in order of distance from Road 29; fig. 2A) compares favorably with the "extinction" curves of the MacArthur-Wilson model (MacArthur and Wilson 1967), suggesting a biogeographic interpretation of the decreasing index.

The number of species breeding in any woodland patch did not decrease with distance from Road 29 (table 2), but the percentage of species at each site that were the same as those at Road 29 did (fig. 2A). Thus, as "mainland" pool species dropped out of the local avifauna, they were

Table 3--Numbers of visits, numbers of variable circular-plot counts, and range of percent of species detected at study locations referred to in this report.

Site	Number of Visits	Number of VCPs	Percent of Species Detected[1]
Round Valley	2	2	40 - 50
Eel River Canyon	5	7	65 - 80
Kekawaka Creek	3	-	-
Olsen Creek	4	8	67 - 82
Madden Creek	8	13	75 - 90
Bald Hills	3	6	62 - 78

[1] Based on bootstrap estimation curves in figure 4 of Verner and Ritter (1985).

Table 2--Breeding bird species found at study sites referred to in this report.

SPECIES	LOCATION						
	Road 29	Round Valley	Eel River Canyon	Kekawaka Creek	Olsen Creek	Madden Creek	Bald Hills
American Kestrel (*Falco sparvarius*)	x[1]	x	x	x	x		x
California Quail (*Callipepla californica*)	x	x	x	x			
Mountain Quail (*Oreorty pictus*)				x			
Mourning Dove (*Zenaida macroura*)	x					x	
Anna's Hummingbird (*Calypte anna*)	x						
Allen's Hummingbird (*Selasphorus sasin*)			x	x			
Acorn Woodpecker[2] (*Melanerpes formicivorus*)	x	x	x	x	x	x	
Nuttall's Woodpecker[2] (*Picoides nuttallii*)	x						
Downy Woodpecker[2] (*Picoides pubescens*)				x	x	x	x
Hairy Woodpecker[2] (*Picoides villosus*)		x	x	x	x	x	
Northern Flicker[2] (*Colaptes auratus*)		x	x		x	x	x
Western Wood-Pewee (*Contopus sordidulus*)			x	x			x
Western Flycatcher (*Empidonax difficilis*)			x	x		x	
Ash-throated Flycatcher (*Myiarchus cinerascens*)	x	x	x				
Western Kingbird (*Tyrannus verticalis*)	x		x				
Steller's Jay (*Cyanocitta stelleri*)		x	x	x	x	x	x
Scrub Jay (*Aphelocoma coerulescens*)	x	x	x	x		x	
Chestnut-backed Chickadee[2] (*Parus rufescens*)			x		x	x	x
Plain Titmouse[2] (*Parus inornatus*)	x	x	x	x			
Bushtit (*Psaltriparus minimus*)	x	x	x			x	
Red-breasted Nuthatch[2] (*Sitta canadensis*)					x?[1]	x	x?
White-breasted Nuthatch[2] (*Sitta carolinensis*)	x	x	x	x		x?	x?
Brown Creeper[2] (*Certhia americana*)					x?		
Bewick's Wren (*Thryomanes bewickii*)	x			x		x	
Bluegray Gnatcatcher (*Polioptila caerulea*)		x	x			x	
American Robin (*Turdus migratorius*)					x	x	x
Solitary Vireo (*Vireo solitarius*)		x	x	x	x	x	x
Hutton's Vireo (*Vireo huttoni*)						x	
Warbling Vireo (*Vireo gilvus*)					x	x	
Orange-crowned Warbler (*Vermivora celata*)			x		x	x	x
Yellow-rumped Warbler (*Dendroica coronata*)					x	x	

Table 2--continued

SPECIES	LOCATION						
	Road 29	Round Valley	Eel River Canyon	Kekawaka Creek	Olsen Creek	Madden Creek	Bald Hills
Black-throated Gray Warbler (*Dendroica nigrescens*)			x	x	x	x	
MacGillivray's Warbler (*Oporornis tolmiei*)					x	x	
Western Tanager (*Piranga ludoviciana*)		x	x		x		
Black-headed Grosbeak (*Pheucticus melanocephalus*)			x	x	x	x	x
Rufous-sided Towhee (*Pipilo erythropthalmus*)			x	x		x	x
Brown Towhee (*Pipilo fuscus*)	x	x	x	x			
Chipping Sparrow (*Spizella passerina*)					x	x	
White-crowned Sparrow (*Zonotrichia leucophrys*)							x
Dark-eyed Junco (*Junco hyemalis*)							x
Western Meadowlark (*Sturnella neglecta*)	x						x
Northern Oriole (*Icterus galbula*)	x		x		x?		
House Finch (*Carpodacus mexicanus*)	x						
Lesser Goldfinch (*Carduelis psaltria*)				x			x
American Goldfinch (*Carduelis tristis*)						x	
SITE TOTAL	17	15	25	20	20	26	17

[1]"x" represents a species known or highly likely to be breeding at a site. A blank indicates that the species was not observed or is considered unlikely to breed at site. "x?" represents a species present during the breeding season, but without adequate data to confirm breeding (primarily used here for scansorial species).

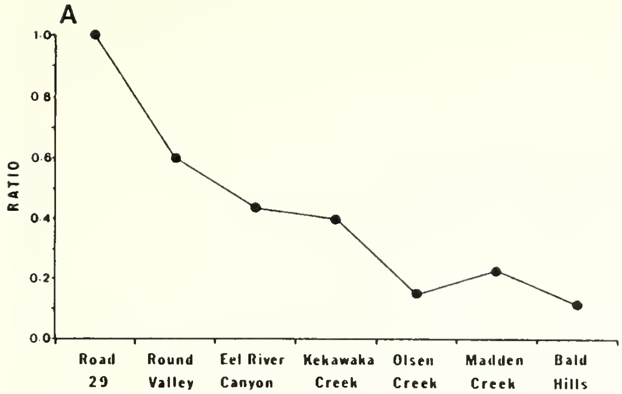
[2]Scansorial species.

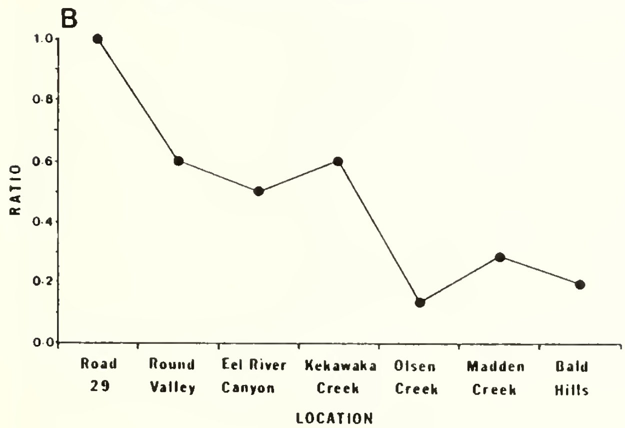
replaced by other species. A comparison of species in table 2 with those in Marcot (1979) suggests that the added species are commonly found in mixed-evergreen forest, the plant community that largely composes the habitat matrix in northwestern California. The declining curve (fig 2A) of mainland species suggests that the "island" approach is reasonable: species in the "mainland" source pool occur as if the intervening habitat were unsuitable.

A similar geographic shift was observed in the composition of the scansorial guild (fig. 2B). The Kekawaka Creek similarity to Round Valley at the other end of the corridor is suggestive (also see table 2), supporting the hypothesis of a "corridor effect." Because the species in this guild are essentially permanent residents, it appears that the turnover indicated for the avifauna as a whole (fig. 2A) was not due solely to regular migration fluxes, but reflects a real geographic pattern.

The percentage of species in each oak woodland patch that are members of the scansorial guild was relatively constant (fig. 2C). I speculate that similar habitat structures in these deciduous oak woodlands lead to relative constancy in the proportion of species that forage by scanning limbs and trunks. The most likely reason is that the distribution of foraging substrate, and the consequent prey distributions, are very similar among the sampled sites (see Holmes and Recher 1986 for a discussion of how substrate availability may determine avian community similarity); ecological mechanisms producing the pattern, however, are far from clear.

The means by which members of a bird community ensure coexistence have been the subject of considerable study and discussion (Cody 1974, Diamond 1975, Simberloff 1978, and others). Explaining the coexistence of these species would carry the geographical analysis one step further. The determinants of community structure are





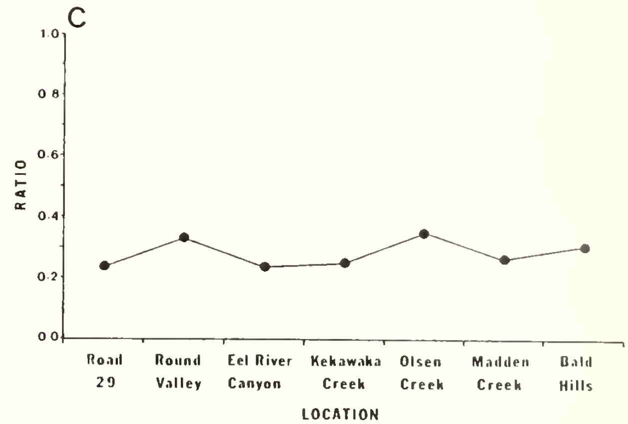


Figure 2--Trends in species' occurrences. A. Ratio of the number species found at both Road 29 and each site to the total species count at the site being compared with Road 29. B. Ratio of the number of scansorial species found at both Road 29 and each site to the total count of scansorial species at the site being compared with Road 29. C. Ratio of the number of scansorial species at each site to the total species count at that site.

unknown for any of these woodlands; oak woodland avifaunas may be an excellent subject for such studies.

These preliminary results probably do not present a completely accurate portrayal of breeding bird species richness in northwestern California oak woodlands. The survey results are not used here to assess densities, however, but only to summarize species' occurrences. Excluding Round Valley, the numbers of VCP counts (table 3) for each site suggest that the VCP counts alone should have detected at least 56 percent of the species present (based on the figure 4 curves of Verner and Ritter 1985). The walkthrough surveys disclosed additional species in each case, so that it is likely that most of the breeding species were observed in these woodlands.

The method I used to designate breeding species for the Kekawaka Creek and Round Valley sites should tend to overestimate the fractions of the observed avifauna that breed at these sites. Even though most of the species have been observed to breed in oak woodlands in northwestern California, they might not breed at these two sites. This result would change the values in the centers of the figure 2A and 2B curves, but the overall shape of the curves would remain the same, and the theoretical considerations would be unchanged.

The objectives of this paper involve testing the applicability of a theory. I believe that the reported data are adequate for this use. More exact results will follow from additional field studies, but I anticipate that the general trend reported here will remain. The similarity in the relative dominance curves (figs. 2A and 2B) for the relatively inexact total species sample and the more accurate scansorial species sample along the geographical gradient suggests applying the theory to preserving diversity in oak woodlands.

Applying Ecological Theory to Oak Conservation

Recommendations for managing and conserving California's oak woodland heritage should be based on bodies of theory recognized by the scientific community. Such a body of theory is landscape ecology, incorporating the concepts of geographical ecology. This theory has implications for managing California's oak woodlands, especially the "hardwood rangelands" around the Central Valley.

"Habitat fragmentation" refers to the effects of removing parts of a once-continuous habitat matrix. Evidence indicates that fragmentation reduces the numbers of species and individuals initially found in a habitat (Whitcomb and others 1981, Harris 1984). The effect of fragmentation on species differs according to each species' ecology. Theoretical considerations and empirical evidence suggest that large habitat fragments support more species than do small fragments (Pickett and Thompson 1976, Whitcomb and others

1981). In some habitats, certain species require a "minimum" habitat area (Forman and others 1976). I know of no study that has addressed the effects of fragmentation or minimum patch size for any plant or animal species in California oak woodlands. Apparently one guideline for conserving diversity in these woodlands might be that fragments should be as large as possible.

A related concept addresses the "connectedness" of fragments. Suitable habitat corridors or "bridges" connecting two or more fragments allow species to move among fragments. It should be relatively easy to preserve connections among patches, and I suggest this as a second guideline. Shelterbelts or "hedgerows" along fencelines, remnant woodlands on steep or rocky areas, riparian corridors, and similar habitat features do not significantly reduce the utility of an area of grazing land. Indeed, they should assist landowners in maintaining land productivity and water quality; Raguse and others (in press) recommended retaining habitat remnants for precisely these reasons.

Evidence and theory also indicate that avian species richness in an area increases as a function of habitat diversity in two ways. First, vertical (Sabo and Holmes 1983, Holmes and Recher 1986) and horizontal (Roth 1976) foliage diversity are positively correlated with the number of bird species found at a site. The number of bird species present also increases with the number of plant species present (James and Wamer 1982). Second, changes in the habitat along an environmental gradient lead to an overall increase in diversity (Lack 1971, 1976), a phenomenon called "beta diversity" (Whittaker 1975). I suggest as a management guideline that habitat remnants have as great a diversity as possible, in terms of the spatial distribution of habitat elements. In woodlands with several oak (and nonoak) species present, a proportional representation of all species should be retained. Where an area under management consideration has a variety of habitat subtypes (savannah, riparian corridor, closed-canopy woodland, and/or chaparral), appropriately-sized remnants of all types should be retained. Vertical foliage distributions in the remnants should be similar to those of the original woodland.

In summary, recommended guidelines for preserving the richness of avian species breeding in California's oak woodlands are: (i) maintain large habitat patches, (ii) maintain connections among the patches, and (iii) maintain structural diversity within the patches. Available data do not indicate which guideline is the most (or least) important in California; managers should implement all three to the greatest degree possible. I suspect that the third guideline represents the greatest contrast to existing management, and in the short term it may be appropriate to emphasize management actions (such as temporary exclusion from grazing) that promote increased habitat structural diversity.

These guidelines for preserving biological diversity are based on existing ecological theory and empirical knowledge. A more comprehensive review and attention to complete theoretical treatments (e.g., Pickett and Thompson 1976, Forman and Godron 1986) undoubtedly will lead to additional guidelines. Additional research effort should be focused upon the ecological mechanisms that underpin biogeographic theories. Such theories have been applied to preserving biological diversity in other contexts, and their application to California's hardwood rangelands can only strengthen resulting management guidelines. Patch sizes, connectedness, and spatial distribution are not trivial considerations for Foothill Woodland plant and wildlife habitats being subjected to firewood harvests, rangeland conversions, and residential subdivision development. I recommend that decisionmakers not make many long-term commitments that would further fragment hardwood resources in California until the impacts of such actions have been studied adequately.

ACKNOWLEDGMENTS

I thank Nancy Tilghman, Ron LeValley, and especially Jerry Verner for helpful comments on this manuscript.

REFERENCES

Cody, Martin, L. Competition and the structure of bird communities. Monographs in population biology, no. 7. Princeton, NJ: Princeton University Press; 1974. 318 p.

Davenport, Dennis R. The Quercus garryana woodland of Redwood National Park and its use by breeding birds. Arcata, CA: Resources management report to Redwood National Park (unpublished); 1982. 24 p.

Diamond, Jared M. Assembly of species communities. In: Cody, Martin L.; Diamond, Jared M., eds. Ecology and evolution of communities. Cambridge, MA: Belknap/Harvard University Press; 1975; 342-444.

Forman, Richard T.T.; Galli, Anne E.; Leck, Charles F. Forest size and avian diversity in New Jersey woodlots with some land use implications. Oecologia 26:1-8; 1976.

Forman, Richard T.T.; Godron, Michel. Landscape ecology. New York, NY: John Wiley and Sons; 1986. 619 p.

Griffin, James R.; Critchfield, William B. The distribution of forest trees in California. Research Paper PSW-82. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture; 1976 (reissue of 1972 original). 118 p.

Harris, Larry D. The fragmented forest--island biogeographic theory and the preservation of biotic diversity. Chicago, IL: University of Chicago Press; 1984. 211 p.

Holmes, Richard T.; Recher, Harry F. Determinants of guild structure in forest bird communities:

an intercontinental comparison. Condor 88(4):427-439; 1986.

James, Frances C. Ordinations of habitat relationships among breeding birds. Wilson Bulletin 83:215-236; 1971.

James, Frances C.; Wamer, Noel O. Relationships between temperate forest bird communities and vegetation structure. Ecology 63(1):159-171; 1982.

Lack, David. Ecological isolation in birds. Cambridge, MA: Harvard University Press; 1971. 404 p.

Lack, David. Island biology illustrated by the land birds of Jamaica. Studies in ecology, vol. 3. Berkeley, CA: University of California Press; 1976. 445 p.

MacArthur, Robert H.; Wilson, Edward O. The theory of island biogeography. Monographs in population biology, no. 1. Princeton, NJ: Princeton University Press; 1967. 203 p.

Marcot, Bruce G. (ed.). California wildlife/habitat relationships program--north coast/Cascades zone. San Francisco, CA: Forest Service, U.S. Department of Agriculture, Region 5; 1979. 5 vol.

Munz, Philip A.; Keck, David D. A California flora, with supplement. Berkeley, CA: University of California Press; 1973. 1705 p.

Pickett, S.T.A.; Thompson, John N. Patch dynamics and the design of nature reserves. Biological Conservation 13(1):27-37; 1976.

Raguse, C.A.; Hull, J.L.; George, M.R.; Albin-Smith, T.K.; Taggard, K.L. Conversion of foothill oak woodland range for beef production in the western Sierra Nevada. In press. (These proceedings.)

Reynolds, R.T.; Scott, J.M.; Nussbaum, R.A. A variable circular-plot method for estimating bird numbers. Condor 82:309-313; 1980.

Roberts, Robert C. Ecological relationships in the Acorn Woodpecker (Melanerpes formicivorus). Davis, CA: University of California; 1976. 100 p. Dissertation.

Roth, Roland R. Spatial heterogeneity and bird species diversity. Ecology 57(4):773-782; 1976.

Sabo, Stephen R.; Holmes, Richard T. Foraging niches and the structure of forest bird communities in contrasting montane habitats. Condor 85(2):121-138; 1983.

Simberloff, Daniel. Using island biogeographic distributions to determine if colonization is stochastic. American Naturalist 112:713-726; 1978.

Verner, Jared; Ritter, Lyman V. A comparison of transects and point counts in oak-pine woodlands of California. Condor 87(1):47-68; 1985.

Whitcomb, R.F.; Robbins, C.F.; Lynch, J.F.; Whitcomb, B.L.; Klimkiewicz, M.K.; Bystrak, D. Effects of forest fragmentation on avifauna of the eastern deciduous forest. In: Burgess, Robert L.; Sharpe, David M., eds. Forest island dynamics in man-dominated landscapes. Ecological studies, vol. 41. New York, NY: Springer-Verlag; 1981; 125-205.

Whittaker, Robert H. Communities and ecosystems, second edition. New York, NY: MacMillan Publishing Co.; 1975. 385 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Use of Pacific Madrone by Cavity-Nesting Birds[1]

Martin G. Raphael[2]

Abstract: As part of a larger study of wildlife habitat associations in Douglas-fir (Pseudotsuga menziesii) forests of northwestern California, I recorded characteristics of nest sites used by 16 species of cavity-nesting birds. Pacific madrone (Arbutus menziesii) contributed only 8 percent of the basal area of the stands I studied, but 24 percent of all cavity nests were in madrone. Although nests were distributed among 17 tree species, only madrone was used at a rate greater than predicted from availability. About 75 percent of available madrone trees were <30 cm dbh, but only 11 percent of the nests were in these smaller trees. Larger than average madrones seem to be an important habitat component for cavity-nesting birds in California's Douglas-fir forests; however, madrones are also a prime fuelwood species. A potential conflict thus exists between commercial use of madrone and its value for wildlife.

Mixed-evergreen forests of northwestern California support one of the most complex vegetation patterns in North America (Whittaker 1961). Much of this complexity results from the diversity of hardwood species comprising the lower overstory canopy. These hardwoods are recognized as a potentially rich resource for wood products and energy (McDonald 1983, Zerbe 1985). Pacific madrone (Arbutus menziesii) is a dominant tree species in this complex and, because of its values as pulpwood and fuelwood, is heavily used locally.

Pacific madrone is also an important food source for birds and other species that feed on its berries. For example, Hagar (1960) found that varied thrushes (Ixoreus naevius) were more abundant in a winter when there was a large berry crop than in years of poor crops. I observed a similar response of varied thrushes and American robins (Turdus migratorius) to changing berry crops: both species were at least twice as abundant in the winter of 1980-81 when the madrone berry crop was heavy compared with the next two winters when berries were much less numerous (Raphael, unpublished data).

The importance of Pacific madrone as nesting habitat is less well known. The objective of this study was to evaluate the use of madrone as a nesting substrate for cavity-nesting birds.

STUDY AREA

This study was conducted from 1981 to 1983 in the Six Rivers, Shasta-Trinity, and Klamath National Forests of northwestern California as part of a larger study of habitat associations of vertebrates in relation to stand age (Raphael 1984). Elevation on the study sites ranged from 427 to 1220 m. Weather was characterized by cool, wet winters (89-137 cm precipitation/yr) and warm, dry summers (maximum temperature usually <35°C). Douglas-fir (Pseudotsuga menziesii) in association with tanoak (Lithocarpus densiflorus) and Pacific madrone dominated the forest cover.

METHODS

During the course of other field work in spring and summer, observers located active bird nests. For each active nest, the observer noted the date, location, bird species, tree species, tree condition (live or dead), tree height, dbh, nest height, nest aspect, substrate type (if the nest was not in a tree), nest status (building nest, incubating eggs, feeding young), and any other relevant observations.

To characterize the structure and composition of vegetation in the study area, 408 0.04-ha circular plots were randomly located. Species, height, dbh, and crown dimensions of each tree or shrub >2.0 m tall within each plot were recorded. These data were used to calculate canopy volume for each species on each plot. The program HTVOL (Mawson and others, 1976) was modified to perform all such volume calculations.

[1]Presented at the symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Table 1--Abundance of dominant trees in Douglas-fir forest of northwestern California. Values are means from 408 0.04-ha plots.

Species	Density (stems/ha)	Basal area (m^2/ha)	Canopy volume (m^3/ha)
Douglas-fir	325.8	37.1	48,138
Tanoak	460.0	8.4	12,874
Pacific madrone	57.8	4.8	3,406

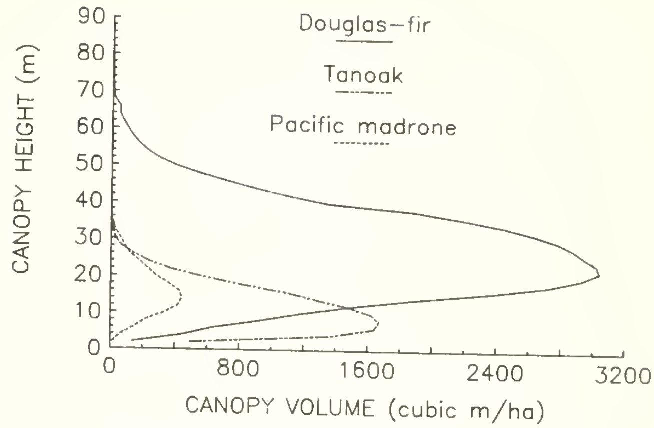

Figure 1. Canopy volume in relation to height of three tree species in Douglas-fir forests, northwestern California. Values at each height are averages from all tree sampled on 408 0.04-ha plots.

RESULTS

Madrone Characteristics

In all, 25,110 trees and shrubs of 37 species on the 408 vegetation plots were sampled. Pacific madrone ranked third in average density, basal area, and canopy volume after Douglas-fir and tanoak (table 1). Madrone occurred as a relatively minor component of the lower canopy in association with tanoak; both species were overtopped by Douglas-fir (fig. 1). Canopy volume of madrone was distributed below about 30 m canopy height, reaching its maximum volume at about 15 m (fig. 1). Madrone was most abundant on drier, south-facing slopes at lower elevations. Its abundance was significantly correlated ($P < 0.001$) only with canyon live oak (*Quercus chrysolepis*), suggesting that the two species have similar habitat requirements.

Nest Tree Characteristics

Observers located 126 nests of 33 bird species (table 2). Overall, most nests were in Douglas-fir, followed by Pacific madrone and tanoak. Among 70 cavity nests, 35 were in Douglas-fir, 17 in Pacific madrone, 7 in tanoak, 3 in *Quercus* species, and 8 in other species. The frequency of cavity nests in Pacific madrone was significantly greater (binomial test, $P < 0.001$) than the relative basal area of madrone

Table 2--Tree species used for nesting by cavity-nesting and other bird species in Douglas-fir forests of northwestern California.

Bird Species	Numbers of nests by species[1]					
	DF	PM	TO	QS	OT	Total
Western screech-owl (*Otus kennicottii*)	1	0	0	1	0	1
Spotted owl (*Strix occidentalis*)	1	0	0	0	0	1
Acorn woodpecker (*Melanerpes formicivorus*)	1	2	0	0	0	3
Red-breasted sapsucker (*Sphyrapicus ruber*)	5	6	0	0	2	13
Downy woodpecker (*Picoides pubescens*)	0	1	1	0	0	2
Hairy woodpecker (*Picoides villosus*)	0	3	0	0	1	4
White-headed woodpecker (*Picoides albolarvatus*)	1	0	0	0	0	1
Northern flicker (*Colaptes auratus*)	2	0	2	0	1	5
Pileated woodpecker (*Dryocopus pileatus*)	1	0	0	0	1	2
Mountain chickadee (*Parus gambeli*)	0	1	0	0	1	2
Chestnut-backed chickadee (*Parus rufescens*)	6	0	0	1	0	7
Red-breasted nuthatch (*Sitta canadensis*)	8	1	1	2	1	13
White-breasted nuthatch (*Sitta carolinensis*)	1	0	1	0	1	3
Brown creeper (*Certhia americana*)	7	0	1	0	0	8
House wren (*Troglodytes aedon*)	1	2	1	0	0	4
Western bluebird (*Sialia mexicana*)	0	1	0	0	0	1
All cavity-nesters	35	17	7	3	8	70
Other birds (17 species)	12	4	13	2	25	56
All species	47	21	20	5	33	126

[1] DF = Douglas-fir, PM = Pacific madrone, TO = tanoak, QS = *Quercus* species, OT = other tree or shrub species.

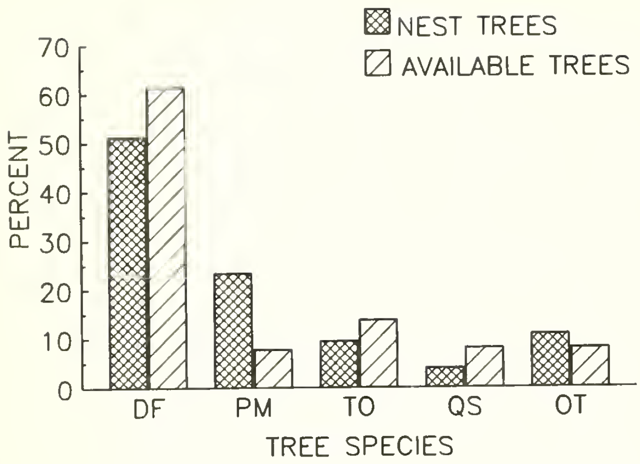

Figure 2. Percent use by cavity nesting birds and percent availability of tree species. DF = Douglas fir, PM = Pacific madrone, TO = Tanoak, QS = *Quercus* species, OT = other.

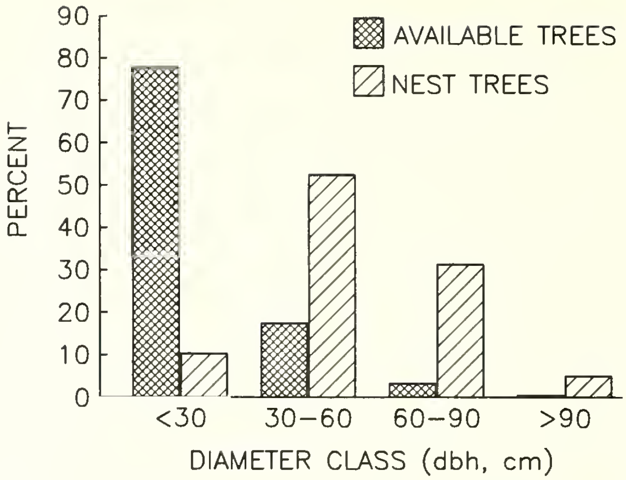

Figure 3. Diameter distribution of madrones used for nesting (n=19) and of available madrones (n=1,061) in northwestern California.

(fig. 2); frequencies of cavity nests in all other tree species did not differ significantly from availability. Open-nesting species, in contrast, used tanoak at a rate significantly greater than expected (35.1 percent of nests versus 14.0 percent basal area, $P < 0.01$).

Among primary cavity-nesting species (those capable of excavating their own nest cavities), red-breasted sapsucker, hairy woodpecker, and acorn woodpecker most often excavated cavities in madrone (table 2). Together, these three species excavated 11 of 17 nests in madrone whereas only 2 madrone nests would be expected if nest selection were random with respect to tree species. Two of these species, red-breasted sapsucker and hairy woodpecker, are the most abundant woodpeckers in the Douglas-fir habitat type (Raphael and others, in press), and their apparently strong preference for Pacific madrone may result in a higher proportion of abandoned cavities (suitable for secondary cavity-nesting species) in madrone versus other tree species.

Trees used by cavity-nesting birds were most frequently in the 30- to 45-cm diameter class (25 percent of all nests). In contrast, most sampled trees were <15 cm dbh (75 percent). Among cavity nests in Pacific madrone, 89 percent were in trees >30 cm dbh, whereas only 22 percent of available trees were that size (fig. 3). Madrones used by cavity-nesting birds averaged 14.9 m tall (range 6.0-44.0, SD=10.2 m); nest holes averaged 9.0 m above the ground (range 3.0-15.0, SD=3.4 m). Nine of the 17 madrone nest trees were live, and five of these trees showed no external evidence of disease or damage.

DISCUSSION

Although sample sizes of nests are small, these data suggest that Pacific madrone is an important component of cavity-nesting bird habitat in Douglas-fir forests of northwestern California. The importance of madrone in this study area seems to parallel the importance of aspen (*Populus tremuloides*) in the northeastern U.S. (Lawrence 1967), especially for hairy woodpecker and sapsucker populations. Aspen and madrone are similar in form: both are smooth barked, both tend to have long trunks that are relatively free of branches, and their wood is similar in texture and hardness.

More important, perhaps, is the frequency of heartwood decay fungi associated with both species. Woodpeckers are known to select aspen infected with *Fomes igniarius* (Kilham 1971). By leaving the sapwood sound while decaying the heartwood, this fungus creates ideal conditions for excavating a nest cavity surrounded by a strong outer wall. The presence of decay within madrone nest trees was not noted, but I have observed a high incidence of heartrot in cut madrones, especially among larger-diameter trees such as those preferred by birds in this study. I believe it is likely that birds in northwestern California select trees that are infected by heartrot fungi. This may explain the apparent preference for madrone and the high incidence of nests located in live trees, unlike other areas in California where dead trees are the preferred substrate (Raphael and White 1984).

Management Recommendations

If Pacific madrone is a preferred nest tree species for primary cavity-nesting birds in this forest type, some considerations should be given

Table 3--Estimated breeding densities of primary cavity-nesting bird species and estimated numbers of Pacific madrone stems >30 cm dbh needed each year to provide nesting substrate.

Woodpecker species	Maximum density (D) (pairs/100 ha)[1]	No. cavities excavated/ pair/yr (C)[1]	Proportion madrone (X)[2]	No. madrone stems needed /100 ha (S)[3]
Acorn woodpecker	8.6	5	0.7	30
Red-breasted sapsucker	27.9	1	0.5	14
Downy woodpecker	4.9	2	0.5	5
Hairy woodpecker	39.5	3	0.8	95
Northern flicker	12.0	1	[4]0.1	2
Pileated woodpecker	0.5	3	[4]0.1	1
Totals	93.4			147

[1] From Neitro and others (1985).
[2] Proportion of nests in madrone, rounded from data in Table 2.
[3] Computed from (D) x (C) x (X).
[4] Values assumed.

for its management. Two considerations are most important--the number of trees and their diameter. To estimate madrone requirements, I used data from Neitro and others (1985) and this study to calculate (S) = (D) x (C) x (X) where (S) is the number of madrone stems needed per year, (D) is the maximum density of each primary cavity-nesting species, (C) is the number of cavities excavated/pair/year, and (X) is the expected proportion of nests excavated in madrone. Results indicate that a total of about 147 madrone stems/100 ha (1.5 stems/ha) should be available each year (table 3). As shown in figure 3, birds rarely nested in madrones <30 cm dbh. Thus, the estimated madrone requirement of 1.5 stems/ha should include only trees >30 cm dbh. The average density of these larger madrones in the vegetation plots was about 13 stems/ha. Therefore, meeting these estimated nesting requirements of primary cavity-nesting birds would entail retention of about 10 percent of the available large stems.

These recommendations are offered as interim guidelines. First, it is not known if birds used madrone opportunistically in this study. The critical question is whether, in the absence of madrone, cavity-nesting birds might shift to another tree species without loss of reproductive fitness. Circumstantial evidence presented in this study suggests otherwise: madrone trees seemed to be actively selected by at least two primary cavity-nesting species. Until results of additional research can resolve these questions, retention of madrone in managed stands would seem to be prudent.

ACKNOWLEDGMENTS

I thank the Pacific Southwest Region and the Pacific Southwest Forest and Range Experiment Station of the USDA Forest Service for funding this study. The University of California (AES Project 3501 MS) also provided support and I thank Reginald H. Barrett for his encouragement. The study would not have been possible without the help of many dedicated field assistants; I thank them all. Douglas Runde and James A. Sedgwick commented on an earlier draft.

REFERENCES

Hagar, Donald C. The interrelationships of logging, birds and timber regeneration in the Douglas-fir region of northwestern California. Ecology 41(1): 116-125; 1960.

Kilham, Lawrence. Reproductive behavior of yellow-bellied sapsuckers. I. Preference for nesting in Fomes-infected aspens and nest hole interrelations with flying squirrels, raccoons, and other animals. Wilson Bulletin 83(2): 159-171; 1971.

Lawrence, Louise de K. A comparative life history study of four species of woodpeckers. Ornithological Monographs 5; 1967. 156 p.

Mawson, Joseph C.; Thomas, Jack Ward; DeGraaf, Richard M. Program HTVOL--the determination of tree crown volume by layers. Res. Paper NE-354. Upper Darby, PA: Northeast Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1976, 9 p.

McDonald, Philip M. Local volume tables for Pacific madrone, tanoak and California black oak in north-central California. Res. Note PSW-362. Berkeley CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1983. 6 p.

Neitro, William A.; Binkley, Virgil W.; Cline, Steven P.; Mannan, R. William; Marcot, Bruce G.; Taylor, Douglas; Wagner, Frank F. Snags (wildlife trees). In: E. Reade Brown, tech. ed. Management of wildlife and fish habitats in forests of western Oregon and Washington. Part I--chapter narratives. Publication R6-R&WL-192. Portland OR: Pacific Northwest Region, Forest Service, U.S. Department of Agriculture; 1985: 129-169.

Raphael, Martin G. Wildlife populations in relation to stand age and area in Douglas-fir forests of northwestern California. In: Meehan, William R.; Theodore R. Merrell, Jr.; Thomas A. Hanley, tech. eds. Fish and wildlife relationships in old-growth forests: proceedings of a symposium; 1982 April 12-15; Juneau, AK: American Institute of Fishery Research Biologists; 1984: 259-274.

Raphael, Martin G.; Rosenberg, Kenneth V.; Marcot, Bruce G. Large-scale changes in bird populations of Douglas-fir forests, northwestern California. Bird conservation 3: In press.

Raphael, Martin G.; White, Marshall. Use of snags by cavity-nesting birds in the Sierra Nevada. Wildlife Monographs 86; 1984. 66 p.

Whittaker, Robert H. Vegetation history of the Pacific coast states and the "central" significance of the Klamath region. Madroño 16: 5-23; 1961.

Zerbe, John I. Fuelwood use spurs hardwood resurgence. Quads report on energy activities 2(1): 1; 1985.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Monitoring Herpetofauna in Woodland Habitats of Northwestern California and Southwestern Oregon: A Comprehensive Strategy[1]

Hartwell H. Welsh, Jr.[2]

Abstract: Herpetofauna representing 26 species were collected for 2 years from 54 terrestrial and 36 aquatic sites in mixed hardwood-coniferous forest in northwestern California and southwestern Oregon, using three different sampling methods: pitfall traps, time-constrained searches, and area-constrained searches (aquatic habitats only). The advantages and disadvantages of each method are discussed in relation to the research and management goals of data quality, data quantity, cost-effectiveness and applicability to long-term monitoring. A comprehensive approach to herpetofaunal monitoring in woodland habitats is recommended, with emphasis on training of personnel in species identification and habitat preferences, timing of sampling effort with respect to climatic variables, repeatability of sampling, and complementation of sampling methods. Such an approach promotes cost-effective and complete species sampling, accurate relative abundance values, and a versatile, reliable long-term monitoring program.

The important role of herpetofaunas in ecosystem dynamics has become increasingly apparent (Burton and Likens 1975, Bury and others 1980). Consequently, there is considerable research interest in the structure of herpetofaunal communities, both temperate and tropical. These communities contain a broad diversity of life forms, presenting a unique challenge for investigators. The herpetofauna in California hardwood habitats is no exception, consisting of a total of 38 species from 4 orders: 9 salamanders, 5 frogs and toads, 9 lizards, 14 snakes, and 1 turtle. Gathering data on the distribution and abundance of all elements in such a diverse community usually requires a combination of sampling techniques. Several sampling methods have been developed (Scott 1982). However, little information is available to compare the relative effectiveness of different sampling methods in different habitats (Vogt and Hine 1982, Campbell and Christman 1982, Bury and Raphael 1983, and Raphael and Rosenberg 1983). The objectives of this study were to compare (1) the numbers and species composition of herpetofauna, and (2) the relative cost effectiveness, using three methods. This sampling approach was developed for the Forest Service's Old-Growth Wildlife Habitat Program (Corn and Bury, Bury and Corn, in prep.) for use in the Douglas-fir dominated forests of the Pacific Northwest. Data reported here are from the Siskiyou Mountains/Klamath Mountains Province of the Old-Growth Wildlife Habitat Program (OGWHP). These methods are equally applicable in the more xeric and open woodland habitats that are the focus of this symposium.

STUDY AREA

The study was conducted within Douglas-fir (Pseudotsuga menziesii) dominated mixed coniferous-hardwood forests of northwestern California and southwestern Oregon; the southwest portion of the Douglas-fir Biome. Fifty-four terrestrial study sites, ranging in size from 21 to 150 ha, and 39 aquatic study sites (15-m lengths of second- or third-order streams) were sampled. Fifteen terrestrial sites and 12 aquatic sites, were located in each of the following: near Branscomb in Mendocino County, California; near Willow Creek in Humboldt and Trinity Counties, California; and near Cave Junction in Josephine County, Oregon. Three terrestrial sites and one aquatic site were located in each of three additional locations: Butte Creek and Redwood Experimental Forest in Humboldt County, California, and on serpentine formations east of the Kalmiopsis Wilderness Area in Josephine County, Oregon.

METHODS

Three methods were used to sample the species composition and abundance of the herpetofauna: pitfall traps (Corn and Bury, in prep.), time-constrained searches (Corn and Bury, in prep; Raphael and others 1982; Inger and Colwell 1977), and area-constrained aquatic searches (modified from Bury and Corn, in prep.). Two of the methods, pitfall trapping and time-constrained searches, were used to sample terrestrial species, while an area-constrained search method was adapted specifically for aquatic habitat. The aquatic search technique is a modified

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, Calif.

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area-constrained technique that can also be applied to terrestrial habitats, and hence these data are comparable in several ways to data collected with the other two methods.

Pitfall Trapping

Pitfall traps consisted of two no. 10 tin cans taped together with duct tape (bottom removed from upper can) with a plastic funnel insert (1-lb margarine tub with its bottom cut out) to prevent animals from climbing out (fig. 1, Bury and Raphael 1983). Each trap was buried flush with the ground, and a wooden cover (a shingle or piece of bark) was propped up on pebbles or twigs to provide 1-3 cm of crawl space. Grids of 36 traps, spaced 15 m apart in rows and columns of six, were installed at 49 terrestrial sites: 15 grids were established in each of the three areas described above, plus 2 grids each at Butte Creek and at the Redwood Experimental Forest in Humboldt County, California. Traps were operated for 50 days in October and November 1984, and for 30 days in October 1985. Traps were checked at 5- to 7-day intervals, and captures were either taken or marked to prevent them from being recounted on subsequent rounds.

Time-Constrained Searches

Time-constrained searches consisted of a two-person, 2-hour search of as much microhabitat at a site (from ground level up to 2 m) as could be covered in that time, for a total of 4 person-hours per site each year. Workers using potato rakes lifted rocks and woody debris, opened decomposed logs, raked rock rubble and leaf litter, probed cracks, crevices and other refuges, peeled bark, and walked through low vegetation to flush out animals. Only the actual searching time counted against the time limit; measuring of specimens and recording of data were performed with the clock stopped. Searches were performed at each of the 54 terrestrial sites between March and June 1984 and again in 1985. In addition, 15 sites near Branscomb, and 15 sites near Willow Creek were searched between April and June 1986.

Area-Constrained Aquatic Searches

Second- or third-order streams (Strahler 1952) on or near the terrestrial sites were searched. Searchers selected three 5-m reaches 1-3 m wide along each stream by walking 50 paces upstream from the nearest trail or road access for the first reach, and from the top of the previous reach for subsequent reaches (systematic random sampling). The searches required two people capturing animals in the water, and a third person at streamside handling the captures and recording the data. Searchers worked upstream, placing nets behind them, and holding face masks at the water's surface where necessary to improve underwater visibility. They worked systematically and thoroughly, moving all rocks, logs, and debris possible and probing all crevices and other cover to capture all animals within the reach. Twenty-one streams were searched in 1984 and 19 in 1985.

Analysis of Data

Results were compared for individual species, total captures, and mean captures per site from 1984 and 1985 for the three methods. Also, the 1984 and the 1985 data from the two terrestrial sampling methods were compared in terms of both number of individuals captured, and the number of new species present—the first record for a particular species at each study site. Data from TCS, taken on a subset of 30 study sites in 1986, were included in this latter analysis. Finally, a cost analysis was performed for each method, based on total captures and total cost during 1984 and 1985, to arrive at a cost-per-capture figure for each method.

RESULTS

Pitfall Trapping

Pitfall trapping (PF) sampled 19 of the 26 species of herpetofauna collected (table 1). In the first 30 nights of trapping in 1984, 121 fewer individuals were captured than in the first 30 nights in 1985 (table 2). Comparison of numbers of individual captures per trap check indicate a markedly higher rate of capture immediately following the first rains of the season (fig. 1).

The numbers of species-presence records were 133 in 1984 and 101 in 1985, with 161 records noted for both years combined (table 2). During the last 20 trap-nights of 1984, 30 new species-presence records occurred; 24 of these records were unique while 6 were duplicated in the 1985 trap session. The rate of accumulation of new species records for both years combined indicates a leveling off began after about 50 days, but new records continued to accumulate throughout the remaining 30 days (fig. 2). Fifty-nine of the new species present were noted only in 1984, while 28 were unique to 1985 (table 2). These 28 additions occurred on 20 sites, with the range of new species added per site at 0-4, and the mean of new species added per site at 0.55. Operation of the traps for a second year resulted in increasing the new species records by 16.8 percent, an appreciable amount. These data indicate that sampling efforts in excess of 50 days, while recording a lower rate of new species, continue to yield new information on species richness as the rarer species are captured.

Amphibians

PF was effective for sampling terrestrial salamanders, capturing all the species that time-constrained searches (TCS) detected (table 1). However, PF sampled few Clouded Salamanders

Table 1--Captures of herpetofauna collected with three methods in woodland habitats of northwestern California and southwestern Oregon in 1984 and 1985.

Species	Pitfall trapping[1] Total	$\bar{X}$[2]	Time-constrained searches[3] Total	$\bar{X}$	Area-constrained aquatic searches[4] Total	$\bar{X}$	Total all methods
			Amphibians				
Tailed Frog (*Ascaphus truei*)	9	0.09 ±0.41	3	0.03 ±0.17	487	12.18 ±18.26	499
Western Toad (*Bufo boreas*)	3	0.03 ±0.17	1	0.01 ±0.10	0	0	4
Pacific Treefrog (*Hyla regilla*)	9	0.09 ±0.29	23	0.21 ±0.61	0	0	32
Yellow-legged Frog (*Rana boylii*)	27	0.27 ±1.25	0	0	21	0.53 ±0.96	48
Frog subtotals	48	0.49 ±1.39	27	0.25 ±0.74	508	12.70 ±17.94	583
Percent of total		8.2		4.6		87.1	10.9
Northwestern Salamander (*Ambystoma gracile*)	4	0.04 ±0.25	1	0.01 ±0.96	0	0	5
Clouded Salamander (*Aneides ferreus*)	5	0.05 ±0.22	153	1.37 ±2.09	0	0	158
Black Salamander (*Aneides flavipunctatus*)	20	0.20 ±0.91	24	0.22 ±0.80	7	0.18 ±0.45	51
Arboreal Salamander (*Aneides lugubris*)	1	0.01 ±0.10	0	0	0	0	1
Calif. Slender Salamander (*Batrachoseps attenuatus*)	72	0.74 ±1.58	631	5.84 ±9.94	2	0.05 ±0.22	705
Pacific Giant Salamander (*Dicamptodon ensatus*)	31	0.32 ±0.73	13	0.12 ±0.47	891	22.30 ±18.95	935
Ensatina (*E. eschscholtzii*)	1194	12.18 ±14.92	1105	10.23 ±8.85	0	0	2299
Del Norte Salamander (*Plethodon elongatus*)	213	2.17 ±13.03	193	1.77 ±6.58	0	0	406
Olympic Salamander (*Rhyacotriton olympicus*)	1	0.01 ±0.10	30	0.28 ±1.11	11	0.30 ±1.43	42
Rough-skinned Newt (*Taricha granulosa*)	39	0.39 ±0.97	34	0.31 ±0.86	3	0.08 ±0.27	76
Salamander subtotals	1580	16.12 ±19.27	2184	20.22 ±15.53	914	22.90 ±13.93	4678
Percent of total		33.8		46.7		19.5	87.1

[1] 49 samplings each year.
[2] X=mean per sampling session ± 1 standard deviation.
[3] 54 samplings each year.
[4] 21 samplings in 1984 and 19 in 1985.

Table 1 (continued)--Captures of herpetofauna collected with three methods in woodland habitats of northwestern California and southwestern Oregon in 1984 and 1985.

Species	Pitfall trapping[1] Total	$\bar{X}$[2]	Time-constrained searches[3] Total	$\bar{X}$	Area-constrained aquatic searches[4] Total	$\bar{X}$	Total all methods
			Reptiles				
Western Skink (*Eumeces skiltonianus*)	5	0.03 ±0.26	13	0.12 ±0.51	N/A	N/A	18
Northern Alligator Lizard (*Gerrhonotus coeruleus*)	4	0.04 ±0.20	29	0.27 ±0.77	N/A	N/A	33
Southern Alligator Lizard (*G. multicarinatus*)	1	0.01 ±0.10	2	0.02 ±0.14	N/A	N/A	3
Western Fence Swift (*Sceloporus occidentalis*)	3	0.03 ±0.22	19	0.18 ±1.20	N/A	N/A	22
Sagebrush Lizard (*Sceloporus graciosus*)	0	0	14	0.13 ±1.09	N/A	N/A	14
Lizard subtotals	13	0.13 ±0.45	77	0.71 ±2.01	N/A	N/A	90
Percent of total		14.4		85.6		N/A	1.7
Sharp-tailed Snake (*Contia tenuis*)	0	0	4	0.04 ±0.23	N/A	N/A	4
Western Racer (*Coluber constrictor*)	0	0	1	0.01 ±0.10	N/A	N/A	0
Ringneck Snake (*Diadophis punctatus*)	0	0	7	0.06 ±0.31	N/A	N/A	7
Mountain Kingsnake (*Lampropeltis zonata*)	0	0	1	0.01 0.10	N/A	N/A	1
Terrestrial Garter Snake (*Thamnophis elegans*)	0	0	2	0.02 ±0.19	N/A	N/A	2
Northwestern Garter Snake (*Thamnophis ordinoides*)	1	0.01 ±0.10	4	0.04 ±0.23	N/A	N/A	5
Common Garter Snake (*Thamnophis sirtalis*)	0	0	1	0.01 ±0.10	N/A	N/A	1
Snake subtotals	1	0.01 ±0.10	20	0.19 ±0.66	N/A	N/A	21
Percent of total		4.8		95.2		N/A	0.4
Reptiles and amphibians combined	1642		2308		1422		5372
Percent of total		30.6		43.0		26.4	100

[1] 49 samplings each year.
[2] X=mean per sampling session ± 1 standard deviation.
[3] 54 samplings each year.
[4] 21 samplings in 1984 and 19 in 1985.

or Slender Salamanders compared with TCS (see also Bury and Raphael 1983, Raphael and Rosenberg 1983). In addition, PF captured one Arboreal salamander, a species not captured by other methods. This species reaches the northern extreme of its range near our southernmost pitfall sites. It rarely occurs in mixed coniferous-hardwood forests, so this result should not be interpreted to indicate the PF's unique ability among the three methods to detect this species. The captures of Tailed and Foothill Yellow-Legged Frogs occurred at sites adjacent to streams, indicating that PF effectively samples some species of aquatic frogs if trapping sessions are timed to correspond with periods of overland migration (see also Bury and Corn 1987).

Reptiles

Pitfall trapping captured only 14.4 percent of lizards and 4.8 percent of snakes taken by the two terrestrial methods combined. They captured all but one species of lizard but only a single species of snake taken by TCS (table 1).

Time-Constrained Searches

TCS yielded 24 species, more than either PF or area-constrained aquatic searches (AQS). Only two species--the Yellow-Legged Frog and the Arboreal Salamander--were not detected by this method. TCS also gave the most captures for the study (table 1). Nine species were captured only or primarily by this method (75 percent or more of captures from all sites in both years).

Species-presence records (table 2) ranged from 1 to 7 for the 54 sites in 1984. The range for new species per plot in 1985 was 0-4, and in 1986 it was 0-3. The dramatic increase in the mean number of captures per site in 1986 (table 2) is a

Table 2--Within- and between-year captures and species-presence records for pitfall trapping and time-constrained searches in woodland habitats of northwestern California and southwestern Oregon, 1984-1986.

	Pitfall grids (49 plots)			Time-constrained searches (54 plots 1984, 1985; 30 plots 1986)		
Sampling session	First 30 nights, Fall 1984	Last 20 nights, Fall 1984	30 nights, Fall 1985	Spring 1984	Spring 1985	Spring 1986
Number of captures	675	414	554	1197	1111	1021
Mean number of captures per plot (±1 S.D.)	13.77 (±18.38)	8.45 (±8.28)	11.31 (±10.51)	22.16 (±15.42)	20.57 (±15.44)	34.03 (±16.36)
Change of mean from previous year (pct.)	--	--	[1]-19.2	--	-7.7	+39.5
Number of new species-presence records	103	30	28	147	62	26
Number of plots with new species-presence records	49	20	20	54	35	22
Percent of plots sampled with new species-presence records	100	40	40	100	65	73
Increase from previous session (pct.)	--	+22.5	+16.8	--	+29.6	+11.0
Mean no. of new species-presence records per plot (+1 S.D.)	2.10 (±1.03)	0.61 (±0.79)	0.57 (±0.89)	2.72 (±1.43)	1.15 (±1.14)	0.87 (±1.04)

[1]Compared with first 30 days of 1984.

result of sampling only the more southern sites. The 15 searches on more northern sites, around Cave Junction, Oregon, yielded markedly fewer individuals per site than the remaining sites in 1984 and 1985, and thus negatively affected the overall mean number of individuals per site for those years.

Comparing the mean numbers of new species present per site and per year (fig. 3) for 1984 and 1985 combined, PF yielded 160 new records or 43.6 percent, and TCS yielded 209 new records or 56.4 percent. In 1984 the two methods were nearly equal at 2.7 new species per site, however in 1985, TCS yielded 62 new records for 69.7 percent while PF produced 27 new records for 30.3 percent. TCS, an active sampling method, is clearly superior, over the long term, for accumulating new species richness information.

Amphibians

TCS was the least effective of the three methods for sampling frogs; however, the primarily terrestrial Pacific Treefrog showed the reverse with 74.2 percent of captures by TCS (table 1). TCS proved highly effective for sampling terrestrial salamanders; 8 of 9 species were collected by this method. TCS is clearly a superior method for sampling Clouded Salamanders and Slender Salamanders, the two species underrepresented in pitfall sampling, and the Olympic Salamander, a species of low vagility that rarely wanders far from the seeps and springs it inhabits.

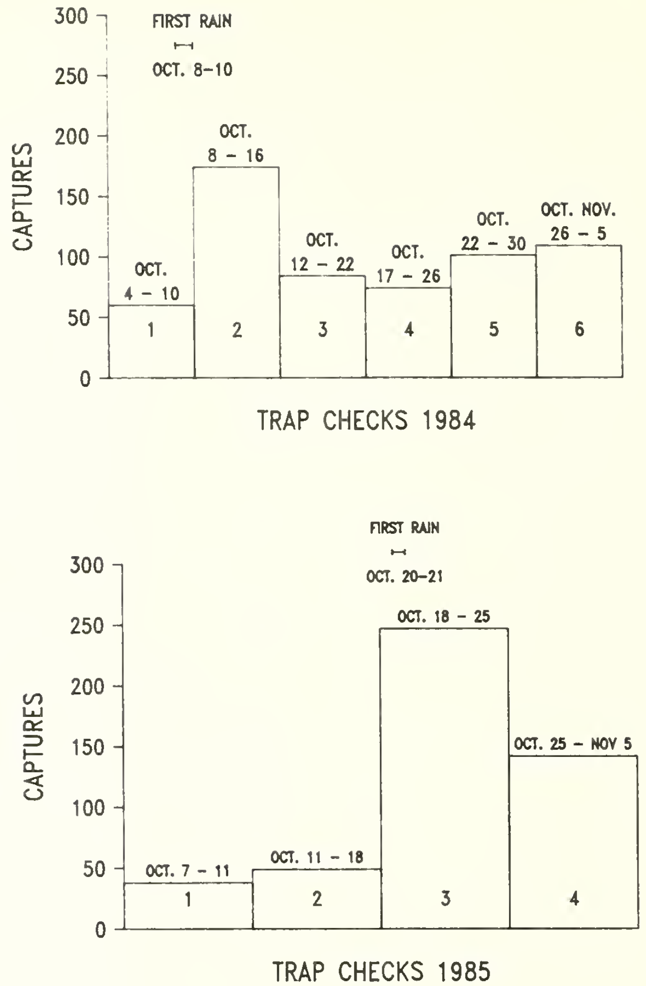

FIGURE 1.--NUMBERS OF HERPETOFAUNA COLLECTED IN PITFALL TRAPS IN WOODLAND HABITATS OF NORTHWESTERN CALIFORNIA AND SOUTHWESTERN OREGON IN 1984 AND 1985.

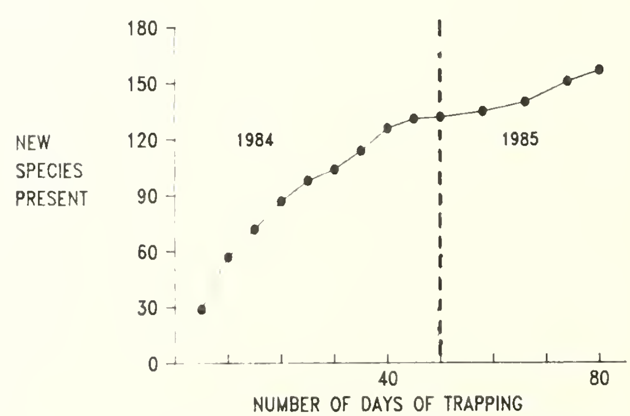

FIGURE 2.--RECORDS OF NEW SPECIES PRESENT, FROM FALL PITFALL TRAPPING AT 49 SITES IN 1984 AND 1985 IN WOODLAND HABITATS OF NORTHWESTERN CALIFORNIA AND SOUTHWESTERN OREGON.

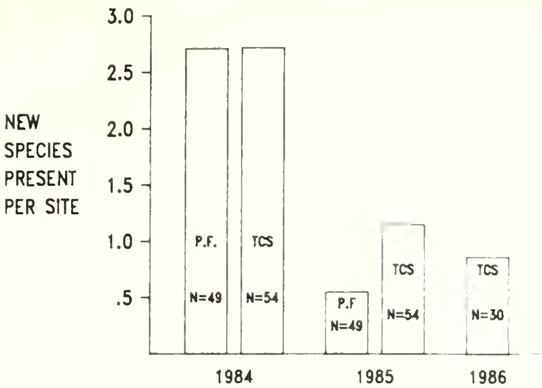

FIGURE 3.--RATES OF NEW SPECIES PRESENT PER SITE FOR PITFALL TRAPPING AND TIME-CONSTRAINED SEARCHES FOR HERPETOFAUNA IN 1984, 1985, AND 1986 IN WOODLAND HABITATS OF NORTHWESTERN CALIFORNIA AND SOUTHWESTERN OREGON.

Table 3--Cost-and-yield of methods used to sample herpetofauna in woodland habitats of northwestern California and southwestern Oregon in 1983 and 1984.

Factor	Pitfall trapping	Time-constrained searches	Area-constrained aquatic searches
Type of data generated	Presence/ absence; relative abundance and biomass of some species sampled; macrohabitat associatiions.	Presence/absence; relative abundance and biomass of all species sampled; macro- and micro-habitat associations.	Presence/absence; relative and absolute abundances' and biomass of all species sampled; macro- and micro-habitat associations; microhabitat preference[1].
Plots sampled each year	49	54	18
Total samples	98	108	36
Species detected	19	24	7
Species detected only or primarily[2] by this method	2	9	2
Total captures	1642 [6](3393)	2308	1422
Mean captures per sample, ±1 S.D. (both years combined)	16.78: [6](34.62: ±19.42 ±28.44)	21.37: ±15.38	35.55: ±22.67
Persons required for one sampling period	1	2	3
Time required for one sampling period (hours)	[3]5	2	[4]6
Person-hours required per sample	[3]5	4	18
Captures per person-hour	3.36 [6](6.92)	5.3	2.02
Cost per sample[5]	$89.96	$27.68	$124.56
Average cost per capture[5]	$5.36 [6](2.60)	$1.30	$3.50

[1] Each study plot was mapped for microhabitat availability as well as searched for microhabitat associations, thus allowing the determination of microhabitat preference.
[2] Method accounts for 75 percent or better of all captures.
[3] Does not include installation time of 3-6 hours for a 36-trap grid; assumes a weekly trap check and a 30-day trapping period.
[4] Based on an average of 2 hours to search a 5-meter reach of second order stream, with 3 reaches searched per stream. Does not include time for scale mapping of reaches needed if microhabitat availability data is desired.
[5] Cost is based on personnel being GS-5 level biotechnicians at $6.92 per hour does not include travel costs. Includes initial set-up cost of $110.72 per plot (16 person-hours) for measuring and marking trap grids and burying traps.
[6] Including small mammals.

Reptiles

TCS was the most effective method for detecting the presence of reptiles; 7 of 12 species of reptiles were taken only by this method (table 1). TCS accounted for 86.5 percent of the 111 reptiles collected.

Area-Constrained Aquatic Searches

AQS captured the smallest share of specimens of the three methods (table 1). However, AQS was used at only about a third as many sites as each of the other methods; it actually yielded the highest average number of captures per site (table 3). All captures were amphibians of seven species, two of which the Tailed Frog and the Pacific Giant Salamander were detected primarily by this method (table 1). The majority of captures of these two species were larval animals. AQS accounted for 97.6 percent of Tailed Frogs and 95.3 percent of the Pacific Giant Salamanders.

Because AQS was so time consuming, only half the sites were sampled in each year. Thus I could not analyze AQS data for year-to-year changes.

Cost Analysis of Sampling Methods

TCS was the most cost-effective of the three techniques tested, requiring an intermediate number of personnel, the least amount of time, and the lowest cost per sampling period, while yielding the highest rate of captures per person-hour of effort and the lowest average cost per capture (table 3). Also, this technique required no site preparation. Sites could be selected and sampled immediately, and sampling was completed in a matter of several hours. Pitfall trapping required a much more extensive site preparation and periodic maintenance along with regular checking during trapping sessions.

Pitfall traps were seemingly the most expensive of the three methods when set-up costs were included in the cost analysis (table 3). Measuring and flagging the trapping grid, and installation of the 36 traps per grid required an average of 16 person-hours; resulting in a set-up cost of $110.72 per grid (based on $6.92/hr per person). This resulted in an average cost per capture of $5.36 for the 1642 reptiles and amphibians collected over the 2 years. However, it is important to bear in mind that this cost considers only the herpetofauna collected. Pitfall traps simultaneously sample small mammals. During the 2 years of this study, the 49 pitfall grids collected 1,751 small mammals representing 17 species. When these data are considered, the average cost per capture, including set-up costs, was $2.60; making PF the second most cost-effective per capture of the three methods (table 3). PF becomes increasingly more cost-effective with repeated grid use.

AQS was the most expensive of the three methods for average cost per capture; it required the most people and the most time per sampling and yielded the lowest rate of capture per person-hour (table 3). As noted above, however, AQS did yield the highest average number of captures per site, illustrating its effectiveness for determining abundance and biomass per unit area. Because of the relative sampling effort per unit area, neither of the other methods can approach the accuracy of AQS for relative density or biomass estimates.

DISCUSSION

Herpetofaunal sampling programs need to be designed with specific information goals in mind, as well as for specific habitats and their associated fauna. For example, data from this study are being analyzed to elucidate differences in the herpetofaunal community relative to changes in the Douglas-fir forest chronosequence. To accomplish this and corollary research objectives, we used sampling protocols (with some modifications) from a companion study in Oregon and Washington (Bury and Corn, Corn and Bury in prep.). For most monitoring requirements, species richness and relative abundance data are sufficient to establish and follow trends. Since pitfall trapping, time-constrained searches, and area-constrained searches can all yield these data, it is important to consider several interrelated factors in evaluating which method is best for a particular application.

Area-Constrained Searches

In terrestrial woodland habitats, a time-constrained method is more cost-effective than an area-constrained technique (Raphael and others 1982, Campbell and Christman 1982, Bury and Raphael 1983, this paper). Raphael and others (1982) found capture rates in northwestern California to be 10 times as high using a general search technique versus measured litter plots, for the same investment of time. Campbell and Christman (1982) found a time-constrained technique to be twice as effective as an area-constrained method in a Florida study. Nevertheless, area-constrained techniques can be effective for some applications in temperate regions (Bury 1982, 1983). For example, this kind of method proved best suited to my research needs in aquatic habitats. Stream ecosystems present special conditions for sampling. Many amphibians are found only or primarily in streams. Riparian and stream areas, spatially limited by nature, tend to concentrate resident fauna, particularly larval amphibians. These areas provide a proliferation of cover among the boulders, debris, and dense vegetation. Area-constrained sampling proved the best choice of available methods to deal with these conditions. This technique is the most successful and cost-effective where an intensive, meticulous search effort is needed in a restricted area with high densities of animals.

Scale mapping of each stream site during this study also allowed calculation of availability of different habitat types (time and cost were not included in this analysis), allowing determination of the microhabitat preferences of each species. Such techniques can be used only with a terrestrial or aquatic area-constrained search method.

Area-constrained methods appear to be more successfully applied and most cost-effective for comprehensive community sampling in tropical rather than temperate areas, where herpetofaunas are more diverse and abundant (e.g., Scott 1976, 1982; Inger and Colwell 1977; Lieberman-Jaffe 1981).

Pitfall Trapping

Raphael and Barrett (1981) and Raphael and Rosenberg (1983) recommend PF for sampling herpetofauna. Yet, despite its obvious effectiveness, no investigators have found that the entire spectrum of terrestrial herpetofauna can be taken by PF alone. Vogt and Hine (1982) experimented in Wisconsin with a variety of PF arrays combined with drift fences of differing heights and lengths, and with and without accompanying funnel traps. They found combinations of pitfalls, drift fences, and funnel traps to be necessary to capture the entire spectrum of herpetofauna. Bury and Corn (1987), in a similar study in Oregon, were able to achieve a "relatively complete species list" at a given site using pitfall traps with drift fences over 60 days of trapping, but they implied that even with these combinations, probably not all species present were taken. Snakes, and some amphibians, because of their relatively low densities and behavioral traits are not readily captured by PF arrays. This is well illustrated by the differences in our capture rates between TCS and PF for three amphibians: the Clouded Salamander and the Pacific Treefrog--both climbing species that probably catch themselves before falling into traps—and the sedentary Slender Salamander (table 1; Bury and Raphael 1983). Such differences in catchability are important considerations when analyzing relative abundance data.

There are notable differences in several important, interrelated factors, including array design, that merit consideration when employing the PF technique. Timing of the trapping period is the most critical factor and was probably the primary cause for the great differences in mean number of individuals per site and capture rate per trap night among this study and two others that employed PF to sample herpetofauna in the Douglas-fir forests of the Pacific Northwest (table 4). Bury and Raphael (1983) ran their traps continuously for 18 months and thus were able to capture relatively high numbers of both reptiles (lizards) and amphibians. Bury and Corn (1987) timed their trapping effort to coincide with the peak activity periods of reptiles and amphibians. They caught 88.3 percent of the

Table 4--Pitfall trapping (PF) and time-constrained sampling (TCS) of herpetofauna from three studies in the Douglas-fir forests of the Pacific Northwest.

Factor	This study[1] PF[2]	This study[1] TCS	Bury and Corn (1984)[3] PF[2]	Bury and Corn (1984)[3] TCS	Bury and Raphael (1983)[1] PF[2]	Bury and Raphael (1983)[1] TCS
Plots sampled	49	54	30	31	166	84
Traps per plot	36	-	[4]24	-	10	-
Sampling duration per plot	80 Nights	8 Person-hours	180 Nights	[5]8 Person-hours	540 Nights	4 Person-hours
Sampling dates	Oct.-Nov. 1984 (50)	Apr.-May 1984	May-Nov. 1983	Apr.-May 1983	Spring 1981 to	Spring 1982
	Oct.-Nov. 1985 (30)	Apr.-May 1985		Jul.-Aug. 1983	Fall 1982	Fall 1982
Total trap-nights	14,1120	--	129,600	--	896,400	--
Total person-hours of effort	--	432	--	280	--	336
Total species captured	19	24	18	16	[8]13	?
Total individuals captured	1,642	2,308	2,180	382	2,330	1,520
Mean captures per plot (±1 S.D.)	33.51 (±33.56)	42.74	72.66	12.32	14.04	18.10
Capture rate per trap-night (x1000)	11.64	--	16.80	--	2.60	--
Capture rate per person-hour	--	5.34	--	1.36	--	4.04
Total amphibians captured	1,628	2,211	2,060	359	[6]1,350	1,451
Mean captures per plot	33.24	40.94	68.66	12.32	[6]8.1	17.3
Capture rate per trap-night (x1000)	11.54	--	15.90	--	1.50	--
Capture rate per person-hour	--	5.12	--	1.45	--	4.32
Total reptiles captured	14	97	120	8	[7]980	69
Mean captures per plot (±1 S.D.)	0.29 (±0.79)	1.79	4.0	0.26	[7]5.9	0.8
Capture rate per trap-night (x1000)	0.10	--	0.93	--	1.10	--
Capture rate per person-hour	--	0.22	--	0.03	--	0.21

[1]All data from northwestern California 1984 and 1985.
[2]Herpetofauna only, mammals not included.
[3]Wash. and Oreg. data combined; PF data source: Bury and Corn 1987.
[4]Twelve pitfall and twelve funnel traps with drift fences (trap arrays).
[5]An additional 4 person-hours on eight plots only, summer 1983.
[6]Salamanders only reported.
[7]Lizards only reported.
[8]Partial list.

reptiles in the first 90 days (June to August), and 89.6 percent of the amphibians in the second 90 days (September to November). By thus timing their trapping sessions, they were able to capture higher numbers of amphibians per site and per trap night than were Bury and Raphael, with a much smaller investment in time. Their lower numbers of reptiles compared with those of Bury and Raphael were probably due to geography, because they were in the central Oregon Cascades. Reptiles decline in numbers of species and individuals as one goes north along the Pacific Rim (Keister 1971). Nonetheless, timing provided Bury and Corn with comparable means per site and rates per trap night for reptiles.

I timed PF to coincide with the peak activity period of amphibians only (fall). Hence, the low capture rate for lizards compares with that by Bury and Raphael (1983) in the same region. More spring trapping data from northwestern California, preferably with funnel traps (Raphael and Marcot 1986), are needed to evaluate the effectiveness of capturing snakes by passive trapping means in these habitats. Bury and Corn (1984) reported that three species of frogs accounted for 42.0 percent of their total pitfall catch of amphibians; frogs accounted for only 7.9 percent of my PF catch (table 1). The relative difference in frog abundance between the two areas of study (as indicated by sampling methods other than PF) could alone account for most of the relative difference in means per site and capture rates per trap night for amphibians between these studies (table 4). The data reported here show a marked drop in total numbers of individuals captured between 30-day trapping periods in fall 1984 and 1985 (table 2). While the decline may indicate natural population fluctuations or depletion from the first year's sampling, it probably stems in part from the arrival of the fall rains, the advent of which triggers the emergence of many amphibians (see Porter 1972:280). In 1984, the first heavy rains came during the first week of the trapping session, whereas in 1985 they did not begin until the 21st night of trapping (fig. 1). This difference indicates that weather may be the primary factor influencing herpetofaunal activity. Vogt and Hine (1982) also found trapping success to be markedly influenced by weather, and secondarily by season.

A second aspect of timing involves the question of duration versus frequency. Species richness data from the last 20 days of the 50-day trap session in 1984 (table 2) suggested that a longer session in a single year may be a better strategy than shorter sessions in successive years. However, the continued accumulation of new species richness data from PF and TCS (fig. 3) clearly indicate the importance of annual repetition of sampling to achieve more complete species inventories.

Bury and Corn (1984, 1987) used the most efficient array combination (pitfall arrays with drift fences) of the three studies (table 4). Our study used a large number of traps per grid (36) to compensate for not using drift fences or funnel traps. Except for frogs, our pitfall grid design (36 traps) yielded mean numbers of individuals per site and capture rates per trap night comparable to the pitfall arrays with fences (Bury and Corn 1984, 1987). We had four times the numbers of amphibians per site as Bury and Raphael (1983), who used the fewest traps per site (10), and no drift fences. Despite the continuous run of 18 months, Bury and Raphael's trapping design was the most inefficient trapping design of the three studies (table 4).

Time-Constrained Searches

My data indicate that PF does not record as many species of herpetofauna as does the TCS method (table 1). Because PF, or PF with drift fences, does not always capture all species of herpetofauna present in a study area, a complementary or alternative method may be desired. Bury and Raphael (1983) recommend a combination of time-constrained searches and pitfall trapping "...for one of the best inventories of terrestrial herpetofaunas." The relatively high capture rates per person-hour of sampling effort (table 4) for my TCS study and that of Bury and Raphael (1983) compared with Bury and Corn (1984), are probably an artifact of the previously mentioned geographic gradient. The advantages of TCS over PF are not as marked in northern as in southern Pacific areas for reptiles and amphibians. The superiority of TCS for sampling reptiles is not as obvious because reptiles are less prominent in northern herpetofaunal communities. Amphibians in the north are more abundant and have more protracted activity periods in the cooler and moister habitats so that PF can adequately sample them. Bury and Corn's (1984) work suggests that PF is the best single choice in the forested areas of Washington and Oregon. TCS is clearly the best method for denoting occurrence of the rarer species (snakes) and for species that are not readily captured by pitfalls (e.g., Clouded Salamander), again because they can be sought out in their favored microhabitat. Furthermore, our study indicated that TCS was more cost-effective than PF, yielding higher captures both per site and per person-hour of sampling effort (table 3).

Aquatic habitats are critical to many species of amphibians, many of which require permanent water during egg and larval stages. Any comprehensive monitoring program for herpetofauna should include surveying of aquatic and riparian habitat. No effort was made to evaluate a time-constrained method in second- and third-order stream habitats. However, I did use a separate TCS method at terrestrial sites with seeps, springs, and first-order streams to sample for Olympic Salamanders. The TCS method is readily adaptable to riparian and aquatic habitats and would be the most cost-effective for meeting the monitoring objectives of determining species richness and relative abundance.

Integrating Methods

My data favor the TCS method over other methods based on comprehensive, cost-effective monitoring of herpetofauna (tables 1 and 3). However, counterbalancing factors such as long-term cost can make PF attractive for many applications. PF grids are initially more expensive than TCS but relatively cheap over the long term, because the major expenses are materials and installation (Raphael and Rosenberg 1983). Thereafter, travel and checking time are the major costs. Pitfalls can then be used for continuous or periodic monitoring indefinitely, with minimal resources and no impact on the habitat (unlike TCS and ACS which can be locally disruptive). However, populations may be locally impacted if mortality occurs, rendering subsequent capture rates biased downward. Another significant advantage of pitfalls is that they simultaneously monitor the small mammal community. Raphael and Rosenberg (1983) point out that the most cost-effective use of PF can be in conjunction with other vertebrate sampling techniques, such as bird censuses, that can be used during the same site visit. Ultimately, the best choice of combined sampling methods depends on the information objectives and site peculiarities of a given situation. The variables to consider and the options available are outlined below.

The relatively high standard deviation values reported for these methods (tables 1 and 2), are a reflection of three interacting phenomena: (1) the rareness of many species; (2) the patchiness of their distributions in forest habitats; and (3) the high variability among study sites. Sites were selected in order to sample the entire age and moisture spectrum present in the Klamath-Siskiyou Mountain Douglas-fir forest. AQS showed the lowest standard deviations per taxa (table 1), probably because only stream habitats were sampled with this method, and these are consistently more uniform than terrestrial habitats. Of the two terrestrial sampling methods, TCS showed the least variability (table 2), probably because this active sampling technique permits the workers to sample the more favored habitat patches in greater proportion to their actual occurrence in the forest during the timed period.

DESIGNING A HERPETOFAUNAL MONITORING PROGRAM

The following outline is a guide for resource managers or investigators who need to collect information on the distribution and abundance of reptiles and amphibians. The variety of herpetofaunal life forms and natural history, and the differences in their abundance and observability, create special problems for designing a comprehensive monitoring program. A suggested approach should address the following:

I. What kind of information is needed about the target species?
   A. Presence/absence or species-richness data
      1. Requires minimum of annual sampling, timed to coincide with the period of greatest visibility or accessibility of subject species. (For some species, such times may correspond to periods of migration when they may not be in optimum habitat.)
      2. Initial and repeat sampling should occur in characterized areas. Application of data to a wider area should be done only with reservation and with particular attention to similarities of substrate, vegetation, elevation,

latitude, and similarities of microclimate.

B. Relative abundance data
   1. All questions of relative abundance require equal sampling effort at each site and each year to assure accuracy and reliability of data.
   2. Types of relative abundance data:
      a. The same species from year to year at site A;
      b. Different species in a given year at site A;
      c. The same species in different habitats (site A vs. site B) in a given year, or between years. (Note: differences in detectability among species, and for a given species by different sampling methods or in different habitat types, sampling designs for the above questions may not yield comparable data.)
   3. Differences in climate from year to year can significantly affect sampling results and may obscure actual relative abundance values. Yearly or seasonal sampling periods should not be by the calendar, but by the onset of spring or fall rains (optimum search time for amphibians), or after the spring rains (optimum search time for reptiles); longer or more frequent sampling periods can also help alleviate this problem.

C. Absolute abundance data (or the closest approximation thereof)
   1. Obtainable only by intensive, area-constrained searches; generally not cost-effective for long-term monitoring of herpetofaunal communities. These methods do, however, produce the only density estimates and therefore can provide the best documentation of change over time.
   2. Most likely application for resource management agencies would be in cases of rare species with limited or patchy distributions.

D. Macro- and microhabitat associations and/or microhabitat preferences
   1. All sampling methods yield macrohabitat data
   2. Microhabitat associations can be obtained from time- and area-constrained methods (Raphael, this symposium).
   3. Microhabitat preferences require area-constrained techniques with scale habitat mapping to quantify available vs. used habitat.

E. Demographic data. These data require area-constrained and mark-release-recapture techniques for the recognition of individuals (Ferner 1979).

II. What species are likely to be encountered and what are their life histories?

A. Seasonal limits of surface activities (e.g., rainy or dry season)

B. Temporal patterns of activities (nocturnal, diurnal, or crepuscular)

C. Basic macrohabitat affinities (terrestrial, aquatic, fossorial, arboreal, or combinations of these).

III. What sampling and monitoring methods are available?

A. Pitfall trapping (and transect census techniques)
   1. Advantages
      a. Yield data on species richness, relative abundance, and microhabitat
      b. Do not require highly trained personnel if specimens are collected for later identification
      c. Most cost-effective for frequent sampling—e.g., continuously, seasonally, or monthly
      d. Least effort required once trap arrays are in place
      e. Animals can be marked and released alive for demographic data if traps are checked frequently (daily)
      f. Will sample small mammals simultaneously
      g. Relatively high sample sizes if timed correctly.
   2. Disadvantages
      a. Unequal catchability—those species with low vagility or with good climbing abilities may not be captured in proportion to other species in an area.
      b. High mortality of captures if the traps not checked frequently
      c. No data possible on microhabitat associations.

B. Time-constrained methods
   1. Advantages
      a. Yield data on species richness, relative abundance, macro- and microhabitat association, and demographics (via mark and release)
      b. Workers can focus on preferred microhabitats, promoting higher sample sizes per unit time than with passive methods
      c. Possible with trained personnel to do minimal destructive sampling of habitat.
   2. Disadvantages
      a. Hard to control for equal sampling effort if personnel change during monitoring program
      b. Important to train personnel to alleviate observer bias in searching; important that all microhabitat be searched, not just where "best" species are found
      c. Untrained personnel can destroy important cover habitat, affecting subsequent sampling.

C. Area-constrained methods
   1. Advantages
      a. Yield data on species richness, relative and absolute abundance, biomass, microhabitat association, habitat preference, and demographics
   2. Disadvantages
      b. Labor intensive and time-consuming, thus the most expensive method

IV. What resources are available and how do they tie in with the resource requirements for each of the monitoring methods?
   A. Equipment
   B. Personnel (and training required to identify species and know their habitat associations to effectively use any of these sampling techniques)
   C. <u>Time (per year or year to year, including travel time)</u>
   D. Actual cost.

ACKNOWLEDGMENTS

I thank the members of the field crews of the Pacific Southwest Forest and Range Experiment Station's, Timber/Wildlife Research Unit for their help in collecting the data. Megan Haney and Amy Lind deserve special thanks for their help with data analysis. I thank Peter W. Paton, R. Bruce Bury, Paul S. Corn, Martin G. Raphael, Jared Verner, Harold Basey , Amy J. Lind, and Megan A. Haney for their comments on earlier drafts of the manuscript.

REFERENCES

Burton, Thomas M.; Likens, Gene E. Salamander populations and biomass in Hubbard Brook Experimental Forest, New Hampshire. Copeia 1975:541-546; 1975.

Bury, R. Bruce. Structure and composition of Mojave Desert reptile communities. In: Scott, Norman J., ed. Herpetological communities: A symposium of the Society for the Study of Amphibians and Reptiles and the Herpetologists League. Wildlife Research Report 13. Washington DC: Fish and Wildlife Service, U.S. Department of the Interior; 1982:135-142.

Bury, R. Bruce. Differences in amphibian populations in logged and old-growth redwood forests. Northwest Science 57:167-178;1983.

Bury, R. Bruce; Campbell, H.W.; Scott, N.J. The role and importance of non-game wildlife. Proceedings of the North American Wildlife and Natural Resources Conference 45:197-207; 1980.

Bury, R. Bruce; Corn, Paul S. Sampling technique, relative abundance, and habitat use by amphibian and reptiles in Pacific Northwest forests. Fort Collins, CO: National Ecology Center. Unpublished draft supplied by authors; 1984. 35 p.

Bury, R. Bruce; Corn, Paul S. Evaluation of pitfall trapping in northwestern forests: trap arrays with drift fences. J. Wildlife Management 57(1); 1987. In press.

Bury, R. Bruce; Corn, Paul S. Sampling aquatic amphibians. In: Carey, A.B.; Ruggiero, L.F., eds. Population monitoring techniques for wildlife in Pacific Northwest forests. Gen. Tech. Rep. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; [In preparation].

Bury, R. Bruce; Raphael, Martin G. Inventory methods for amphibians and reptiles. In: Bell, J.F.; Attersburg, T., eds. Renewable resources inventories for monitoring changes and trends. SAF 83-14. Corvallis, OR: Oregon State University; 1983: 416-419.

Campbell, Howard W.; Christman, Steven P. Field techniques for herpetofaunal community analysis. In: Scott, Norman J., ed. Herpetological communities: A symposium of the Society for the Study of Amphibians and Reptiles and the Herpetologists League. Wildlife Research Report 13. Washington DC: Fish and Wildlife Service, U.S. Department of the Interior; 1982:193-200.

Corn, Paul S.; Bury, R.B. Sampling terrestrial amphibians and reptiles. In: Carey, A.B.; Ruggiero, L.F., eds. Population monitoring techniques for wildlife in Pacific Northwest forests. Gen. Tech. Rep. Pacific Northwest Forest and Range Experiment Station, U.S. Department of Agriculture; [In preparation].

Ferner, John W. A review of marking techniques for amphibians and reptiles. Herpetological Circular 9. Oxford, Ohio: Society for the Study of Amphibians and Reptiles; 1979. 41 p.

Inger, Robert F.; Colwell, Robert. Organization of contiguous communities of amphibians and reptiles in Thailand. Ecol. Monographs 47(3):229-253; 1977.

Keister, Ross A. Species density of North American amphibians and reptiles. Systematic Zoology 20(2):127-137; 1971.

Lieberman-Jaffe, S. Ecology of the leaf-litter herpetofauna of a tropical rain forest: La Selva, Costa Rica. Corvallis, OR: American Society of Amphibians and Reptiles; 1981; 1 p. abstract.

Porter, Kenneth R. Herpetology. Philadelphia, PA: W.B. Saunders Company; 1972. 524 p.

Raphael, Martin G.; Barrett, Reginald H. Methodologies for a comprehensive wildlife survey and habitat analysis in old-growth Douglas fir forests. Cal-Neva Wildlife Transactions 1981: 106-121.

Raphael, Martin G.; Marcot, Bruce G. Validation of a Wildlife-Habitat-Relationships Model: Vertebrates in a Douglas-fir Sere. In: Verner, Jared; Morrison, Michael L.; Ralph, C. John, eds. Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates. Madison: University of Wisconsin Press, 1986: 129-138.

Raphael, Martin G.; Rosenberg, Kenneth V.; Taylor, Cathy A. Administrative study of relationships between wildlife and old-growth forest stands, phase III. San Francisco, CA: USDA Forest Service, Pacific Southwest Region. Unpublished report. 1982; 30 p.

Raphael, Martin G.; Rosenberg, Kenneth V. An integrated approach to wildlife inventories in forested habitats. In: Bell, J.F.; Attersburg, T., eds. Renewable resources inventories for monitoring changes and trends. SAF 83-14. Corvallis: Oregon State University; 1983: 219-222.

Scott, Norman J. The abundance and diversity of the herpetofauna of tropical forest litter. Biotropica 8:41-58; 1976.

Scott, Norman J., ed. Herpetological communities: A symposium of the Society for the Study of Amphibians and Reptiles and the Herpetologists League. Wildlife Research Report 13. Washington DC: Fish and Wildlife Service, U.S. Department of the Interior; 1982. 239 p.

Strahler, A. N. Hypsometric (area-altitude) of erosion topography. Bulletin of the Geological Society of America 63:1117-1142; 1952.

Vogt, Richard C.; Hine, Ruth L. Evaluation of techniques for assessment of amphibian and reptile populations in Wisconsin. In: Scott, Norman J., ed. Herpetological communities: a symposium of the Society for the Study of Amphibians and Reptiles and the Herpetologists League. Wildlife Research Report 13. Washington DC: Fish and Wildlife Service, U.S. Department of the Interior; 1982: 201-217.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Preliminary Results From a System for Monitoring Trends in Bird Populations in Oak-Pine Woodlands[1]

Jared Verner[2]

Abstract: Three observers independently sampled the bird assemblage at the San Joaquin Experimental Range, in central California, by completing 5-min point counts at 210 counting stations during April 1985. Either total counts or frequencies, or both, could be used for monitoring trends in relative abundance of birds, but density estimates are not suitable because only a small percentage of bird species are detected often enough to permit such estimates. Results indicate that difference between observers is the major source of variation in counts; probably at least three observers should be used to monitor trends in bird populations.

The National Forest Management Act of 1976 (U.S.C. 1600-1614) mandates the monitoring of wildlife populations on all National Forest lands. Some guidelines are given in regulations pursuant to the Act (36 CFR 219), but specific methods are not covered. Because cost analyses show that some methods now used to measure animal abundance would be prohibitively expensive in a large-scale monitoring effort (Verner 1983), research is needed to identify suitable methods that are more cost effective. Much interest in the development of such methods for wildlife populations in hardwood habitats has been expressed, not only in the Forest Service, but also at the State level in California (Graves 1985, Mayer 1985).

This paper reports certain results of the first year's sampling of a test system of point counts installed in oak-pine woodlands at the San Joaquin Experimental Range, Madera County, in central California, to monitor yearly variations in bird populations. The system is applicable to areas of medium to large size (>1800 ha); smaller areas would not accommodate the number of counting stations needed at a minimum distance of 300 m between stations. The primary objectives of this study were to evaluate total counts, frequencies, and density estimates as measures of the relative abundance of birds, specifically for use in monitoring population trends over time; and to characterize observer variability for each of these measures.

STUDY AREA

The San Joaquin Experimental Range (SJER) is an area of 1875 ha, ranging in elevation from 215 to 520 m, in the western foothills of the Sierra Nevada of California. The climate is characterized by cool, wet winters and hot, dry summers. Annual precipitation averages 48.6 cm (43-yr mean, 1935-77), most of which is rain from November through March. Vegetation over most of SJER is characterized by an overstory of blue oak (*Quercus douglasii*), digger pine (*Pinus sabiniana*), and interior live oak (*Q. wislizenii*). An understory of scattered shrubs includes mainly buck brush (*Ceanothus cuneatus*), chaparral whitethorn (*C. leucodermis*), redberry (*Rhamnus crocea*), and Mariposa manzanita (*Arctostaphylos mariposa*). In a few smaller patches, the overstory is primarily blue oak, and a shrub understory is meagre or missing. Some areas of typical annual grasslands extend throughout the remainder of SJER where the overstory and understory are not dense enough to shade them out or are lacking altogether.

METHODS

Seven lines with 30 counting stations each were established primarily in oak-pine habitat throughout SJER, with the aid of aerial photos and topographic maps (scale = 13,500:1; contour interval = 38 m). Counting stations were at least 200 m apart along the same line and between the separate lines. (Closer spacing than is ideal for independent samples was used here to allow six counts per hour.) All counting stations were clearly identified by placement of large cattle ear tags wired to fences, trees, shrubs, and occasionally to steel fence posts set in open areas specifically for that purpose. Numerous additional tags placed between stations along the line gave directions for continuing along the line; a "tour guide" was prepared to describe in detail the location of each tag, what it was wired to, and the distance and direction to the next tag along the line. With this system, observers unfamiliar with the lines were able to follow them quickly and accurately.

Recording of birds along any line began at the first station on the line at 10 min after official sunrise. The counting period was 5 min, after which the observer moved quickly to the next station and began counting at exactly 10 min after counting began at the first station. By

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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adhering to this schedule, an observer recorded birds at 6 stations per hour, so all 30 stations on a line could be sampled within 5 hr, and the entire system could be sampled by one observer in seven mornings. Counts were not done during rainy mornings, and counts done during days when wind consistently exceeded 20 mph (by Beaufort scale) were repeated the following count day. Windy day counts were not included in the present analysis.

Results reported here were taken from April 22 to May 1, 1985, by three observers randomly assigned to lines in such a way that none sampled the same line on the same day and all sampled all seven lines. Observers were carefully selected to be expert birders and especially to be expert in the identification of birds at SJER by sight and sound. At each station, they recorded the date, time, wind velocity, percent cloud cover, rain activity, and temperature. For each bird detected, they recorded the species, cue (visual, song, call, or other sound) first detected, distance (in meters) from the counting point, age (adult or juvenile), and whether the bird had probably been detected from a previous point that morning. Each observer's hearing was tested within a week after the field work was finished.

Statistical tests are identified, as appropriate, in the results section; statistical significance has been arbitrarily set at a probability level of 0.05.

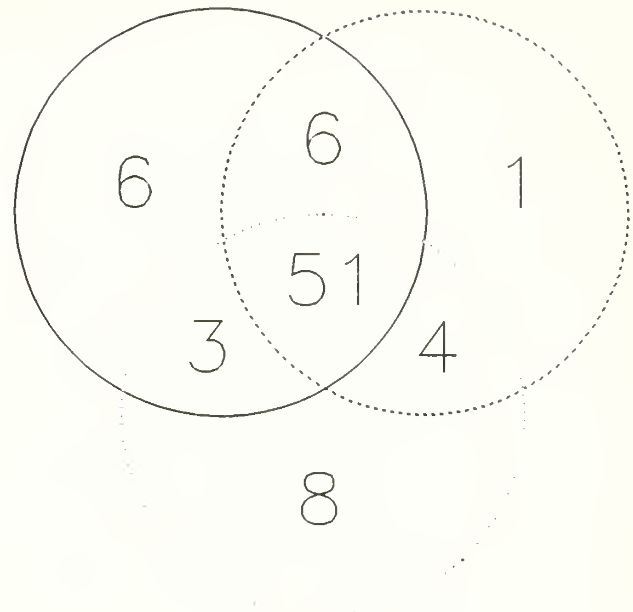

Figure 1.--Venn diagram showing the numbers of species detected only by Observers 1 (solid circle), 2 (circle with heavy dots), and 3 (circle with light dots); by the three possible pairs of observers; and by all three observers combined.

RESULTS

Community Measures

Total Count

Collectively the three observers recorded 7380 individual birds: 2470 for Observer 1, 2995 for Observer 2, and 1915 for Observer 3 (table 1). Total counts of all birds on the seven lines of counting stations differed significantly (paired *t* tests) in all pairwise comparisons between observers (table 2). Variability in total counts of individual species among the three observers was surprisingly large (table 1). Coefficients of variation (CV) ranged from 6.9 to 173.2 percent, with a mean of 77.7 percent (n = 79). Frequency data were no better, with a mean CV of 74.7 percent and a range of 0 to 173.2 percent (see table 1).

Observer differences contributed more to this than did differences among counting stations. When results were totaled separately for each of the seven lines of 30 counting stations (table 2), the mean CV of total counts for observers by line was 23.7 percent (range = 18.7 to 33.6 percent), but that for lines by observer was only 14.2 percent (range = 12.7 to 15.8 percent). These CVs were less than those for total counts by species separately because they consisted of much larger samples--pooled results for all species at each of 30 counting stations in each sample.

Species Richness

The three observers combined recorded 79 species; 51 were seen by all observers, 13 were seen by only two, and 15 were seen by only one (fig. 1). Most of the species seen by only one or two observers were uncommon, with only 3 or fewer being detected by any observer. Some striking exceptions occurred, however. For example, Observers 2 and 3 recorded 9 and 8 American Robins, respectively, and 10 and 7 Golden-crowned Sparrows, but Observer 1 recorded none of either species. Observer 3 recorded 8 Nashville Warblers, Observer 1 recorded 2, but Observer 2 recorded none. Other disquieting variation was found in the data. For example, among the common and easily detected species, Observer 2 recorded more California Quail than the other two observers combined, and Observer 1 recorded more than twice the number of Acorn Woodpeckers recorded by Observer 3.

Although Observers 1 and 3 each recorded 66 species, Observer 3 detected significantly fewer species per line than Observer 1 (t = 2.66, n = 7) (table 2). On the other hand, Observer 2 did not differ significantly from either of the other observers in the mean number of species detected per line, although detecting only 62 species over the whole set of 210 counting stations. Finally, bootstrap simulation of species-accumulation curves showed no significant differences in any pairwise comparison of observers when results were taken over all 210 counting stations (fig. 2).

TABLE 1. Total counts and frequencies (number of stations where detected/total number of stations sampled, with frequency <0.0050 denoted as +) of all species recorded by each observer during the 1985 sample of the monitoring system at the San Joaquin Experimental Range.

Species	Total counts					Frequencies			
	Obs. 1	Obs. 2	Obs. 3	Mean	2SE	Obs. 1	Obs. 2	Obs. 3	Mean
Wood Duck (*Aix sponsa*)	1	7	0	2.7	4.3	+	0.02	0	0.01
Mallard (*Anas platyrhynchos*)	4	0	1	1.7	2.4	0.01	0	+	+
Turkey Vulture (*Cathartes aura*)	48	62	43	51.0	11.2	0.15	0.18	0.11	0.15
Cooper's Hawk (*Accipiter cooperii*)	1	5	0	2.0	3.0	+	0.02	0	0.01
Red-tailed Hawk (*Buteo jamaicensis*)	49	51	37	45.7	8.6	0.20	0.21	0.13	0.18
Golden Eagle (*Aquila chrysaetos*)	0	1	3	1.3	1.7	0	+	0.01	+
American Kestrel (*Falco sparverius*)	5	5	3	4.3	1.3	0.02	0.02	0.01	0.02
California Quail (*Callipepla californica*)	72	135	46	84.3	51.8	0.28	0.53	0.20	0.33
Killdeer (*Charadrius vociferus*)	17	2	4	7.7	9.2	0.06	0.01	0.02	0.03
Mourning Dove (*Zenaida macroura*)	183	186	103	157.3	53.3	0.50	0.64	0.39	0.51
Greater Roadrunner (*Geococcyx californianus*)	5	0	9	4.7	5.1	0.02	0	0.04	0.02
Great Horned Owl (*Bubo virginianus*)	2	1	1	1.3	0.7	+	+	+	+
Northern Pygmy-Owl (*Glaucidium gnoma*)	1	0	0	0.3	0.7	+	0	0	+
Vaux's Swift (*Chaetura vauxi*)	0	0	1	0.3	0.7	0	0	+	+
Anna's Hummingbird (*Calypte anna*)	30	22	22	24.7	5.2	0.14	0.10	0.10	0.11
Unidentified hummingbird	0	7	0	2.3	4.6	0	0.03	0	0.01
Acorn Woodpecker (*Melanerpes formicivorus*)	311	294	151	252.0	99.4	0.72	0.82	0.59	0.71
Nuttall's Woodpecker (*Picoides nuttallii*)	3	13	14	10.0	6.9	0.01	0.06	0.07	0.05
Hairy Woodpecker (*Picoides villosus*)	0	0	2	0.7	1.3	0	0	+	+
Northern Flicker (*Colaptes auratus*)	2	19	12	11.0	9.7	0.01	0.08	0.06	0.05
Dusky Flycatcher (*Empidonax oberholseri*)	3	1	1	1.7	1.3	0.01	+	+	0.01
Gray Flycatcher (*Empidonax wrightii*)	0	1	3	1.3	1.7	0	+	0.01	0.01
Unidentified *Empidonax* Flycatcher	13	12	7	10.7	3.6	0.06	0.06	0.03	0.05
Black Phoebe (*Sayornis nigricans*)	2	1	1	1.3	0.7	0.01	+	+	0.01
Ash-throated Flycatcher (*Myiarchus cinerascens*)	167	217	119	167.7	55.4	0.58	0.74	0.49	0.60
Western Kingbird (*Tyrannus verticalis*)	57	43	34	44.7	13.1	0.15	0.15	0.14	0.15
Tree Swallow (*Tachycineta bicolor*)	0	0	2	0.7	1.3	0	0	+	+
Violet-green Swallow (*Tachycineta thalassina*)	135	189	90	138.0	56.1	0.31	0.42	0.25	0.33

TABLE 1 cont'd

Species	Total counts Obs. 1	Obs. 2	Obs. 3	Mean	2SE	Frequencies Obs. 1	Obs. 2	Obs. 3	Mean
Barn Swallow (*Hirundo rustica*	2	0	0	0.7	1.3	0.01	0	0	+
Scrub Jay (*Aphelocoma coerulescens*)	118	164	96	126.0	39.3	0.45	0.53	0.40	0.46
Common Raven (*Corvus corax*)	18	18	15	17.0	2.0	0.06	0.08	0.07	0.07
Plain Titmouse (*Parus inornatus*)	226	296	103	208.3	110.6	0.71	0.78	0.46	0.65
Bushtit (*Psaltriparus minimus*)	24	35	50	36.3	14.8	0.05	0.13	0.13	0.11
White-breasted Nuthatch (*Sitta carolinensis*)	43	95	58	65.3	30.3	0.19	0.39	0.25	0.28
Rock Wren (*Salpinctes obsoletus*)	2	6	10	6.0	4.5	0.01	0.02	0.04	0.02
Canyon Wren (*Catherpes mexicanus*)	16	18	16	16.7	1.3	0.07	0.09	0.08	0.08
Bewick's Wren (*Thryomanes bewickii*)	77	127	85	96.7	30.0	0.31	0.46	0.40	0.39
House Wren (*Troglodytes aedon*)	146	108	106	120.0	25.5	0.51	0.40	0.47	0.46
Ruby-crowned Kinglet (*Regulus calendula*)	0	0	5	1.7	3.3	0	0	0.02	0.01
Blue-gray Gnatcatcher (*Polioptila caerulea*)	9	10	11	10.0	1.1	0.04	0.05	0.05	0.05
Western Bluebird (*Sialia mexicana*)	43	51	27	40.3	13.8	0.12	0.20	0.10	0.14
Townsend's Solitaire (*Myadestes townsendi*)	1	0	0	0.3	0.7	+	0	0	+
American Robin (*Turdus migratorius*)	0	9	8	5.7	5.6	0	0.03	0.03	0.02
Wrentit (*Chamaea fasciata*)	0	0	1	0.3	0.7	0	0	+	+
Phainopepla (*Phainopepla nitens*)	4	3	1	2.7	1.7	0.01	0.01	+	0.01
European Starling (*Sturnus vulgaris*)	114	94	85	97.7	16.8	0.33	0.28	0.29	0.30
Solitary Vireo (*Vireo solitarius*)	6	3	13	7.3	5.8	0.02	0.01	0.06	0.03
Hutton's Vireo (*Vireo huttoni*)	9	19	15	14.3	5.7	0.03	0.08	0.07	0.06
Warbling Vireo (*Vireo gilvus*)	5	10	23	12.7	10.5	0.02	0.04	0.10	0.05
Orange-crowned Warbler (*Vermivora celata*)	4	9	23	12.0	11.2	0.02	0.04	0.11	0.06
Nashville Warbler (*Vermivora ruficapilla*)	2	0	8	3.3	4.7	0.01	0	0.04	0.02
Yellow-rumped Warbler (*Dendroica coronata*)	10	23	22	18.3	8.2	0.04	0.10	0.10	0.08
Black-throated Gray Warbler (*Dendroica nigrescens*)	4	3	6	4.3	1.7	0.01	0.01	0.03	0.02
Townsend's Warbler (*Dendroica townsendi*)	2	2	1	1.7	0.7	0.01	0.01	+	0.01
Hermit Warbler (*Dendroica occidentalis*)	3	2	10	5.0	4.9	0.01	0.01	0.05	0.02
MacGillivray's Warbler (*Oporornis tolmiei*)	1	0	0	0.3	0.7	+	0	0	+
Wilson's Warbler (*Wilsonia pusilla*)	23	13	29	21.7	9.1	0.08	0.06	0.13	0.09

TABLE 1 cont'd

Species	Total counts					Frequencies			
	Obs. 1	Obs. 2	Obs. 3	Mean	2SE	Obs. 1	Obs. 2	Obs. 3	Mean
Western Tanager (*Piranga ludoviciana*)	2	2	0	1.3	1.3	+	0.01	0	+
Black-headed Grosbeak (*Pheucticus melanocephalus*)	10	17	24	17.0	7.9	0.05	0.08	0.11	0.08
Lazuli Bunting (*Passerina amoena*)	8	4	0	4.0	4.5	0.01	0.01	0	0.01
Rufous-sided Towhee (*Pipilo erythrophthalmus*)	0	0	3	1.0	2.0	0	0	0.01	+
Brown Towhee (*Pipilo fuscus*)	59	92	79	76.7	18.8	0.25	0.35	0.37	0.32
Rufous-crowned Sparrow (*Aimophila ruficeps*)	0	0	2	0.7	1.3	0	0	0.01	+
Chipping Sparrow (*Spizella passerina*)	9	27	14	16.7	10.5	0.04	0.12	0.07	0.07
Lark Sparrow (*Chondestes grammacus*)	26	27	19	24.0	4.9	0.10	0.12	0.08	0.10
Lincoln's Sparrow (*Melospiza lincolnii*)	0	0	2	0.7	1.3	0	0	0.01	+
Golden-crowned Sparrow (*Zonotrichia atricapilla*)	0	10	7	5.1	5.8	0	0.04	0.03	0.02
White-crowned Sparrow (*Zonotrichia leucophrys*)	30	15	18	21.0	9.0	0.05	0.05	0.04	0.05
Dark-eyed Junco (*Junco hyemalis*)	1	4	0	1.7	2.4	+	0.01	0	0.01
Red-winged Blackbird (*Agelaius phoeniceus*)	17	24	5	15.3	10.9	0.04	0.06	0.01	0.04
Western Meadowlark (*Sturnella neglecta*)	35	35	31	33.7	2.6	0.15	0.13	0.13	0.14
Brewer's Blackbird (*Euphagus cyanocephalus*)	10	14	3	9.0	6.3	0.01	0.04	0.01	0.02
Brown-headed Cowbird (*Molothrus ater*)	75	98	59	77.3	22.2	0.28	0.35	0.20	0.28
Northern Oriole (*Icterus galbula*)	97	111	38	82.0	43.9	0.35	0.38	0.15	0.29
House Finch (*Carpodacus mexicanus*)	8	21	25	18.0	10.1	0.03	0.07	0.12	0.07
Lesser Goldfinch (*Carduelis psaltria*)	49	101	50	66.7	33.7	0.15	0.34	0.20	0.23
Lawrence's Goldfinch (*Carduelis lawrencei*)	3	1	0	1.3	1.7	0.01	+	0	+
American Goldfinch (*Carduelis tristis*)	3	0	0	1.0	2.0	+	0	0	+
House Sparrow (*Passer domesticus*)	4	0	0	1.3	2.6	0.02	0	0	0.01
TOTAL SPECIES	66	62	66						
TOTAL INDIVIDUALS	2470	2995	1915						

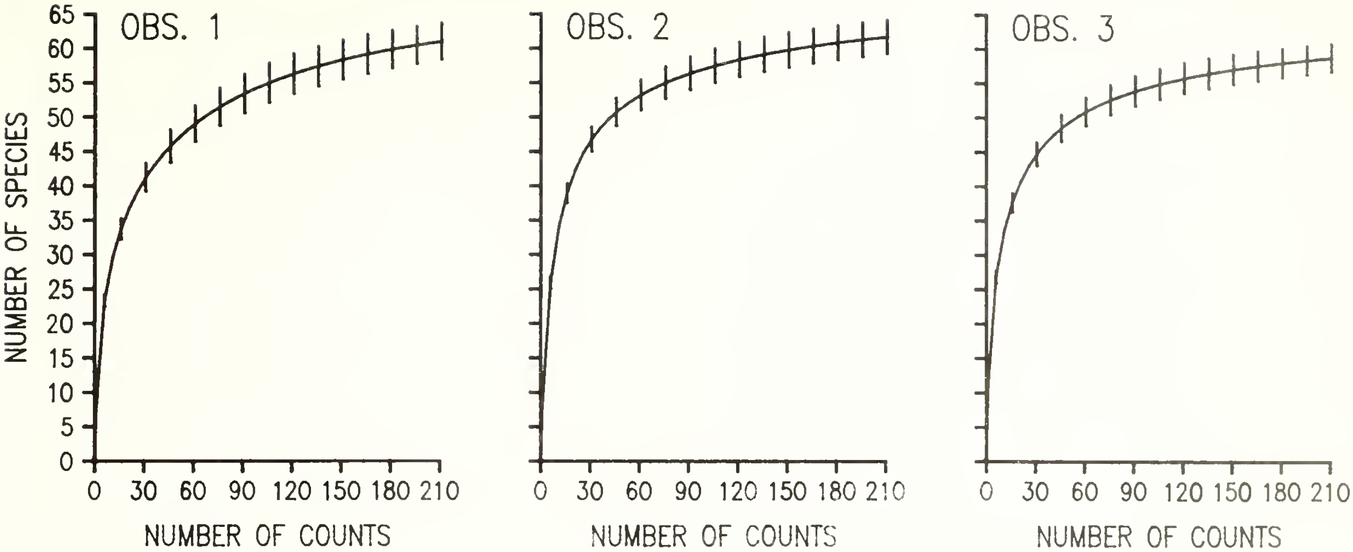

Figure 2.--Bootstrap simulations of species accumulation curves, with confidence intervals shown for each additional 15 counts.

In contrast to results for total counts, observer differences in the number of species detected were less variable than the differences in species counts among the lines. The mean CV of total species for observers by line was 9.4 percent (range = 3.9 to 16.8 percent), and that for lines by observer was 38.3 percent (range = 33.6 to 39.5 percent) (table 2).

Species Measures

Density Estimates

Densities of the most commonly detected species were estimated using the exponential polynomial estimator of program TRANSECT (Laake and others 1979). Judging by a recently completed analysis of data from SJER (Verner and Ritter 1986), I consider 80 records of a given species in a given sample to be the minimum needed for estimating density by transects or point counts. Only seven species satisfied this criterion for all observers in this study (table 3).

Density estimates of the same species differed markedly among observers in most cases (table 3), with the highest estimate exceeding the lowest from 37.7 percent (Acorn Woodpecker) to 201.1 percent (Plain Titmouse). The mean difference across all seven species was 91.8 percent. Pooling data sets between pairs of observers improved this variability markedly. For all species, the percentage difference between the highest and lowest density estimate was reduced, with a mean difference of 36.7 percent (range = 12.2 to 71.6 percent). The overall improvement was significant (t = 3.26; $0.02>P>0.01$; n = 7).

Observer 1 had the highest density estimate for most species, with a mean rank of 1.3 (1 = best score possible), and Observer 2 had the lowest estimate for five of the seven species, with a mean rank of 2.7 (3 = worst score possible). In the data sets pooled between pairs of observers, Observers 1+3 had a mean rank of 1.4 and Observers 2+3 had a mean rank of 2.6.

Rank-Order of Abundance

If different observers and different methods accurately measure the relative abundance of bird species, all should rank them in the same order of abundance from most to least common. I tested this for all pairwise comparisons of total counts and frequencies for all observers (table 1), using both Spearman's rho and Kendall's tau. All correlations were significant at the 0.0001 level, those for Spearman's rho (r_s) ranging from 0.82 to 0.99, and those for Kendall's tau ranging from 0.66 to 0.97. At a coarse scale of ranking all species (n = 79) in order of abundance from rare to abundant, all observers performed similarly and the total counts and frequencies of each species gave equivalent rankings.

A similar analysis, using only those species for which density could be estimated, showed that (1) 19 of 28 comparisons among total counts and frequencies were significant at the 0.05 level (r_s >0.713) and 15 of those were significant at the 0.01 level (r_s >0.892)--the lowest r_s was 0.559; (2) no comparison of a count or frequency score with the corresponding density estimate was statistically significant; in fact the highest

TABLE 2. Numbers of species and individuals detected by each observer and all observers combined on each line of 30 counting stations.

Line	Species detected[1]							Individuals detected						
	Obs. 1	Obs. 2	Obs. 3	Total	Mean	SD	%CV	Obs. 1	Obs. 2	Obs. 3	Total	Mean	SD	%CV
A	32	40	45	50	39.0	6.6	16.8	319	424	274	1017	339.0	77.0	22.7
B	36	39	40	54	38.3	2.1	5.4	373	397	274	1044	348.0	65.2	18.7
C	38	47	42	56	42.3	4.5	10.7	356	421	279	1054	352.0	71.1	20.2
D	37	48	47	60	44.0	6.1	13.8	340	435	270	1045	348.3	117.1	33.6
E	42	39	39	53	40.0	1.7	4.3	382	417	271	1070	356.7	76.2	21.4
F	45	42	45	61	44.0	1.7	3.9	380	497	282	1159	386.3	107.6	27.9
G	37	38	45	53	40.0	4.4	10.9	320	404	265	989	329.7	70.0	21.2
Total	66	62	66	79				2470	2995	1915	7380			
Mean	38.1	41.9	43.3	55.3				352.9	427.9	273.6	1054.0			
SD	15.1	15.9	16.2	18.6				49.4	54.5	43.3	85.7			
%CV	39.5	38.0	37.3	33.6				14.0	12.7	15.8	8.1			

[1]Totals for species represent the cumulative numbers of different species detected, not simply the sums of numbers in the respective columns or rows.

r_s in 32 comparisons was 0.429; and (3) 18 of 21 correlations between density estimates of different observers singly or pooled were significant at the 0.05 level, and 10 of those were significant at the 0.01 level.

Although no biological significance can be inferred from values of the correlation coefficients in Spearman's or Kendall's tests (other than the fact that correlations may be significantly different from zero), values in this study suggest that pooling data sets of at least two observers may give more stable estimates of density. The density estimates from data sets pooled for pairs of observers resulted in correlations all significant at the 0.01 level (r_s = 0.964, 0.929, and 0.893), but those comparing density estimates between data sets of single observers were significant only at the 0.05 level or not at all (r_s = 0.857, 0.786, and 0.643).

DISCUSSION

These preliminary results have profound significance for the design of a reliable monitoring system. Variability attributable to counting stations can be eliminated in a monitoring system by using the same counting stations every time a sample is taken. That attributable to observer variability could be similarly controlled if it were possible to use the same observers, year after year, during the life of the monitoring program. Because this is unlikely to be feasible in the vast majority of cases, however, the next best alternative would be to increase the number of observers. The reduction in CV gained by using more observers can be estimated from the formula

$$CV = \frac{(Var/n)^{0.5}}{x}$$

where Var = the variance of a given sample,

n = the number of observers to be used,

x = the sample mean.

Based on the sample obtained in 1985, using two observers would reduce CV by about 29 percent, using three observers would reduce it by about 42 percent, and using four observers would reduce it by 50 percent. The rate of gain from adding

TABLE 3. Density estimates[1] (birds/40 ha) as computed from data of each observer separately, all combinations of two observers pooled, and all three observers pooled. (Two standard errors are shown in parentheses below each estimate.)

Species	Density estimates						
	Obs. 1	Obs. 2	Obs. 3	Obs. 1+2	Obs. 1+3	Obs. 2+3	Obs. 1+2+3
Mourning Dove	4.2 (1.7)	1.9 (1.1)	3.4 (0.8)	3.8 (0.6)	4.9 (0.7)	2.9 (1.0)	3.3 (0.7)
Acorn Woodpecker	7.3 (2.2)	5.3 (1.7)	7.3 (1.3)	5.7 (0.6)	6.0 (1.4)	4.5 (0.5)	5.4 (1.1)
Ash-throated Flycatcher	9.0 (3.2)	8.9 (1.4)	13.7 (5.5)	9.1 (2.1)	10.5 (2.7)	9.1 (2.2)	14.2 (3.0)
Scrub Jay	8.8 (1.7)	5.1 (0.9)	3.9 (0.8)	4.9 (1.3)	4.8 (1.5)	4.0 (1.2)	4.6 (1.1)
Plain Titmouse	28.3 (4.0)	21.4 (2.7)	9.4 (4.4)	18.7 (1.7)	17.5 (1.9)	10.9 (2.5)	13.7 (1.2)
House Wren	12.5 (4.9)	8.6 (1.8)	12.5 (5.5)	12.3 (3.3)	12.5 (1.6)	13.8 (2.7)	10.4 (1.2)
European Starling	10.9 (2.1)	6.9 (3.6)	10.3 (4.9)	9.8 (2.7)	11.4 (1.6)	8.6 (2.9)	9.9 (2.6)

[1]Estimates were computed only for species with a total count of 80+ by each observer, using the exponential polynomial estimator from program TRANSECT (Laake and others 1979), with observations grouped into 25-m intervals and truncated at 150 m.

observers beyond four is low enough that it probably would not be profitable.

Density estimates could be used to monitor trends only for the few species abundant enough to give the counts of 80 or more needed for these estimates. The sample could be enlarged to increase the count of every species, but to bring the count of all species to at least 80 in the present study would have required 16,800 counting stations (80 times that used). Any such alternative is unfeasible because of both cost and logistic constraints. Even if such an ambitious effort could be made, however, additional species would be detected, and at low total counts.

Total counts and frequencies appear to be the best measures for monitoring trends in bird populations. I was surprised to find, however, that frequency values of the three observers were as variable as total counts. Frequencies require only that the observer detect the presence of the various species at a location, but total counts require the additional step of detecting the number of each species, introducing more opportunities for observer error. Because total counts and frequencies are slightly different indices of population attributes, different statistical models would be applicable in their analyses. Whether or not this will make one of these two measures substantially less costly than the other remains to be determined.

I am optimistic that observer variability need not be as large as that found in this study. Although all three observers are widely acknowledged as experts in the identification of birds in the foothill pine-oak woodlands by sight and sound, Observer 3 (lowest total counts) is about 90 percent deaf in one ear and Observer 1 (intermediate total counts) admitted to me long after the 1985 field season that an inordinate fear of the cattle using the habitats sampled probably influenced counting efficiency. More careful preselection of observers based on factors known to bias their ability to count birds, especially their hearing, should reduce observer variability. Further gains can probably be made with more intensive training than was given to observers before this study. However, whether or not such measures can overcome observer variability enough to allow monitoring with only one or two observers remains to be tested.

ACKNOWLEDGMENTS

I thank Ellen L. Hammond, Zev Labinger, and John C. Lovio for the field work for this study; and Reginald H. Barrett and Hartwell H. Welsh, Jr. for their review of the manuscript.

REFERENCES

Graves, Walter C. Wildlife Management Supervisor, California Department of Fish and Game, Sacramento. [Personal conversation]. 22 October 1985.

Laake, Jeffrey L; Burnham, Kenneth P.; Anderson, David R. User's manual for program TRANSECT. Logan: Utah State Univ. Press; 1979. 26 p.

Mayer, Kenneth E. Wildlife and Range Ecologist, California Department of Forestry, Sacramento. [Personal conversation]. 22 October 1985.

Verner, Jared. An integrated system for monitoring wildlife on the Sierra National Forest. Trans. North Amer. Wildl. and Nat. Resour. Council 48: 355-366; 1983.

Verner, Jared; Ritter, Lyman V. A comparison of transects and spot mapping in oak-pine woodlands of California. Unpublished draft manuscript. 1986.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Monitoring Small Mammal Populations in Oak Woodlands[1]

Reginald H. Barrett[2]

Abstract: Methods for monitoring long-term trends in the abundance of smaller mammals, including small carnivores, include the use of animal sign, track plates, pit traps and direct observation. A suggested sampling scheme consists of a 1000-ha grid with 100 stations at 300-m intervals. Each station would be operated for 5 consecutive days. Once a site was established, each sampling session would require the work of one person for 10 consecutive days. Sampling should occur annually during the dry season on at least 15 sites established throughout the oak woodland zone of California. The Fisher Randomization Test can be used to detect significant trends in detection rates. This scheme should be reconsidered after pilot testing.

Landscapes are increasingly being modified by man, and resource managers are confronted with the need to monitor a variety of resources in a timely fashion to ensure that important ones are not irreparably lost or damaged. Over 100 species of smaller mammals form an important component of the wildlife community of oak woodlands in California (Barrett 1980). These woodlands, or "hardwood rangelands," are being modified by such things as urbanization, fuelwood cutting, burning and grazing (Mayer et al. 1986).

In this paper I consider monitoring to include only the detection of trends over a long period of time. The goal of monitoring is to ensure that important resources are not seriously damaged or lost due to currently unpredictable causes. Experiments to test hypotheses about responses of wildlife to specific habitat treatments will not be considered here (see Eberhardt 1978, Hayne 1978).

While our knowledge of wildlife-habitat relationships is expanding, many environmental factors other than visible changes in vegetation may govern the abundance of wildlife (Laymon and Barrett 1986). Biocides and predation are two obvious examples. Thus, although managers may be able to infer changes in the community of small mammals by monitoring major changes in the vegetation, there is still a need to monitor wildlife directly in a number of randomly selected sample areas. The problem is that any method of monitoring wildlife is considerably more costly than monitoring vegetation. Ideally one might hope to monitor the density of a small mammal on a monthly basis over a series of sample sites of many hectares each. Such effort has rarely been expended even in experimental research projects. A practical monitoring scheme for detecting long-term trends must be restricted to obtaining some index to abundance at a certain season.

My objective here is to briefly explore some options for monitoring the relative abundance of smaller mammals in oak woodlands, to discuss sample size requirements, and to suggest a practical monitoring system.

METHODS FOR ESTIMATING ABUNDANCE

Animal Sign

Small mammals such as moles, voles, gophers, woodrats, ground squirrels and rabbits leave species-specific sign that can be counted (Davis and Winstead 1980, Davis 1982). Research projects involving "double sampling" (Seber 1982) of the density of the animals as well as their sign have have shown that there may be a reasonable correlation between sign and animal density (Anthony and Burns 1983). Many more such studies are needed. Meanwhile it is probably reasonable to assume that a positive relationship exists between the density of sign and animal density for unstudied species.

Small carnivores can be detected by attracting them to track stations where species-specific tracks may be identified (Barrett 1983, Clark and Campbell 1983). Of course small mammals may also be detected this way (Raphael et al. 1986). This method is similar to trapping but the animals are not captured.

Trapping

Most studies of small mammals have used snap traps or box traps of some kind, depending on whether the animals are to be captured dead or alive (Smith et al. 1975). Live trapping is

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[1]Presented at the Symposium on Multiple-use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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preferred for studying animal density at frequent intervals, whereas snap trapping is typically less costly. Traps for larger species, such as raccoons or coyotes, are too cumbersome or too expensive for a monitoring program.

Pit traps (2-10 liters) may be used to capture small mammals and are particularly effective for shrews (Pankakoski 1979, Beacham and Krebs 1980, Dedon and Barrett 1982). Animals may be captured alive or dead, and pit traps may be baited or unbaited. Barriers may be used to increase the efficiency of pit traps. They are expensive to install initially, but once in place they may be covered and reused with less effort than required to set out snap or live traps. Barriers may be rolled up and stored in the pit traps when not in use (Raphael and Barrett 1981).

Direct Observation

A few species, especially the diurnal squirrels, may be sampled directly using methods more commonly used for birds or large mammals. Such methods include time-area counts (Davis 1982) and line-transect counts (Anderson et al. 1979). Species such as tree squirrels may be detected more readily by stimulating them to call.

SAMPLE SIZE

As indicated above, one is unlikely to measure animal density directly in a monitoring program, rather some type of catch-per-unit-effort or frequency-of-occurrence index would be obtained. Although it would be good to know the relationship between the index and true density, comparisons of indices over time should be done on the original data. The type and amount of effort expended should be carefully standardized (Caughley 1976:12-25).

The number of sample sites considered should be dispersed throughout the total area of oak woodland (Green 1979). For example, to monitor the state of California, but still be able to track regional differences, I suggest that at least three sample sites be allocated to each of the following regions: north coast, south coast, northern sierra, southern sierra, southern California.

The number of stations per sample site should be a function of the precision desired in detecting trends. This in turn is affected by the "detectability" of a species by a given sample method and the sample period each station is operated. For most species in oak woodland, the optimum prescription for these variables is not yet known. Hence pilot projects should be done before settling on a final standard. For example, one should run tracking stations for 10 or more nights to see if the cumulative number of stations visited levels off (Raphael and Barrett 1981). In most instances leveling off should occur, so the inflection point of the curve could be used to indicate the optimum sample period.

The next step is to determine the likely frequency of occurrence of the rarest important species expected. Some species will always be so rare (long-tailed weasel, Mustela frenata), or so difficult to detect with any known method (bats), that monitoring their abundance will simply not be feasible. For example, imagine that spotted skunks (Spirogale gracilis) typically visited 12 of 100 track stations even after a 5-day sample period. To detect a decline (alpha = 0.05; beta = 0.20; two-tailed Z test) in skunk abundance, the frequency would have to drop to only 1 of 100 stations visited (Davis and Zippin 1954, Fleiss 1981) (Table 1). Although a Z Test or a Wilcoxon Signed Rank Test is appropriate for determining significant trends in such data, the Fisher Randomization Test is preferred (Roughton and Sweeny 1982). Roughton and Sweeny provide a listing of the FORTRAN source code to accomplish all these tests. The important point here is that if a species is normally detected at less than 10 percent of the stations, it will be difficult to show a statistically significant decline.

If more sample stations are desired, the area of the sample site must be increased, given a constant distance between stations. The relationship between the size of the sample site and the distance between sample stations is indicated in Table 2. The home range of the largest species of interest should guide the distance between sample stations. Stations should be far enough apart that finding one is unlikely to influence an individual animal's finding another. Thus, if carnivores are being

Table 1. Examples of the ability of a pair of 100-station samples to detect a significant (alpha = 0.05, beta = 0.20, two-tailed test) change in visitation rate (Fleiss 1981:41-42). The visitation rate must drop from the first value to the second value or less to be considered a significant decline.

Stations visited first year	Stations visited second year
12	1
14	2
16	3
18	4
19	5
27	10
33	15
39	20
51	30
61	40
71	50

Table 2. Relationship between the area of a sample site and the distance between grid stations for a 100-station grid.

Between-station distance (m)	Grid area (ha)
10	1
100	100
316	1,000
1,000	10,000

considered, sample stations should be hundreds rather than tens of meters apart.

Frequency of sampling is another issue. Theoretically it would be preferable to sample once per year during the season at which populations were least variable (typically just prior to the reproductive season). However, given the difficulty of running pit traps and track stations during rainy periods, the summer season is the only feasible one. Moreover, this is the season when qualified labor, in the form of students, is most readily available. Nevertheless, we still need detailed studies of the annual cycles of many smaller mammals in oak woodlands. Furthermore, many species show marked fluctuations between years. Knowledge of normal patterns would greatly assist the interpretation of data derived from a monitoring program.

PROPOSAL FOR A STANDARD MONITORING SYSTEM

This proposal assumes that it is not feasible at this time to monitor bats and certain very rare species such as the long-tailed weasel. It also assumes that sample areas are preferentially located in flat to moderately steep sites within a short distance of vehicle access. It further assumes that 100 sample stations are sufficient to provide the desired precision and 300 meters between stations is sufficient for visits by larger mammals to be independent occurrences among stations. Such a grid laid out as a square would cover approximately 1000 ha. One track plate (Barrett 1983) would be established for 5 nights at each station. Additionally, one 5-gal pit trap (Dedon and Barrett 1982) would be established 150 m beyond each track station along one axis of the grid, thus making 2 grids offset by one half grid cell. Pit traps would also be run for 5 nights. Individuals captured in pit traps would be marked or removed to avoid double counting. Finally, sign of certain species (e.g. gophers) would be recorded if present within a 10-m radius of each pit trap. Tree squirrels and ground squirrels would be recorded if observed while walking between each track station.

One person should be able to complete one sample site in 10 consecutive days of work. Two lines would be established each day for the first 5 days (7 km walked per day). Then on the 6th day the first two lines would be checked, and so on until the last two lines were checked on the 10th day. Of course, initial establishment of the grid would require considerably more work to survey the grid and to dig in pit traps. Once established, nearly all equipment could be left on site. Pit traps would be covered and track plates could be buried. All stations would be marked with permanent survey markers.

CONCLUSION

I will conclude with two questions. Is it time to institutionalize a monitoring program for nongame mammals as is done in some European countries? If so, is the scheme outlined here the optimal design? Only a pilot project will determine this. In any case, there is certainly a need for further research on monitoring methodology, as well as additional autecological studies.

Acknowledgments: I thank Jared Verner and the Monitoring Subcommittee of the California Interagency Wildlife Task Group for a series of stimulating discussions on wildlife monitoring. Daniel F. Williams and David Sharpnack provided constructive criticism of an earlier draft.

REFERENCES

Anderson, D. R.; Laacke, J. L.; Crain, B. R.; Burnham, K. P. Guidelines for line transect sampling of biological populations. J. Wildl. Manage. 43(1):70-78; 1979.

Anthony, R. M.; Barns, V. G., Jr. Plot occupancy for indicating pocket gopher abundance and conifer damage. In: Kaukeinen, D. E., editor. Vertebrate pest control and management materials: Fourth Symposium ASTM STP 817. Philadelphia, PA: Amer. Soc. for Testing and Materials; 1983; 247-255.

Barrett, R. H. Mammals of California oak habitats--management implications. In: Plumb, T. R., tech. coord. Ecology, management, and utilization of California oaks. June 26-28, 1979, Claremont, California. Gen. Tech. Rept. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture; 1980; 275-291.

Barrett, R. H. Smoked aluminum track plots for determining furbearer distribution and relative abundance. Calif. Fish and Game 69(3):188-190; 1983.

Beacham, T. D., Krebs, C. J. Pitfall versus live-trap enumeration of fluctuating populations of _Microtus townsendii_. J. Mammalogy 61(3):486-499; 1980.

Caughley, G. Analysis of vertebrate populations. New York, NY: John Wiley & Sons; 1976. 234 p.

Clark, T. W.; Campbell, T. M., III. A small carnivore survey technique. Great Basin Naturalist 43(3):438-440; 1983.
Davis, D. E., editor. Handbook of census methods for terrestrial vertebrates. Boca Raton, FL: CRC Press; 1982. 397 p.
Davis, D. E.; Winstead, R. L. Estimating the numbers of wildlife populations. In: Schemnitz, S. D., editor. Wildlife management techniques manual. 4th ed., rev. Washington, DC: The Wildlife Society. 1980; 221-246.
Davis, D. E.; Zippin, C. Planning wildlife experiments involving percentages. J. Wildl. Manage. 18(2):170-178; 1954.
Dedon, M.; Barrett, R. H. An inventory system for assessing wildlife habitat relationships in forests. Cal-Neva Wildl. Trans. 1982:55-60; 1982.
Eberhardt, L. L. Appraising variability in population studies. J. Wildl. Manage. 42(2):207-238; 1978.
Fleiss, J. L. Statistical methods for ratios and proportions. 2nd ed. New York: John Wiley & Sons; 1981. 321 p.
Green, R. H. Sampling design and statistical methods for environmental biologists. New York, NY: John Wiley & Sons; 1979. 257 p.
Hayne, D. W. Experimental designs and statistical analyses in small mammal population studies. In: Snyder, D. P., editor. Populations of small mammals under natural conditions. Pittsburg, PA: Pymatuning Laboratory of Ecology, University of Pittsburg, Special Publ. Ser. 5:3-13; 1978.
Laymon, S. A.; Barrett, R. H. Developing and testing habitat capability models: pitfalls and recommendations. In: Verner, J.; Morrison, M. L.; Ralph, C. J., editors. Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. Madison, WI: University of Wisconsin Press; 1986; 87-91.
Mayer, K. E.; Passof, P. C.; Bolsinger, C.; Grenfell Jr., W. E.; Slack, H. Status of the hardwood resource of California: A report to the Board of Forestry. Sacramento, CA: Department of Forestry; 1986. 126 p.
Pankakoski, E. The cone trap as a useful tool for index trapping of small mammals. Ann. Zool. Fennici 16:144-150; 1979.
Raphael, M. G.; Barrett, R. H. Methodologies for a comprehensive wildlife habitat analysis in old-growth Douglas-fir forests. Cal-Neva Wildl. Trans. 1981:106-121; 1981.
Raphael, M. G.; Taylor, C. A.; Barrett, R. H. Smoked aluminum track stations record flying squirrel occurrences. Res. Note PSW-384. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture; 1986. 3 p.
Roughton, R. D.; Sweeny, M. W. Refinements in scent-station methodology for assessing trends in carnivore populations. J. Wildl. Manage. 46(1):217-229; 1982.
Seber, G. A. F. The estimation of animal abundance and related parameters. London: Griffin; 1982. 654 p.
Smith, M. H.; Gardner, R. H.; Gentry, J. B.; Kaufman, D. W.; O'Farrell, M. H. Density estimations of small mammal populations. In: Golley, F. B.; Petrusewicz, K.; Ryszkowski, L., editors. Small mammals: Their productivity and population dynamics. New York, NY: Cambridge University Press; 1975; 25-54.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Managing Blue Oak for Wildlife Based on Acorn Production[1]

Laurence A. McKibben and Walter C. Graves[2]

Abstract: Acorn production for individual blue oak trees was determined by the visual-estimate method. Production was also measured by weighing the entire acorn crop of selected trees. The mean weights of acorns produced by individual trees in Classes 2, 3 and 4 were calculated. Analysis showed a statistically significant difference in acorn weight per square meter of canopy and per individual tree among Classes 2, 3 and 4. An individual tree must produce an annual acorn yield in Class 3 or 4 to provide a meaningful amount of food for wildlife.

Of the 17 species of oaks that occur in California (Tucker 1980) blue oak (Quercus douglasii) is among those of greatest concern because of its extent, utilization and apparent lack of regeneration. Moreover, blue oak is the primary species that ranchers clear from their lands to increase grazing capacity and generate income. It is the dominant tree in the oak woodlands surrounding the inland valleys and Coast Range.

In response to these pressures and concerns, the California Department of Fish and Game initiated studies of wildlife dependency on oaks in 1974 (Graves 1975). The original objective was to determine relationships between oaks and wildlife in order to develop habitat management plans. However, it became apparent early in the study that to achieve the objective a method was needed to monitor acorn yield. This paper briefly describes that method, evaluates its precision, and provides management recommendations based on a 10-year study using this method.

Methods

A permanent study area was established in blue oak habitat in the eastern foothills of Tehama County (Figure 1). Three hundred sixty-three trees on a 24,300-ha ranch were selected and marked in 1977. A survey route was established along roads to accommodate large areas and to ensure sampling efficiency. Sample plots were established at 0.32 kilometer intervals and five trees were selected randomly at each stop. Tree selection alternated from right to left along the road to facilitate random selection. Trees were selected at various distances from roadways depending on their availability but far enough to avoid unnatural edge effects. The dbh, crown diameter, height, and canopy depth of each tree were estimated and recorded. Because mast production may vary by slope and elevation, plots included trees on various slopes and at different elevations but these were not equally represented in the sample. Visual estimates of the acorn production were then recorded annually for each tree prior to the acorn drop from 1977 through 1985.

Acorn production for individual trees was determined by the visual-estimate method (Graves 1980). Trees were assigned to one of four classes according to the following procedure.

Class 1 - No Visible acorns (Score 1).

Class 2 - Acorns visible after very close examination. Maybe only one or two were observed (Score 2).

Class 3 - Acorns were readily visible, but they did not cover the entire tree and the limbs did not appear to bend from their weight (Score 3).

Class 4 - Acorns readily visible and covering the entire tree; limbs appeared to sag from weight of acorns (Score 4).

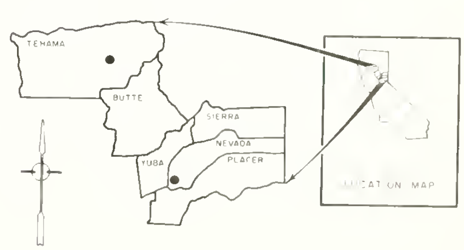

Figure 1-- Tehama Study Area, Tehama County and Spenceville Wildlife Area, Nevada County, California.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

[2]Wildlife Biologists, Department of Fish and Game, Sacramento and Yountville, California.

Information collected early in the study showed that the best period, phenologically, to estimate mast production was between August 15 and September 15.

To determine the total weight of acorns produced per square meter of canopy and per tree, 10 Class 2 trees, 20 Class 3 trees, and 10 Class 4 trees were sampled on the Spenceville Wildlife area in Nevada County (figure 1). The entire acorn crop was collected from these trees and weighed within 24 hours after being collected to reduce variation in weight due to moisture loss. The same tree measurements were taken for these trees as for those at the Tehama study area.

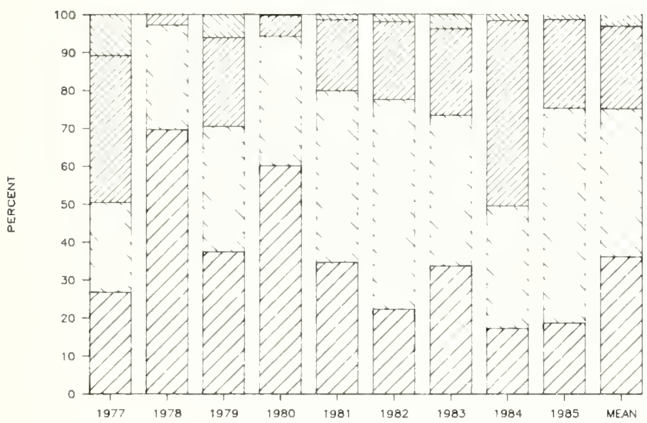

Figure 2-- Blue oak acorn yield class distribution in Tehama County, California from 1979 to 1985. Visual classes designated as follows: 1 2 3 4

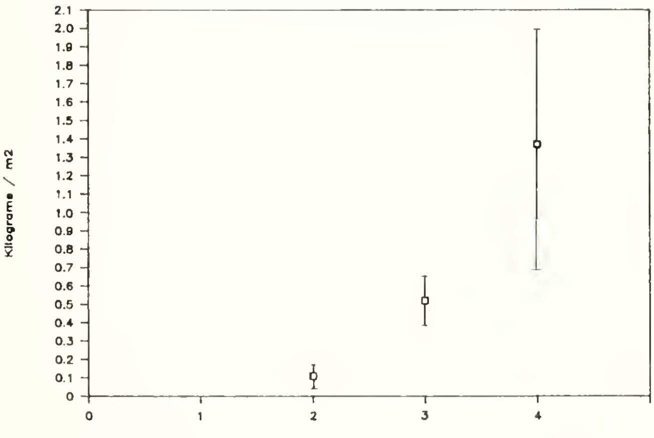

Figure 3-- Mean weight and 95 percent confidence intervals of blue oak acorn crop per m^2 of canopy by visual class.

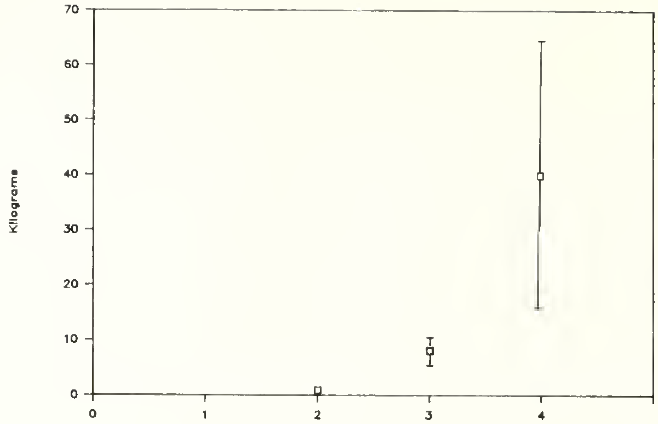

Figure 4-- Mean weight and 95 percent confidence intervals for total blue oak acorn crop per tree by visual estimate.

Results

The average acorn yield class for blue oaks on the Tehama study area ranged from 1.35 in 1978 to 2.34 in 1984 (figure 2). The 9-year average was 1.93. During this same period, 15 trees (4 percent) were rated Class 1 and 73 (20 percent) were rated Class 2 in all years. Thus, nearly 25 percent of the total sample was essentially non-productive during the entire study. The long-term trend showed that, on the average, only 25 percent of the trees were Class 3 or better in good production years.

Analysis showed a statistically significant (P=0.05) difference in acorn weight per m^2 of canopy between classes (figure 3). Acorn production was highest in Class 4 with 1.37 kg/m^2. The mean for Class 3 was 0.52 kg/m^2. The Class 2 mean was 0.11 kg/m^2.

A second important measurement that supported the value of the visual estimate method was the mean weight of acorns produced per tree in each visual class. As with the weight per square meter of canopy, all tree classes differed significantly from all others (figure 4). Class 2 trees produced a mean of 0.80 kg of acorns per tree; Class 3 trees averaged 8.01 kg per tree and Class 4 trees averaged 40.53 kg per tree.

Management Recommendations

Many landowners would like to harvest various amounts of oak trees on their land. By visually estimating annual acorn production and classifying individual trees, landowners can remove selected non-productive oaks and still provide acorns for wildlife in specific areas. Trees need to be visually classified and marked according to acorn yield class during one or preferably two high acorn production years. The percentage of trees producing at least 1 year at the Class 3 level increases with the number of years classified. Based on the Tehama County information, a good year would be defined as one in which 25 percent are producing as Class 3 trees or better in a random sample of 100 trees. Once producing trees have been identified, all or a portion of the non-producing trees (Class 1 and 2) can be removed. This probably would reduce competition between trees for nutrients and moisture although this has not been tested. This recommendation, of course, is based only on the value of oaks for mast production and does not consider other values.

When landowner goals are to improve the land for wildlife, only a small percentage of the non-producing trees should be removed. Furthermore, slash should be piled to provide ground cover for many game and nongame species. In some areas, when blue oak trees are harvested in winter, they have a greater tendency to sprout (Thornton 1980). Sprouts provide browse for deer and may become shrub-like in form to add diversity and ground cover.

Landowners wishing to remove as many trees as possible to meet management objectives could conceivable harvest all of the non-producing trees. Up to 75 percent of the trees in a given area could be removed without a significant loss (less than 10 percent) in acorn production. The actual percentage of trees to be removed would vary from area to area and must be determined by visual surveys, preferably for several years. In Tehama County during the best years, half of the trees were Class 3 or 4. This occurred in 2 of the 9 years for which data were collected. If a landowner had classified the trees during those 2 years, only half would have been marked for removal.

This method addresses only one element: acorns as food for wildlife. Greater oak densities may be necessary to provide cover for some wildlife species. Also, a good oak management plan needs to allow for recruitment of acorn-producing trees over time by leaving immature (too young to produce acorns) trees in the stand when they are present.

For larger areas such as counties, deer herd units, or geographical regions, annual acorn yield data can be used with other information such as herd composition counts, population surveys and food habits to explain or predict trends in wildlife numbers. Monitoring acorn production annually will provide quantifiable data on one of the many variable affecting wildlife populations.

An individual tree must produce an annual acorn yield in the Class 3 or 4 category to provide a meaningful amount of food for wildlife. For blue oaks, it is more important to show the frequency distribution of each class in the total sample than to simply refer to the average class. This is very critical when using yield classes to manage oaks for wildlife or making predictions on the value of the annual acorn crop to wildlife in any given area. For example, in a sample of 100 trees, when all the trees are Class 2, the yield would be 2. The total acorn yield would be 80 kg per tree. The same sample with a class average of 2 but with 50 Class 1 and Class 3 trees would yield 400 kg per tree--a five-fold increase in yield with the same class average. The difference would be even greater if Class 4 trees were included in the sample. By examining class frequency, we also identify the non-producing segment within the area over time.

To use this type of information to manage specific areas, annual acorn yield estimates should be used along with the average weight per square meter of canopy per visual class to estimate the pounds of acorns available for a given area. On private lands, this information can be an important consideration in setting harvest levels for pigs and deer.

Acknowledgments

We thank Jared Verner, Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service; William Laudenslayer, Tahoe National Forest, U.S. Forest Service, and Ken Mayer, Forest and Rangeland Resources Assessment Program, California Department of Forestry for their review and helpful comments.

References

Graves, Walter C. The dependency of upland game on oak mast production. Calif. Dept. of Fish and Game progress report, Project W-47-RR-23, Job IV-1.4, 1975.

Graves, Walter C. Annual oak mast yields from visual estimates. In: Proceedings of symposium on the ecology, management and utilization of California oaks. Gen. Tech. Rep. PSW-44, Berkley, CA.: Pacific Southwest Forest and Range Experiment State, Forest Service, U.S. Department of Agriculture; 1980; 270-274.

Tucker, John M. Taxonomy of California oaks. In: Proceedings of the symposium on the ecology, management and utilization of California oaks. Gen. Tech. Rept. PSW-44. Berkley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980; 19-30 368 pp., 1979.

Thornton, William. California Department of Fish and Game, Willows, CA. (personal communication 1980).

Wood Products-Utilization

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Utilization Opportunities for Hardwoods[1]

Peter C. Passof[2]

Multiple-use management clearly implies that California's hardwood resources have important benefits and values whether left standing or converted into primary or secondary products.

California's native and exotic hardwoods offer a wide range of utilization opportunities. In the following papers you will learn how various hardwoods may be exploited for their organic compounds (silvichemicals), chips, fuelwood, low value boards and high value products such as those used in fine furniture.

For as many reasons as there are potential useful products for these hardwoods, most Californians have maintained a cautionary attitude toward increased utilization, preferring to wait on the threshold. Some have ventured forth with exciting ideas and even a smaller number have put their time and energies into practice.

Making a decision to utilize a specific species of hardwood whether it be for furfural, firewood, furring, or furniture is one that requires gathering up information from many sources and evaluating it carefully. For those entrepreneurs who have been less than successful in utilizing hardwoods, perhaps the ideas put forth in the following papers will shed new light and bring opportunity. For those still waiting in the wings, view the information as another important step in your data gathering process.

Public concern has been expressed that some species of hardwoods are being overutilized, and may in fact be reaching a point where the situation is unacceptable in multiple-use management schemes because it ignores basic conservation principles. A successful hardwood utilization operation is one that understands the limits of the resource as well as the marketplace.

Our knowledge base concerning the wise management, protection, and utilization of California's hardwood resources has definitely increased since the last statewide symposium. More studies are underway which will provide you with even better information in the future. For those who need the information now, the papers in this section provide a full spectrum of up to date thinking.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986. San Luis Obispo, Calif.

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Overview of the Hardwood Utilization Problem[1]

Stephen L. Quarles[2]

Abstract: The hardwood resource in California is comprised of a wide variety of species including some in fairly sizable quantity. Despite this, significant utilization of this unique resource has never taken place. This paper discusses the most likely future utilization in terms of volume and wood properties. These are compared to the other commonly used species in the United States. Factors limiting the utilization of California hardwoods are discussed including processing and marketing problems.

During the last 30 years there have been numerous research papers reporting on various physical properties and processing characteristics of the major California hardwoods. Participating institutions have included the University of California and United States Forest Products Laboratories and the Forest Resources Laboratory at Oregon State University. During the same period, there have been many efforts made to establish and sustain a hardwood utilization industry in California. These efforts have included two major feasibility studies including the Hoopa Valley Reservation Hardwood Study Report (1968) and another by Winzler and Kelly Consulting Engineers (1979). Each of these investigated the economic potential of developing a hardwood utilization facility in the North Coast region (Humboldt County) of California. To date, little has come of these studies, both of which indicated that such an undertaking was economically viable. In fact, with the exception of Cal-Oak in Oroville, most of the larger facilities have ceased operating.

The reasons for the lack of greater hardwood utilization in California are somewhat complicated. There are definitely some processing problems associated with the primary breakdown with respect to sawing for grade, and with the drying operation, but exactly to what extent these problems can be traced exclusively to the fact that operations are geared toward the better known softwood processing procedures is difficult to say. It is also clear that well defined supply channels to some of the larger users in the state do not exist. In the remainder of this paper, I will expand on these ideas, and attempt to define issues that should be addressed in order to increase utilization of the California hardwood resource.

VOLUME COMPARISONS AND PHYSICAL PROPERTIES

Forest Service Report Number 23 (1982) reported that approximately 90 percent of our nations hardwood growing stock is located in the Southern, Eastern, and Midwestern states. Only 6.6 percent is located in Pacific Coast states, which amount to 16,866 million cubic feet. The most recent survey of California hardwoods estimates a timberland volume of approximately 7700 million cubic feet[3]. This represents approximately 46 percent of the 1977 Pacific Coast volume figure. While it is clear that most of the US hardwood resources lie outside California, there is still a sufficient quantity on which to build a hardwood industry.

Four species make up 85 percent of the hardwood timberland volume in California. These species are California black oak (Quercus kelloggii), Tanoak (Lithocarpus densiflorus), Canyon live oak (Quercus crysolepis) and Pacific madrone (Arbutus menziesii). They comprise roughly 29, 25, 17, and 14 percent of the total volume, respectively[3]. California-laurel (Umbellularia californica) is the fifth most abundant species, comprising almost 4 percent of the timberland volume. Any major utilization effort must rely on one or more of these species.

The physical properties of these hardwoods have been documented in a series of University of California Forestry and Forest Products Reports (available from the University of California Forest Products Laboratory) and publications from other institutions, as previously mentioned. A comprehensive review and comparison of eastern and western hardwood properties can be found in the Hoopa Valley Reservation Hardwood Study Report (1968). A summary of physical properties is given here in Table 1. Properties of California hardwoods generally compare favorably with Eastern hardwoods, and it is not felt that these properties should limit utilization.

PROCESSING AND MARKETING PROBLEMS

Several problems currently exist which limit utilization. These can be divided into two distinct areas, the first dealing with processing problems, and the second dealing with marketing aspects.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, Calif.

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[3]Personal Communication, 1986, Charles Bolsinger, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Table 1--Selected physical properties of major California and Eastern hardwoods.

Species	Specific Gravity, Swollen Volume Basis	Volumetric Shrinkage, %	Bending Strength lb/in^2	Modulus of Elasticity, 10^6 lb/in^2	Compression Perpendicular to the Grain, lb/in^2	Side Hardness, lb
Eastern white oak	0.68	16.3	15,200	1.78	1070	1360
Black cherry	0.50	11.5	12,300	1.49	690	950
Sugar maple	0.63	14.7	15,800	1.83	1470	1450
Yellow birch	0.62	16.8	16,600	2.01	970	1260
Yellow poplar	0.42	12.7	10,100	1.58	500	540
California black oak	0.49	10.9	7,150	1.03	524	870
California laurel	0.55	12.2	10,030	0.94	900	1305
Pacific madrone	0.65	20.5	9,270	1.64	525	1250
Tanoak	0.67	19.2	14,450	2.26	640	1455

Note: The Wood Handbook (1974) is the source for data on all Eastern hardwoods. California hardwood data is taken from information compiled by Dost (1969).

The three major processing areas include harvesting, log breakdown, and drying. Hardwoods cause problems in each of these areas, especially when compared to softwoods. Harvesting will only be briefly discussed here. It would tend to be a problem because of the lack of pure stands of any given hardwood species and because of the potential for lower quality material on the stump.

Cutting to optimize grade is an essential component for the financial success of any major operation, and should be emphasized over maximizing yield. Malcolm (1956) discusses in some detail methods which can be used to maximize high grade lumber from hardwood logs. Several newer programs have been introduced recently by the United States Forest Service which should help in processing some of the low quality, and potentially low recovery California hardwoods. One of these, System 6 (Reynolds and Gatchell 1982), was developed to aid in processing low quality, small diameter Eastern hardwoods, species which are probably no easier to process than those in California. The major end products of System 6 are standard sized blanks for use in furniture and cabinetry manufacturing. It is possible, and desirable, to also incorporate a firewood, and chipping operation into the System 6 process. In spite of the apparent advantages of System 6, no large producer has incorporated it into their production process[4].

Drying is the other processing aspect which make hardwood utilization difficult. Regardless of how hardwoods are dried, they require more care and longer drying times than commercial softwood species. Longer drying times exist whether the lumber is initially air dried, or dried green from the saw. To minimize degrade, all hardwood lumber should be air dried to approximately 30 percent prior to conventional kiln drying. This leads to higher inventory carrying costs, and is in that respect undesirable.

Drying schedules for the major California hardwoods have been published by both the UC and US Forest Products Laboratories. Theoretically, these schedules can be used to dry lumber from the green condition. The problem lies in the fact that low temperatures (around 110°F) and high relative humidities are called for in the early portion of the schedule. To avoid excessive degrade it is therefore critical to have a kiln which can hold close tolerances. It is generally difficult for conventional kilns to do this.

California black and other California oaks are generally no harder to dry than Eastern oaks, and all are susceptible to surface checking. Tanoak is the most difficult to dry of the California hardwoods, and it is debatable whether it can be successfully dried from the green condition in a kiln operating at conventional temperatures. Darker colored portions of the tanoak heartwood are extremely collapse susceptible, and the wood in general is prone to surface checking. Consistent high quality drying of tanoak is a critical problem which must still be overcome for successful utilization.

Several systems offer some hope for speeding up the drying of hardwoods, while maintaining a high quality end product. One such system involves the use of a predryer. These are relatively large chambers (a capacity of roughly 100,000 board feet) which operate at extremely low temperatures (85-95°F) and high relative humidities (75-80 percent). As with conventional kilns, fans are used for circulating air. Predryers are intended to be used as a controlled air drying yard. Lumber is

[4]Personal Communication, 1986, William Sullivan, Humboldt State University, Arcata, California.

dried to about 30 percent and then transferred to a conventional kiln for drying to the final moisture content. Use of predryers can therefore significantly reduce drying time and reduce degrade. Total time in the predryer is approximately one month. Dehumidification kilns have also been used successfully in hardwood drying and offer a good alternative to air drying. The success has mainly been due to slow heating up time and a relatively low maximum temperature, both of which are conducive to slow drying and consequently fewer defects. Certain changes in the dehumidification unit (specifically to the refrigerant) now make it possible to dry at temperatures used in conventional steam heated kilns. Dehumidification units so equipped become an attractive alternative for drying western softwoods, since drying time can be reduced relative to earlier dehumidification units. However with respect to hardwoods, they offer no additional product quality benefits over conventional steam heated units. In addition, equipment must be available to supply low pressure steam to the kiln for equalizing and conditioning the lumber, steps which are necessary to equalize the moisture content of the lumber in the kiln and to relieve stresses which develop during drying.

Some of the newer systems on the market involve vacuum drying in conjunction with either a heating medium such as heated platens or blankets, or with radio frequency heating. Many of these systems appear to give good results in terms of both drying time and quality, but independent verification is not available for these claims.

MARKETING PROBLEMS

There are several major marketing problems which hinder greater utilization. These include the lack of any continuous supply channels which would move the material from the primary to secondary processing facilities. There is also no formal outlet for technical information concerning secondary manufacturing processes such as wood machining and bending characteristics, although much of this information already exists. The furniture industry in California will always be leery of buying into the California hardwood market as long as there is no steady, consistent, supply.

In general, California hardwoods are single species. California black oak does not look like a typical eastern red oak. The same can be said for tanoak and Pacific madrone, in that they show little resemblance to eastern hardwoods. These species must stand alone, and really cannot be used as a look alike for a better known species. Only the California white oaks look like typical white oak. The fact that most of California hardwoods are stand alone species is not necessarily bad, but it does mean that some marketing effort is needed to "sell" these species. It would be helpful, in this respect, to adopt the same grading rules as used by the National Hardwood Grading Association (NHGA). Discrepancies between NHGA grading rules and Red alder grading rules, have apparently led to some confusion on the part of some secondary processors.

FUTURE UTILIZATION

It seems unlikely that any large primary processing operation will start up in the near future. One possible exception would involve an established eastern or midwestern hardwood producer to participate in a joint venture with an established west coast softwood producer with a sizable hardwood resource base[5]. The established hardwood producer would presumably provide processing expertise as well as access to markets. I am becoming more aware of one and two person operations which are operating throughout the northern part of the state. These operations are facing the same processing problems that any large operation would, and on initial start up, must wait up to a year to sell any dry lumber. In short and midterm, these small operations will likely continue, in addition to others starting up.

It seems prudent to nurture and support this developing cottage industry, especially since most of the larger operations have failed for one reason or another. The biggest problem faced by the small independent is drying the lumber. Developing one or more drying cooperatives would be one way to help alleviate this problem. It would be possible to take this idea one step further and establish a primary processing cooperative, where both primary breakdown and drying would be performed.

Secondary processing cottage industries which have the potential to develop around the primary processors include flooring (tanoak is ideal due to its exceptional hardness), cooperage (white oak would be best suited for the same reasons Eastern white oaks are used), furniture (all hardwoods), pallets and pallet stock, veneer, and firewood. Bill Dost, of the University of California Forest Products Laboratory, suggests that an ideal use of white oak cooperage would be for one to five gallon wine casks for sale at do it yourself wine shops.

In summary, the best short term potential for California hardwood utilization appears to be with the small but growing, cottage industry. It seems that resources would be best utilized by supporting the development of these concerns through the establishment of cooperative processing centers, especially for drying. A clearing house for transferring current technology to producers and users and to act as a middle man to match hardwood suppliers with potential manufacturing centers would help overcome some of the processing difficulties and also aid in establishing the necessary supply channels. Finally, an investigation of some of the cottage industry operations in the East may help realize our potential somewhat quicker, with fewer false starts.

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[5]Personal Communication, 1986, William Sullivan, Humboldt State University, Arcata, California.

LITERATURE CITED

Dost, William A. 1969. Western hardwoods challenge wood users. Wood and Wood Products. 74(4):32-34.

Hoopa Valley Reservation Hardwood Study Report. 1968. U.S. Department of Commerce Economic Development Administration, Technical Assistant Project. Contract Number 7-35519.

Malcolm, F.B. 1956. A simplified procedure for developing grade lumber from hardwood logs. USDA Forest Products Laboratory Report Number 2056. 13 p.

Reynolds, Hugh W. and Charles J. Gatchell. 1982. New technology for low grade hardwood utilization: system 6. USDA Northeastern Forest Experiment Station Research Paper NE-504.

U.S.D.A. Forest Service. 1982. An analysis of the timber situation in the United States 1952-2030. Chapter 6, Domestic Timber Resources. Forest Resources Report Number 23.

Winzler and Kelly. 1979. A study of the feasibility of developing a hardwood process facility in Humboldt County, California. Prepared for Redwood Region Economic Development Commission County of Humboldt, California.

Wood Handbook. 1974. Forest Service Agricultural Handbook Number 72. USDA Forest Products Laboratory, Madison, Wisconsin.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Ethanol Fuel, Organic Chemicals, Single-Cell Proteins: A New Forest Products Industry[1]

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Abstract: Production of a minimum slate of products; for example, ethanol, Torula yeast, furfural and process power using the hydrolysis-fermentation-combustion process has been shown to be both technically and economically feasible on a demonstration scale using New York hardwoods and California manzanita. Using the same conservative approach the minimum return on investment using a California hardwood feedstock at a rate of 600 OD tons per day also shows economic feasibility. The cost of fermentables at $0.097 per pound when wood costs are $30 per OD ton is competitive with other U.S. sources of sugar.

Our exceptional national capacity for production of organic matter, i.e., lignocellulosic materials (LCM) through silvilculture and agriculture, is an asset that can be brought to bear directly upon the national energy and chemical raw material shortages which are currently deceptively dormant. The ultimate need for diversification from a petroleum-based economy is inevitable. A prime candidate for implementing diversification involves the hydrolysis of LCM to intermediate soluble organic compounds and insoluble ligneous residues. These intermediates then serve as feedstocks to produce numerous products. The concept being presented in this paper is for an integrated process in which virtually all of these intermediate products will be utilized to produce a value. Furthermore, it is an objective to provide limited flexibility of the design that will allow for changes in the ratio of products. Thereby, return on investment can be maximized. In the base case presented the final products are single cell proteins and furfural for intermediates obtained by hydrolysis of hemicelluloses and ethanol from glucose obtained by hydrolysis of cellulose. Other products are recovered and used for their fuel value. Certain organic compounds in this fraction could be recovered as products having substantially higher values than that of a fuel. Development of one or more of the additional products could substantially enhance the base case presented here. Finally, numerous commercial fermentations other than for Torula yeast and ethanol are available for the production of products.

The economic conditions and petroleum supply vs demand have so drastically altered since 1973 that a threshold for initiation of a wood chemical industry is at hand. This is supported by advances that have been made in engineering and biotechnology which reduce the costs and broaden the range of products that can be produced.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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A program to utilize LCM in a new industry should have far-reaching salutary effects on local and national economies. Benefits include: the location of new industrial units in rural areas, particularly those which are economically-depressed; and the provision of new employment opportunities in the production units, in harvesting and silvicultural operations, and in ancillary businesses providing goods and services.

Improved forestry practices would include increased use of thinnings; logging residues; insect, fire, and incipient decay damaged wood; residues from primary and secondary lumber manufacturing and the new opportunity to utilize so-called weed species and brush.

It is the purpose of this paper to outline the results of a decade of work carried out at the University of California Forest Products Laboratory (UCFPL) in which a process has been designed for the hydrolysis of LCM and production of products therefrom using modern technology. Moreover, it will be shown that a process producing a minimum number of products which is specifically related to California hardwoods can be economically viable. This program, since 1979, has been carried out with cooperation and support from GeoProducts Corporation of Oakland, California.

LIGNOCELLULOSE

All cells of woody plants are composed of LCM which comprises the vast majority of terrestrial biomass. Extractive-free LCM is a mixture of two quite different types of biopolymers, i.e, polysaccharides and lignins. These biopolymers are laid down by the protoplasma of each cell in a sequence of layers that gives a complex interpenetrating system.

The principal component in the system, cellulose, is deposited first in linear molecules composed of five thousand to fifteen thousand D-glucose units linked by primary valence bonds. Accompanying or closely following the deposition of the cellulose, polysaccharides of a second class known as hemicelluloses are deposited. These hemicelluloses occupy interstitial space surrounding the cellulose fibrils, and penetrate small bundles of microfibrils. The molecules of hemicellulose comprise relatively short chains of

100 to 200 monosaccharide units. Some units in these chains bear other substituents or side-chains.

The major type of hemicellulose present in the angiosperms (hardwoods and grasses) is xylan comprising linear molecules of the 5 carbon (pentose) monosaccharide, D-xylose. Substituents on the xylan backbones include D-glucuronic acid and/or 4-O-methyl-D-glucuronic acid. In hardwood xylans the acetyl group is also a substituent; whereas, in softwood xylans L-arabinose (a pentose) is a substituent.

The major hemicellulose in gymnosperms (conifers or softwoods) is glucomannan comprised of two 6-carbon (hexose) monosaccharides, D-glucose and D-mannose, as backbone units. Of several glucomannan types in the softwoods, galactoglucomannans predominant. In this type, some glucose and mannose units in the linear chain bear the hexose, D-galactose, as well as acetyl groups, as substituents. Relatively small amounts of glucomannan, without substituents, are present in hardwoods.

The polysaccharides present in lignified tissues are hydrolyzed to monosaccharides by specific enzymes and by the hydrogen ion.

Lignin is deposited interstitially with or just after the deposition of the hemicelluloses. A portion of the lignin, particularly in softwoods, is chemically bonded to hemicelluloses but not to cellulose. Chemically, lignin is comprised of substituted benzene rings to which 3-carbon (propyl) side chains are attached. These arylpropane or C_6-C_3 units are interconnected at two or three sites per unit by carbon-to-carbon or carbon-to-oxygen-to-carbon (ether) bonds. Unlike the polysaccharides, the bonds linking the C_6-C_3 units into three dimensional high molecular weight lignin polymers are not significantly hydrolyzed by enzymes or by hydrogen ion, even at elevated temperatures.

Typical amounts of cell wall components found in extractive-free wood are:

Cell Wall Components	Angiosperms	Gymnosperms
	Percentage of Cell Wall Components	
Cellulose	42±3	42±3
Hemicelluloses		
Xylans	27±7	12±3
Glucomannans	4±2	20±5
Lignins	25±5	30±5

This lignocellulosic structure of interpenetrating polymers is the raw material or feedstock from which relatively simple chemical compounds can be produced and isolated as products. It is these products that can provide the basis for an organic chemical industry. In this paper the economic production of simple organic chemicals from California hardwoods is addressed. This activity holds the promise of a new forest products industry.

HYDROLYSIS OF LIGNOCELLULOSE

The polysaccharides of LCM are hydrolyzed readily by enzymes or by hydrogen ions when certain necessary conditions are present. The process requires the intimate contact of the large bulky molecules of enzymes with the surface of LCM where the glycosidic bonds involved in the linkages of the monosaccharides are hydrolyzed; i.e., the components of one molecule of water are added to each bond that is cleaved. The surface area of the polysaccharides that may be brought into such contact is limited even after reduction of the LCM to small particle sizes. Because excessive amounts of energy are required to reach particle sizes that substantially affect the rates of hydrolysis, the size reduction necessary is uneconomical.

The second means for hydrolyzing polysaccharides of LCM to monosaccharides employs the hydrogen ion as the catalytic agent. Hydrogen ion concentrations required to effect these hydrolyses may be obtained using concentrated mineral acids at essentially ambient temperatures or weak acids at elevated temperatures (Goldstein, 1981; Harris, 1949; Conner et al, 1985). The use of concentrated mineral acid has been uneconomical for decades because of the technical problems and resulting high costs that are involved in the recovery and recycle of the acid. Our recognition of these limitations in the mid 1970's was the major consideration selecting weak acid hydrolysis as the method having the greatest economic potential.

It was known that the rates of weak acid hydrolysis of hemicelluloses are several times greater than that of cellulose (Saeman, 1945; Harris, 1975). Under conditions required for dilute acid hydrolysis, degradation of monosaccharides takes place at significant rates. Accordingly, to obtain satisfactory yields of hemicellulosic sugars as well as glucose from cellulose, two sets of hydrolytic conditions had to be used. Conceptually, in the process that was to be designed, hemicelluloses were to be hydrolyzed in a first stage. The resulting solution of sugars had to be removed from the lignocellulosic residue before appreciable acid dehydration of sugars could take place. Finally, the solid residue still containing most of the cellulose had to be subjected to more severe hydrolysis to produce glucose.

Criteria we considered as necessary to maximize the economic viability of a modern wood hydrolysis process in the United States included:

1. The use of a dilute mineral acid.
2. Minimal energy usage to procure and prepare the LCM feedstock.
3. Two or more stages of hydrolysis to maximize sugar yields.
4. Continuous flow of process streams.
5. Optimization of temperature, time, acidity, and number of hydrolysis stages to maximize production of specific products.
6. Production of those products in maximum yields which give highest return on investment for a given process design.

7. Production of process effluents and emissions that are environmentally benign for each process design.

UCFPL CONTINUOUS FLOW REACTOR STUDIES

Reactors were designed and constructed in our laboratory in order to conduct a multistaged continuous flow process study. The reactors were sized to process, nominally, ¼ to ½ ton (OD wood basis) per day (24 hours). In the first stage the hemicelluloses were to be hydrolyzed, essentially quantitatively, the hydrolyzates were to be removed, and the partially hydrolyzed wood particles were to be treated with additional dilute acid and hydrolyzed in the second stage reactor. In this stage the major parameters, space time, temperature and hydrogen ion concentration were selected to rapidly hydrolyze the cellulose in order to optimize the yield of glucose and to minimize acid degradation of glucose to the initial degradation product, hydroxymethylfurfural (HMF).

An initial study was carried out using chips of white fir (Abies concolor Lindl. and Gord.) and Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco). Results met or exceeded predicted results (Brink and Merriman, 1980). Glucose, mannose, xylose and acetic acid in the first stage (S1) hydrolyzates, after pretreatments to remove the inhibitors and adjust pH, were readily utilized in aerobic fermentation to produce Candida utilis. This product is isolated and marketed as Torula yeast. Similarly, after pretreatments to remove inhibitors and adjust pH, the second stage (S2) hydrolyzate proved to be a good medium for the production of ethanol by anaerobic fermentation using the yeast, Saccharomyces cerevisiae.

A second study was carried out for GeoProducts under a contract with United Engineers and Constructors of Philadelphia, Pennsylvania, in which chips from four species of Eastern hardwoods were mixed and used as a feedstock. Again yields and other results obtained exceeded expectations.

Paper separated from municipal solid wastes was used as a feedstock in a third study. Cellulose was particularly high in this feedstock and this was reflected in the high yields of glucose obtained.

A fourth study was carried out for GeoProducts under a contract with the California Department of Forestry in which two species of California manzanita, Greenleaf manzanita (Arctostaphylos patula Green) and Common manzanita (A. manzanita Parry) were used as feedstock. This investigation proved to be equally successful relative to yields of products, operation of the continuous flow hydrolysis units, and fermentation of sugars present in the hydrolyzates. Second stage reaction kinetics and a computer simulated process flow were developed.

To demonstrate the technical and economic feasibility of the process as developed and the fermentability of the sugars in the hydrolyzates, a fifth large-scale demonstration project was carried out for GeoProducts under contract with the New York State Energy Research and Development Authority. In this study chips of seven predominant hardwood species were procured and mixed in a proportion that was judged to be typical of wood that is available commercially in the vicinity of Tupper Lake, New York,. These species were: American beech (Fagus grandifolia Ehrh.), sugar maple (Acer saccharum Marsh.), red maple (Acer rubrum L.), quaking aspen (Populus tremuloides Michx.), black cherry (Prunus serotina Ehrh.), yellow birch (Betula alleghaniensis Britton), and white ash (Fraxinus americana L.). Over two tons of wood (OD basis) were processed through the S1 reactor and the S1 residues isolated in this work were then processed through the S2 reactor. Four replicate S1 run series were carried out in which 57 steady-state intervals averaging 2.43 hours per interval were completed. A series of 16 S2 runs were carried out in which 42 steady-state intervals averaging 2.83 hours per interval were completed. Major variables studied included temperature, space time and pH. Second stage reaction kinetics developed in the fourth study were verified.

Hydrolyzates isolated in both S1 and S2 reactions were used in studies involving fermentation of component monosaccharides and recovery of various hydrolytic products and acid degradation products formed from the monosaccharides.

SIMULATED PROCESS FLOW

The process flow, given in figure 1, was simulated in essence in the fifth and most recent experimental study.

The analyzed composition of the mixture of New York hardwood chips used in the fifth study and the California manzanita chips used in the fourth study and an estimated composition of a mixture of California hardwoods that could represent a potential northern California supply are given in table 1.

The composition of the California hardwood mixture was calculated using three of the four most abundant species (madrone, Arbutus menziesii Pursh; tanoak, Lithocarpus densiflorus (Hook & Arn.) Rehd.; and California black oak, Quercus kelloggii Newb.) listed in a current inventory of the growing volume of hardwoods in California (Bolsinger, 1986) and for which a chemical composition was available (Pettersen, 1984). The "average" chemical composition of this mixture was taken as the summation of the composition of the three species, each weighted by the relative contribution each made to the total statewide growing volume of the three species.

Using the composition of California hardwoods (table 1) and the experimental results, including S2 kinetics, achieved with New York hardwoods in the fifty study allows the estimation of inter-

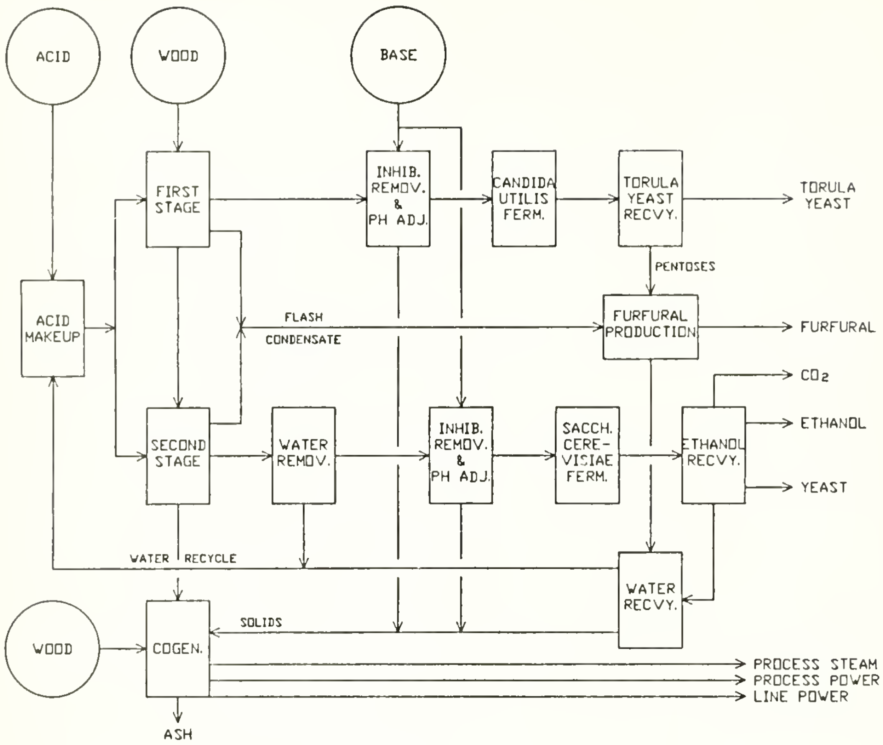

Figure 1--Process flow schematic for UCFPL-GeoProducts Hydrolysis-Fermentation-Combustion process.

Table 1--Composition of HFC process feedstocks.

Chemical components	New York hardwood 7-species mixture	California manzanita 2-species mixture	California hardwood 3-species mixture
		Percentage[1]	
Glucan	38.1	28.6	36.9
Mannan	1.9	1.4	2.0
Galactan	1.2	1.6	1.5
Xylan	14.9	16.4	19.3
Arabinan	0.6	1.9	0.5
Acid insoluble residue	23.6	32.9	20.7
Acetyl	3.8	4.0	4.0
Other organics	15.6	12.7	14.5
Ash	0.3	0.5	0.6
Total	100.0	100.0	100.0

[1]Oven Dried (OD) wood basis.

Table 2--Intermediate products of hydrolysis from California hardwoods.

Solid component	Slurry solids S1	Slurry solids S2	Hydrolyzate Component	Hydrolyzate Soluble solids S1	Hydrolyzate Soluble solids S2
	Yield, pounds per ton OD wood basis				
Glucan	700.4	196.9	Glucose	36.1	358.0
Mannan	0.0	0.0	Mannose	31.2	0.0
Galactan	0.0	0.0	Galactose	26.0	0.0
Xylan	25.5	0.0	Xylose	375.0	17.2
Arabinan	0.0	0.0	Arabinose	8.4	0.0
Acid insoluble solids	404.0	402.0		0.0	0.0
Acetyl	3.4	1.2	Acetic acid	106.9	7.7
Ash	0.9	0.9		11.1	0.6
Methanol	0.0	0.0		15.5	0.0
Furfural	0.0	0.0		23.9	18.7
HMF[1]	0.0	0.0		1.3	24.8
Levulinic acid	0.0	0.0		0.0	13.3
Formic acid	0.0	0.0		0.0	8.8
Other organics	200.8	199.8		114.2	158.1
Total	1335.0	800.8		749.6	602.2

[1]HMF is 5-hydroxymethylfurfural.

mediate product yields from hydrolysis of California hardwoods given in table 2. Based on the yields of intermediate products and known conversion efficiencies the final product yields can be calculated as shown in table 3. Assumptions used in calculating these yields include: 95 percent washing efficiencies; conversion of 100 percent of the glucose, mannose and acetic acid and 10 percent of the xylose in treated S1 hydrolyzate to give 50 percent yields of Torula yeast; 90 percent recovery of Torula yeast; overall recovery of 88 percent of furfural from S1 and S2 hydrolyzates and conversion of xylose in treated S1 hydrolyzate; and 46 percent recovery of ethanol from glucose in treated S2 hydrolyzate. By changing hydrolysis conditions the yields of intermediate products in table 2 and of final products shown in table 3 can be altered.

Table 3--Products predicted from HFC process utilizing California hardwoods[1].

Product	S1	S2	Total
Torula yeast	98.0	--	98.0
Furfural	207.5	12.8	220.3
Methanol[2]	9.0 (1.37)	--	9.0
Ethanol[2]	--	156.6 (23.8)	156.6
Brewers yeast		10.6	10.6
Subtotal			494.2
Hydroxymethylfurfural	1.1	21.1	22.2
Levulinic acid	0.0	13.3	13.3
Insoluble solids (S2-residue)			800.8
Soluble solids			602.5
CO_2 (ethanol fermentation)			152.9
Total output products			2083.9

[1]Pounds per ton of wood feed (OD basis).
[2]Gallons in ().

PROCESS ECONOMICS

A database has been developed for the HFC process which has been used to estimate with high confidence the economic feasibility of a two stage process for New York hardwoods and California manzanita. Given the chemical composition of a different lignocellulosic feedstock (e.g. the 3-species California hardwood mixture in table 1), the predicted intermediate product yields (table 2) and the final product yields for the simulated process (table 3), then the estimated gross revenues from products produced in the simulated HFC process were calculated for a 600 OD ton per day (tpd) plant and are given in table 4. Values are based upon 330 days of production per year and current or projected market prices. Though the current price for furfural is 50 to 100 percent higher, it may be predicted that increased production will increase its use and lower its price to that given. Ethanol is used primarily as an octane enhancer in gasoline and its price is linked to the price of crude petroleum and, also, of corn from which it is produced. Thus, its price fluctuates widely and unpredictably. With the inevitable rise in crude petroleum costs the price given for ethanol may be expected to rise. The amounts of methanol and brewers yeast produced are trivial but the products are formed, will be produced and enjoy good markets and, therefore, have been included.

In addition to these five products 5-hydroxymethylfurfural and levulinic acid are produced, can be isolated on a practical basis, and could enhance the profitability of the process. These two chemicals have been included in table 4 with an estimated gross value to indicate the magnitude of the increase in gross revenue they might contribute using a comparatively low price for this type of organic compound. Elsewhere in this paper it is assumed these two products are combined with other organics and formic acid listed in the hydrolyzates in table 2, assigned a fuel value, and together with the insoluble ligneous residue enter into the credit given for power developed in cogeneration.

Table 4--Estimated gross revenue from products[1].

Product	Market price $/lb (gal)	Lbs (gal) per year, millions	Gross value, $ millions
Torula yeast	[2]0.30	19.41	5.82
Furfural	0.30	43.62	13.09
Methanol	(0.70)	1.79 (0.272)	0.19
Ethanol	(1.25)	31.03 (4.71)	5.89
Brewers yeast	0.30	2.11	0.63
Total		97.95	25.62
Hydroxymethylfurfural	0.50	4.39	2.20
Levulinic acid	0.50	2.24	1.12
Total		104.58	28.94

[1]Yields based upon 600 OD tons of wood per day.
[2]Feed grade; food grade is currently about $0.50-0.60/lb.

The return on investment (ROI) predicted for a 600 tons per day HFC plant utilizing California hardwoods is given in table 5. The estimated operating expenses, other than wood costs, including operating labor, maintenance, maintenance materials, chemicals, taxes and insurance and overhead, are fixed. The two variables most affecting ROI are the costs of wood and the price of ethanol. Sensitivity analyses were carried out to predict the effects of these two variables on the estimated profitability of this plant. In figure 2 the affect of the cost of wood on ROI is given assuming no and 4 percent inflation and an ethanol price of $1.25 per gallon. In figure 3 the affect of the price of ethanol on ROI is given assuming no and 4 percent inflation and a wood cost of $30 per OD ton.

Table 5--Return on investment for 600 OD ton per day HFC plant.

1.	Gross revenue	$, millions	
	Five product plant	25.6	
2.	Operating expenses	6.1	
3.	Wood costs at $30/ODT	5.9	
4.	Total investment	59.2	
5.	ROI[1] - No inflation		15.5 pct
	4 pct inflation		19.1 pct

[1]Assumes federal tax rate 33 pct, net state tax rate 7 pct, depreciation 15 yr. double declining balance.

Another measure of the economic feasibility of this process is the cost of the intermediate fermentable products. The yields of the five sugars and acetic acid recovered in the S1 and S2 hydrolyzates are calculated from table 3 on an annual basis. The unit cost per pound of the recovered products is then estimated from the investment in the hydrolysis plant and the operating expenses required to produce the specified intermediate products in the hydrolyzates treated and ready for fermentation. Results of these calculations are given in figure 4 using variable wood costs.

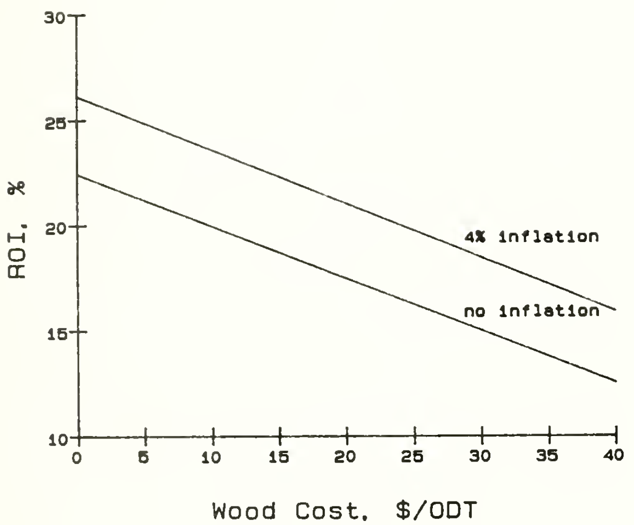

Figure 2--Influence of wood cost on ROI of the HFC process. Ethanol price at $1.25/gal.

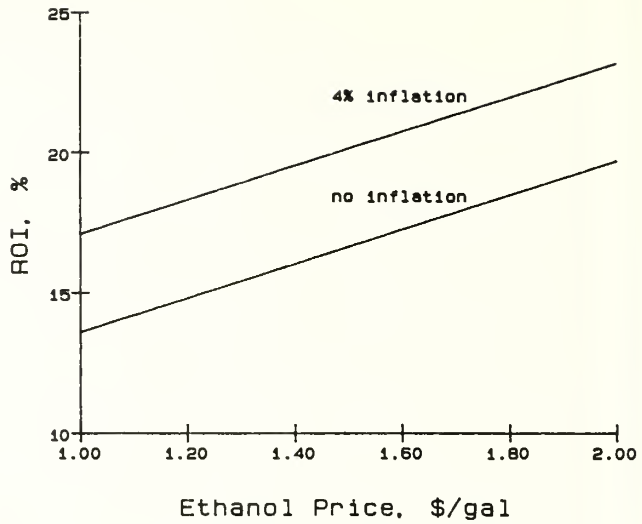

Figure 3--Influence of the price of ethanol on ROI of the HFC process. Wood cost at $30/ODT.

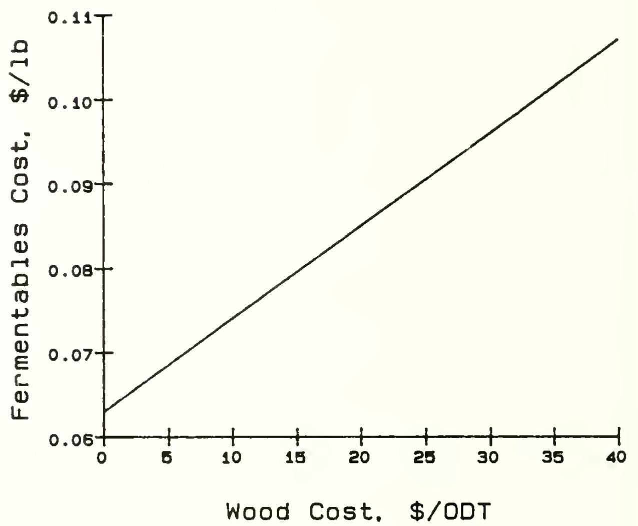

Figure 4--Influence of wood cost on the cost of fermentable products from hydrolysis.

DISCUSSION

Based on the extensive database developed for the HFC process, particularly with New York hardwoods and California manzanita feedstocks, it is now possible, using the process flow developed experimentally and modeled in a computer program, and the kinetics developed for hydrolysis, to predict product yields for a lignocellulosic feedstock of a known composition. This has been done and is presented here using a mixture of California hardwood species.

The feedstocks in table 1 are given on a whole wood basis. The analyzed New York hardwood mixture is mostly bark-free whole wood, the analyzed California mixture is whole stem chips including bark, and the estimated California hardwood mixture is calculated on a bark-free wood basis. In practice a feedstock will include a varying amount of bark.

Final products from the process flow, figure 1, are listed in table 4. The five products subtotaling 494.2 pounds are considered as those that would be first produced and provide the basis of the economic estimates made herein. HMF and levulinic acid could be added to the product slate with relative ease but market development will be required for these two chemicals. Carbon dioxide is a product that represents 48.8 percent of the weight of a hexose on fermentation to ethanol. Under appropriate conditions it could be recovered as a commercial product.

The estimated gross revenue from a plant utilizing California hardwoods, table 5, is subject to change in market prices of the commodities that would be produced as discussed under Process Economics. The prices used are considered to be conservative. The most difficult to predict, ethanol, provides 23 percent of the gross revenue. This could be increased substantially by fermenting the pentose as well as the hexose sugars in the S1 hydrolyzate to ethanol. The fermentation of pentoses as well as hexoses by microorganisms, such as Pachysolen tannophilus, is rapidly approaching commercial feasibility. If the hexoses in table 3 were converted in 47 percent yield and xylose was converted in 40 percent yield, about 56 gallons of ethanol could be produced per ton of feedstock. However, no Torula yeast, only 29.2 pounds of furfural, plus 27.8 pounds of brewers yeast would be produced per ton of feedstock. On the other hand ethanol fermentation could be replaced by one of several alternative uses of glucose in the S2 hydrolyzate. Thus, there is considerable flexibility in selecting the products to be produced from the intermediate products listed in table 3.

The ROI of 15.5 percent given in table 6 for a 600 tpd plant producing the five products discussed and using wood costs at $30 per ton delivered to the plant site and no inflation, shows that this process is economically viable. This is considered particularly significant since conservative estimates have been made throughout this evaluation. This viability is further indicated in the sensitivity analyses given for wood costs (figure 2) and ethanol prices (figure 3). As new products are added ROI can be considerably enhanced.

The second estimate made of economic feasibility is indicated by the analysis of the cost of fermentables (i.e., glucose, mannose, galactose, xylose, arabinose and acetic acid). The sensitivity of these costs to wood costs, given in figure 4, shows the process is economically competitive with sugar from other sources. A value of about $0.10 per pound is competitive in the United States.

A system of the kind described could be put into operation in any region in which there are sufficient hardwoods to sustain a feedstock of 600 OD tons per day. Coupled with such a plant a sawmill utilizing the logs of a grade to produce lumber would provide an integrated operation such as that currently enjoyed by pulp mills and lumber mills. A number of potential sites could be selected in California for such an integrated operation. The benefits that would accompany a development of this kind are discussed in the introduction. A major benefit and one that would have an immediate impact concerns employment. It is estimated that a plant of the kind described would directly employ 100 persons. An additional 60 people would be employed in the woods operations supplying the feedstock. Also, other employment would be generated in the service industries and activities ancillary to the plant and woods operations.

Production units of this kind would have, in particular, salutary effects upon silvicultural operations. Thinning, recovery of otherwise unmerchantable wood, and utilization of brush species, which were previously uneconomical, could be practiced.

REFERENCES

Bolsinger, C.L. (In press). The hardwoods of California timberlands, woodlands, and savannahs. USDA Forest Service and Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Brink, D.L.; Merriman, M.M. Potential for producing alcohol from organic residues. In: Proceedings of the Western Cotton Production Conference, cosponsored by Southwest Five-State Cotton Growers Association and Cooperative Extension Services of Texas, New Mexico, Arizona and California; 1980, February 19-21; Fresno, CA; 63-73.

Conner, A.H.; Wood, B.F.; Hill, Jr., C.G.; Harris, J.F. Kinetic modeling for the dilute sulfuric acid saccharification of lignocellulose. J. Wood Chem. Tech. 5(4):461-489: 1985.

Goldstein, I.S. Chemicals from cellulose. In: Goldstein, I.S., ed. Organic chemicals from biomass, Boca Raton, FL: CRC Press, Inc.; 1981:101-124.

Harris, E.E. Wood saccharification. In: Pigman, W.W. and Wolfrom, M.L., eds. Advances in carbohydrate chemistry, Vol. 4, New York: Academic Press, Inc.; 1949:154-188.

Harris, J.F. Acid hydrolysis and dehydration reactions for utilizing plant carbohydrates. Appl. Polym. Symp., 28:131-144; 1975.

Pettersen, R.C. The chemical composition of wood. In: Rowell, R., ed. The chemistry of solid wood, Washington, D.C.: American Chemical Society; 1984; Advances in Chemistry Series 207; 57-126.

Saeman, J.F. Kinetics of wood saccharification. Ind. Eng. Chem. 37:43-52; 1945.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

The University of California's Woody Biomass Extension and Research Program[1]

Richard B. Standiford, Dean R. Donaldson, and Roy M. Sachs[2]

Abstract: In response to the energy crisis in the early 1970's, the University of California became involved in an integrated research and extension effort to evaluate woody biomass plantations. The genera Eucalyptus has been determined to be the most promising on a statewide basis. 20 research/demonstration plots range in growth from 6 to 30 tons per acre per year. Clonal propogation of Eucalyptus has been greatly advanced, and several promising clones have been released to private nurseries. A financial and biological growth model for Eucalyptus has been developed as well as preliminary data on spacing, weed control and fertilization. Future work on identification of genetically superior trees and establishment of improved seed orchards is anticipated, as well as an expanded effort in harvesting technology and market development.

HISTORICAL DEVELOPMENT OF A BIOMASS PROGRAM

Beginning in the early 1970's, with the Arab oil embargo and rapidly increasing energy costs, national interest in the development of alternative energy sources began to develop. One technology which received renewed emphasis in response to the "energy crisis" was wood energy. Firewood, and cogeneration technology, two already developed uses of wood for energy, received new emphasis.

Firewood was the primary source of man's energy prior to the 1900's, and still is the principal source of energy for much of the world's population. The burning of wood residue to produce electricity and process steam (cogeneration) has been a standard technology in the forest products industry for much of the last 30 years. The use of firewood for the home market, and the interest in cogeneration increased markedly in the mid-1970's. Fortunately there was a rich literature to refer to in initiating the UC program in biomass production. In the 50s and 60s the paper industries sponsored research worldwide on short rotation, intensively managed plantations; reported 3-10 fold increases in yield over conventionally managed forests were common. Improved seed and clonal outplanting stock, particularly of hardwood species (including poplars, willows, and eucalypts), were used routinely in such plantations and were available for testing in California. Turn-of-the-century, privately owned eucalyptus plantations in California, and some USDA and industry-sponsored programs with eucalyptus and other hardwoods begun in the early 60s, made it abundantly clear that wood fiber production in California could be increased dramatically by intensive culture of improved hardwood species, with particular emphasis on eucalyptus. Biomass projects were officially funded at UC institutions in the early 70s.

The UC's Landscape Tree Evaluation (LTE) program, begun in the early 60s, also helped get the program going relatively rapidly. The objective of LTE was to evaluate a wide range of native and exotic trees for their use in landscape plantings in a variety of planting sites and report on their overall growth rate and form. LTE required a collaborative effort on the part of Farm Advisors and Specialists and Agricultural Experiment Station faculty members; as a consequence the identification of some fast-growing tree species in the eucalyptus, pine, casuarina, and poplar genera, that were also adaptable to marginal planting conditions, were revealed to a research group accustomed to working together. Given the impetus of the energy crisis, a UC biomass team was formed relatively rapidly from this LTE nucleus.

As ranchers, forest landowners, and owners of small rural properties began to come to Cooperative Extension in the mid to late 1970's with questions about planting trees to produce energy crops, predominantly firewood, personnel with LTE experience were called upon to give answers. The LTE program had identified major gaps in what was known about the management of trees, in general, not only for energy production. Interest in tree planting escalated when growers heard claims, often unsubstantiated, of extremely high growth rates, especially with eucalyptus. This led to the establishment of research plots in several counties and at UC Agricultural Field

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Stations to give local growers a better idea of what species would grow on different sites, what management practices were necessary, and what range of growth rates could be expected.

COORDINATED U.C. EFFORTS IN BIOMASS

As clientele interest in planting biomass species increased, and research gaps became increasingly glaring, Cooperative Extension and Agricultural Experiment Station researchers formally organized the Biomass Working Group in 1982 to address problems involved in the growth, management, harvest, and marketing of tree species for biomass. Initial priorities for the Group focused on:

(1) Identifying data on biomass production;

(2) Identifying information gaps;

(3) Developing standardized procedures for developing new research-based information;

(4) Addressing claims of super growth;

In order to determine the state of our knowledge about biomass production, and especially eucalyptus production, Cooperative Extension, together with the USDA Forest Service's Pacific Southwest Forest and Range Experiment Station, organized the Eucalyptus Symposium in Sacramento in June of 1983. This brought researchers involved in eucalyptus production from throughout the state, nation, and with international contributions as well. The symposium helped bring our knowledge about eucalyptus and biomass production in the state up to date, it provided the opportunity to see how other countries organized their research and extension efforts to address their problems in biomass production and it identified the various industry, agency, and landowner organizations with an interest in biomass production (Standiford and Ledig, 1984).

As a result of this widespread interest in eucalyptus and biomass production, U.C. Cooperative Extension, in its role as a coordinator and facilitator of information exchange, worked with the California Department of Forestry to organize a cooperative group of interested parties, as a part of the California Tree Improvement Association. This group, now known as the Eucalyptus Improvement Association, has established goals and by-laws which gives it the potential to influence the rate of development of eucalyptus-derived biomass in California. Cooperative Extension assisted in development of an initial membership list, which led to a statewide membership of 683, representing over 2190 acres of land planted in eucalyptus in the state. The Biomass Workgroup has worked closely with the Eucalyptus Improvement Association since its inception. Currently, the Workgroup is composed of 27 individuals with backgrounds in forestry and forest products, horticulture, engineering, agricultural economics, agronomy, weed science, and range management.
Following the Eucalyptus Symposium, and after input from the newly formed Eucalyptus Improvem Association, the Biomass Workgroup was able to refine and give priorities to its list of goals The highest priority items identified were:

(1) Determine per acre growth rates for various species for different levels of management input, for different regions and climatic areas in the state;

(2) Evaluate the economic factors of production to provide growers with an assessment of the management potential in different areas of the state;

(3) Develop genetically improved sources of the most promising species/seed sources.

RESULTS OF COORDINATED EFFORTS

As a result of a team oriented workgroup approach, considerable headway has been made in achieving some of the goals listed above. Some of the accomplishments of the Biomass Workgroup to date include:

(1) Development of a cost of production data base for use in assisting potential growers (Klonsky, 1983).

(2) Development of a model to optimize financial returns or biological production from a eucalyptus operation, based on initial tree density and rotation length, using site information and economic data as inputs. This model is available to growers, or through the County Extension offices on microcomputer (Rinehart and Standiford, 1984).

(3) Standardization of planting design and data collection procedures (based on early experiences with biomass yield trials).

(4) Establishment of 18 field trials in 12 counties in the state, investigating over 13 different species, seed sources or clones.

(5) Lists of nurseries supplying biomass tree species; lists supplied to each county office (Donaldson, 1985).

(6) Development of recommendations for species and cultural practices assembled in a "How To" publication (Standiford, Donaldson and Breece, 1984).

(7) Lists of harvesting equipment for biomass operations, as well as lists for cogeneration facilities.

(8) Organization of local grower meetings and tours, reaching over 1000 growers and potential growers in 1983 alone.

(9) Development of clonal propagation methods with several species (Sachs et al. 1984).

(10) Development of slide tape on how to grow your own fuelwood (in cooperation with the International Tree Crops Institute); available through U.C.'s audiovisual library, used in presentations to several hundred prospective growers.

Based on a survey of nurseries supplying eucalyptus and other biomass species, it is estimated that in 1984, one million seedlings were planted on 1000 acres throughout the state (LeBlanc, 1985). Some of the accomplishments that coordinated research have had on changing grower behavior are:

(1) Yield plots and growth modelling show that growth ranges from 6 tons per acre per year on marginal sites with little management to over 30 tons per acre per year on high quality, intensively managed sites (3 to 15 cords per acre per year). Table 1 shows a list of U.C. Field plots, and summarizes current yield data. This research-based information, which has been distributed at grower meetings and in publications, has virtually eliminated the overly-inflated growth estimates that existed in the industry in previous years, and has given potential growers a more realistic estimate of growth.

(2) Nursery stock used to be supplied in a variety of container types, resulting in seedlings with varied physiological condition for outplanting. Seedlings are now routinely supplied in containers allowing for well-developed root systems, at least partially a result of research on nursery propagation at U.C.

(3) Research developed by the U.S. Forest Service on seed source performance has resulted in more attention to seed source by nurseries and growers. The provenance of a tree is now routinely specified when ordering seedlings, thereby improving the match of a seedling to a given growing site.

(4) Clonal propagation of eucalypts has been greatly advanced. Several promising eucalyptus clones have been identified released to private nurseries. Improved clonal propagation techniques have been passed along to several nurseries.

(5) There has been an increase in support of projects by growers and other state organizations, leading to more field projects throughout the state.

(6) Preliminary data from spacing trials, and results from computer simulation, has resulted in adoption of a tree density standard for biomass production of 25 to 50 square feet of growing space per tree (5' x 5' to 7' x 7'). Previous industry information suggested densities of as close as 15 square feet of growing space per tree (3' x 5'). These new standards means less capital outlay by landowers for trees, more trees available for planting additional acres, and little if no decline in total per acre yields. Planting design trials, to include densities similar to those above but with different between and within row spacing, are continuing.

(7) The importance of weed control and irrigation in the first two years after planting has been demonstrated, and is now routinely practiced in new plantings, therby greatly increasing survival (by as much as 80%).

FUTURE BIOMASS ACTIVITIES

There is a well-established clientele of individuals interested in growing trees as an energy crop in the state. It is anticipated that this area will continue to be important in the future, especially if energy costs increase as projected. The number of cogeneration facilities in the state is expected to double in the next 5 years, based on the number of license applications currently pending. In addition, several forest products companies are currently purchasing chips for use in paper manufacturing. This new and expanding market would give growers of biomass more flexibility in marketing. Work is expected in the 7 areas below in the next 5 to 10 years.

Genetic Improvement

Cooperative projects with the Eucalyptus Improvement Association have been developed, and are awaiting funding. Selection of superior trees of promising species are needed for use in provenance testing and seed orchard establishment. In addition, clonal propagation of superior trees would be carried out for furthur testing. Selections would take place in plantings throughout the state, with cold and salinity tolerance, growth rate and form as key criteria for selection.

Management Practices

Production functions are needed for cultural practices such as irrigation and fertilization on different sites in order to make better recommendations on the optimum management input for different sites.

Furthur Species/Seed Source Evaluation

Existing field plantings do not cover all potential planting areas in the state. Expansion of field plots to cover new areas will take place, and inclusion of new plant materials in future and existing field plantings will be evaluated.

Table 1. Summary of Woody Biomass field trials conducted by the University of California

County	Proj #	Leader	Year Estab	Year Measured	Species (Clone)	Density (trees/a)	Irr/ Fert	Yield * tons/acre/yr.
1 Solano	3608	Miller	83		E. cam. (C2)	2719	Yes/Yes	33 (est)
2 Solano	3608	Sachs	79	81	Ailanthus altissim	5000	Yes/Yes	13 (max)
					Acacia melanoxylon	(3x3)	Yes/Yes	13.4 (max)
					Salix babylonica	5000	Yes/Yes	15.1 (max)
					E. camaldulensis	5000	Yes/Yes	20.3 (max)
					E. cam x rudis	5000	Yes/Yes	16.9 (max)
					"Fry" poplar	5000	Yes/Yes	6.8 (max)
3 Solano	3608	Sachs	81	83	E. cam x rudis (CR-1 and CR-2)	1714 (5x5)	Yes/Yes	16 (avg)
4 Solano	3608	Sachs	83	85	E. cam. (C-1,C-2)	1936	Yes/Yes	13.2 (est)
						1452	Yes/Yes	16.3 (est)
						1162	Yes/Yes	13.7 (est)
						871	Yes/Yes	13.6 (est)
						830	Yes/Yes	13 (est)
						622	Yes/Yes	13 (est)
5 Orange	3608	Sachs	76	78	E.grandis,seedl.	11000	Yes/Yes	6.2 (avg)
				79	(harvested at 6	ca 10000	Yes/Yes	8.3 (avg)
				80	mo intervals)	ca 10000	Yes/Yes	9.7 (avg)
				81	E.grandis,above plots thinned (no border)	1900	Yes/Yes	39 (total plot)
6 Orange	3608	Sachs	82	85	E.grandis,seedl. (from Florida)	1714	Yes/Yes	13.7 (avg)
7 San Mateo		Costello	81	--	E.globulus	Coppice	No/No	----
8 Napa		Donaldson	79	81	E. camaldulensis	1740	Yes/No	1.7
			79	81	E. dalrympleana	1740	Yes/No	.5
			79	83	E. camaldulensis	1740	Yes/No	8.8
			79	83	E. dalrympleana	1740	Yes/No	4.8
			79	85	E. camaldulensis	1740	Yes/Yes	20.2
			79	85	E. dalrympleana	1740	Yes/Yes	7.3
9 Napa		Donaldson	77	81	E. camaldulensis	680	Yes/No	2.0
			78	81	E. viminalis	680	Yes/No	1.9
			77	83	E. camaldulensis	680	No/No	4.0
			78	83	E. viminalis	680	No/No	7.0
10 Napa		Donaldson	83		E. viminalis	870	Yes/No	---
					E. viminalis	870	No/No	---
11 Riv.		Cockerham	82	85	E. camaldulensis	302-907	Yes/No	2.3 - 5.7
12 San Joaquin		Hickman	86	--	E. grandis	1210-1815	Yes/No	---
					E. cam. (C2)	1210	Yes/No	---

continued

Table 1. Summary of Woody Biomass field trials conducted by the University of California (continued)

County	Proj Leader #	Year Estab	Year Measured	Species (Clone)	Density (trees/a)	Irr/ Fert	Ave. DBH(in)	Ave. Ht(ft)
13 Yuba	Hasey	84	85	E. globulus	1210	Yes/Yes	2.45	25.6
		84	85	E. camaldulensis	1210	Yes/Yes	2.21	19.5
		84	85	C-1 clone	1210	Yes/Yes	1.65	15.8
		84	85	C-2 clone	1210	Yes/Yes	2.16	22.6
		84	85	E. viminalis	1210	Yes/Yes	1.79	17.9
		84	85	E. dalrympleana	1210	Yes/Yes	1.80	17.6
		84	85	Poplar hybrid	1210	Yes/Yes	1.82	20.4
14 Imperial	Mayberry	82	85	E. camaldulensis	907	Yes/Yes	4.00	27.5
		83	85	E. camaldulensis	1210	Yes/Yes	3.50	22.5
15 San Luis Obispo	Weitkamp	86	--	E. camaldulensis	680	No/No		
		86	--	E. viminalis	680	No/No		
		86	--	E. sideroxylon	680	No/No		

*Assumes 85 cubic feet/cord, 2 dry tons/cord

Coppice Management

One coppice management is currently underway. As new plantings reach maturity and are harvested, trials investigating different coppice management strategies will be necessary.

Harvesting Technology

There is currently a great deal of information on biomass harvesting, predominantly oriented to large ownerships. Technologies for small plantings, as well as a list of contractors who provide biomass harvesting services, are needed.

Market Development

Identification of future markets, as well as a mechanism for comparing prices for different products (i.e., firewood, delivered logs, delivered chips, sale of stumpage, etc.) will become increasingly important as more market outlets come on line.

Biomass Conversion

Evaluation of existing burners, for efficiency, emissions, and cost, as well as design of improved burners is necessary, in order that the maximum possible capture of energy is obtained, and reliable information is available for prospective buyers.

U.C. became involved in biomass research and extension in response to the social demand for alternative energy sources, and grower demand for alternative cash crops. Great strides have been made in making recommendations about feasible management systems, however more work is anticipated in the future. A multi-disciplinary team approach has proven successful in solving key problems with a major impact on this developing crop in a very short time.

REFERENCES

Donaldson, D.R. Commercial sources of fuelwood seedlings in small containers. Napa County: University of California Cooperative Extension; 1 p.

Klonsky, K. Sample costs to produce Eucalyptus for firewood. Glenn County: University of California Cooperative Extension; 1983; 6 p.

LeBlanc, J. Eucalyptus planting study. Berkeley, CA: University of California Cooperative Extension; What's Happening in California Forestry 12:4-5; 1985 December.

Low, C.B.; Matson, G.H; Sachs, R.M. Propagating fast growing eucalypts for energy crops. California Agriculture 37(5,6):20-22; 1983.

Rinehart, J; Standiford, R.B. Blue gum plantations analyzed for economic return. California Agriculture 38(5,6):19-21; 1984.

Standiford, R.B; Ledig, F.T. Proceedings of a workshop on Eucalyptus in California. Res. Paper PSW-69. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1983. 128 p.

Standiford, R.B; Donaldson, D.R; Breece, J.R. Planting Eucalyptus for firewood, Berkeley, CA: UC Division of Agriculture and Natural Res. Leaflet 21297. 1984. 4 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Central California Oak Residue Utilization and Marketing: Better Hardwood Management from Improved Utilization[1]

Timothy O'Keefe and Douglas Piirto[2]

Abstract: Limited information and observations indicate that there are some significant amounts of hardwood residue resources now available in the Central Coast area. Experience gained from managing and marketing eastern hardwoods is considered as our basis for dealing with western hardwood problems.

Inventory of the oak resource is discussed as a preliminary requirement for management. In addition, hardwood marketing, research and extension needs are also considered.

Evidence indicates that western hardwood use will be improved by better funded programs of research and extension in residue utilization and marketing. Improved hardwood utilization will yield both direct and indirect benefits. Direct benefits include additional, better quality wood at lower consumer cost and increased tax receipts. Other, indirect benefits include improved hardwood forest management, better fire management, and improved multiple resource management for watershed, range and recreation values.

Throughout the natural range of California oaks (Quercus spp. and Lithocarpus spp.), there is growing concern about the question of over-cutting and under-utilization. During the past few years, greater attention has been given to the problem of oak regeneration growth. However, oak utilization and particularly residue use is far less clear.

The Board of Forestry on the occasion of its Centennial anniversary sought to find new ways to approach forestry in California. It was reported at the Centennial II Conference (California Board of Forestry, 1985) that:

> Within California, both the timber and range-livestock industries are suffering. Both have prolonged periods of low product prices and major readjustment among producers. A number of ranchers have lost their property to foreclosure. Several of the major timber producers have been absorbed as part of leveraged buy-outs from investors without any historical interest in timber growing in California. In addition, a number of smaller landowners and loggers have either gone out of business or have had to limit their operations. Events such as these raise serious questions about the ability to attract and maintain private investment capital in the traditional resource industries such as timber and ranching. This is compounded by the negative perception that investment in forestry in California will be burdened with increasingly expensive regulations.

One of the major issues facing the citizens and land managers of California (identified at the California Centennial II Conference-California State Board of Forestry, 1985) is: "How can California forest and rangeland owners and industries better market existing and new products?" Several strategies have been identified including: 1.) research and develop new products (e.g., furniture, panels, pre-fab products) to meet identified demand; 2.) improve utilization of California timber species; 3.) develop active marketing associations for export of forest and range products; 4.) set up production teams to brainstorm, identify innovative programs, and analyze current and potential markets; 5.) improve marketing techniques to increase demand through advertising and other techniques. Other strategies have been identified, but the above directly apply to the issue of extending utilizaiton of the California hardwood resource. It is our contention that better land management will occur on California's hardwood lands through better utilization. Ranchers, for example, would approach hardwood land as areas to be managed rather than converted to grasslands given a better economic picture through integrated multiple use management (e.g., wildlife, range, hardwood utilization).

The purpose of this paper is to explore non-traditional approaches to multiple use management of the hardwood lands in Central California. Traditionally, the full value of California's oak and hardwood resources has not been widely recognized. Until the late 1950's, oak was a major material that supported the sizable Central Coast charcoal business. More recently, since the Arab Oil Embargo in the early 1970's, the California oak resource has again been recognized as an important fuelwood resource. However, aside from this wood energy use, only a very limited use has been made of the California oak resource. A few sawmills now manufacture a limited amount of oak lumber, and oaks have

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been used for other products like pallets, posts, and ties on a restricted basis. This paper will discuss some alternatives for better management, utilization and marketing of California's oak resource.

EASTERN HARDWOODS

In sharp contrast to this picture of under-utilization of California oaks, the hardwood resource in the northeastern United States has undergone, in recent years, a kind of "economic renaissance." For many years, the rate of hardwood utilization in the northeast declined steadily. This decline was due primarily to a decrease in wood quality, which included an increase in small sized, poorly formed and defective stems. As a result of the increasing quantity of this low quality hardwood material, many speciality mills in the northeast were forced out of business and competition for the lucrative export market became extremely difficult. This increasing problem of low quality hardwood growing stock was exasperated by the increased accumulation of hardwood residues.

In the late 1970's, local demand for eastern hardwoods as a wood energy raw material source and for wood pellets increased significantly. However, the most significant improvement in northeastern hardwood utilization resulted from the development of new, engineered panel products. These new particleboard products, called wafer board, and oriented strand board (OSB) are products that can be made from relatively low quality hardwood raw materials. As a result, these new wafer board mills and the OSB plant which opened in 1981 at Clardon, New Hampshire, had a very significant impact on utilization of low quality northeastern hardwoods.

The northeastern hardwood business has faced many of the same problems now facing the California hardwood industry. Of course, the northeastern industry is a much older business which is well established with a unique marketing system. Through a complex matrix of hardwood trade associations (see Appendix) the eastern hardwood marketing system includes a relatively strong technology transfer process. It is interesting to note that most of these associations are located in the eastern and midwest areas of the United States. Presently, there is only one major west coast hardwood association.

The technology transfer segment is a joint system where the wood industry, together with state and federal agencies, such as the State Utilization and Marketing Forester, as well as the Cooperative Extension Service, have developed a system to connect the university and state research laboratories with the technology user at the plant level. Of course, this system is a "two way" pipeline which not only moves information from the lab to the user, but also provides a mechanism by which field problems are transmitted to the laboratory for appropriate solutions. Timely applications is one of the most significant aspects of this technology transfer process. In a relatively short time, the oversupply problem of low quality eastern hardwoods was identified, and practical solutions were developed and implemented, on a timely basis.

New technology and technology transfer alone will not solve the California hardwood problems. However some of the techniques used to deal with the northeastern hardwood problem may, in fact, have application to the western oak utilization problem.

WESTERN HARDWOODS

A number of problems relating to the utilization of California's hardwood resource have been identified. Some of the major western hardwood management problems focus on: 1.) inventory techniques; 2.) lumber drying and machining techniques; 3.) volume and biomass (both total and available); 4.) multiple use management (e.g., range, wildlife, recreation, watershed) interaction with wood value; 5.) residue utilization; and 6.) hardwood marketing. Other researchers and managers have earlier addressed some of these problem areas, in at least a preliminary investigation. For example, the California Forest Products Laboratory has carried out a number of drying, machining, and a variety of other wood property evaluation tests of several California hardwoods. In addition, the California Cooperative Extension Service during this past year has published a management guide for multiple use management of oak woodland for wildlife, range and wood resources.

However, the question of residue utilization and marketing are two western hardwood problem areas that have not been widely addressed. For this reason, it is now timely to consider these two problem areas more closely. In terms of hardwood residue utilization, there are still many unanswered questions, such as:

1. What is the volume of residues on hardwood lands?
2. What types of products could be manufactured from these residues?
3. What can be done to better organize the very fragmented fuelwood market?
4. What is the significance of oak residue in terms of: soil nutrients; fire hazards; aesthetics; restricted access; regeneration shade and shelter; insect and disease; air pollution-disposal; additional fiber source?

These and many more questions remain to be answered. The remainder of this paper will focus on a research approach to identify ways to extend the utilization of hardwood (oak) residues.

OAK RESIDUE RESOURCES

At present, there are some reliable oak volume tables available that will permit satisfactory estimates of oak growing stock. However, there is very little information available now that will help a landowner determine volume and value of oak residue. For purposes of this paper, oak residue has been defined as including the total biomass material of the tree and stand that has not been conventionally utilized (e.g., bole for lumber, fuelwood products).

On any walk through an oak stand, it is clear that total wood volume must include not only the live growing stock, but also the dead and down residue materials. For this reason, a "standard" cruise over an oak forest area will yield only a partial estimate of the total biomass volume. Total volume is a composite of both live, upright, and dead, down, materials. In many stands, depending on age and general condition, there is a very significant volume of raw materials in the residue category.

Biomass cruising techniques to estimate northeastern hardwood residue volumes have been developed and refined over the past twenty years. These biomass cruising techniques, which have been very effective, represent the first step in more efficient hardwood utilization.

An effective system of oak biomass/residue inventory could be based on the following procedures:

1. Field sample residues on a known area.

    a. These initial procedures would involve measurement and weight of oak residue in a clearly defined stand.
    b. Stands sampled could be correlated with stand density and volume.

2. On low altitude air photos of the study area, establish relationships between live crown diameter and residue volume.

3. On other appropriate study areas, field test these biomass/residue cruise techniques.

4. Develop and implement an appropriate technology transfer effort.

The initial phase of a residue inventory will be a field sample to determine both volume and condition of the residue material. On a series of one-half acre sample plots identified from low altitude air photos, a full sample of oak residue will be measured and correlated with individual tree size and crown diameter. These residue volume measurements will be based on direct volume measurement of larger pieces and direct biomass weight of smaller materials. In addition, the condition of all residues, in terms of soundness, will also be noted and a moisture content sample taken from different size materials for lab analysis.

The second phase of an oak residue resource inventory would be construction of residue tables to crown diameter. These residue tables will then be field tested, using low altitude air photos and "ground truth" test plots. Results of these field tests will provide a measure of the accuracy with which it is possible to predict the volume of oak residues based on air photo, biomass cruising techniques.

If these oak residue, biomass inventory techniques are indeed effective, the final step of the project will be to develop an effective technology transfer system. Information and details about collecting oak residue field information will be provided to interested individuals and groups throughout the state in a timely systematic process. This technology transfer effort will be the first step towards better utilization of this important oak residue resource. Beyond this point of oak residue resource inventory and technology transfer process lies the very important element of a marketing strategy.

RESEARCH NEEDS

Improved residue utilization is only a small part of a much larger utiiizaiton problem of California hardwoods. A fractured market, at best, exists for the sale of hardwood products (e.g., fuelwood, lumber, and specialty products). This market picture would be improved with: 1.) execution of research on more effective ways of utilizing and marketing the California hardwood resource; 2.) formation of trade associations or cooperatives focused on management and utilization of California hardwoods (similar to the effort put forward by the California Redwood Association to find available markets for coast redwood); and 3.) development of landowner assistance programs.

Leadership is the key to improving the underutilization and land management problems of California's hardwood lands. Technical trade associations and/or land owner cooperatives along with the California Board of Forestry could play a key role in responding to the Centennial question "How can California forest and rangeland owners and industries better market existing and new products?"

SUMMARY AND CONCLUSIONS

At present, there is in California a large and valuable hardwood resource that suffers from limited management and utilization. In recent years, similar problems in connection with eastern hardwoods have been identified, and solutions developed. One method that can improve western oak utilization is to extend the use of residues. However, more efficient residue utilization must be preceded by a stronger hardwood research and market development program.

A more efficient hardwood marketing process can be constructed on the following strategies: 1.) extend hardwood association activity; 2.) develop active hardwood landowner and marketing cooperatives; and 3.) more aggressive national and international sale promotion program.

A complete residue utilization program must include a strong research component. Some of the major residue use questions include: 1.) residue volume, total and available; 2.) inventory techniques and costs; 3.) new residue and solid wood products; 4.) residue harvest, techniques and cost; 5.) effect of residue use on other multiple use, oak resource values. In order to investigate these residue use and marketing questions, it is essential that an adequate and continuing funding source be provided. At present, there is a great need for more fundamental data on hardwood resources.

Improved hardwood utilization will require an expanded technology transfer effort. It is encouraging to note that just recently, the California Cooperative Extension Service, in cooperation with the California Department of Forestry, has funded several extension specialists to provide information about the hardwood resource. This is a good start, but additional technology transfer is still needed for a complete, efficient hardwood information program.

Improved hardwood utilization will require expanded program efforts and funding support in terms of: 1.) residue utilization, 2.) hardwood marketing and 3.) hardwood information transfer. Better hardwood utilization is the basis for improved forest resource management, on a sustained yield, multiple use basis. Improved utilization and management will provide forest landowners with additional alternatives to the current practice of woodland conversion. In addition, improved management and utilization also offers other public benefits in terms of: 1.) more wood at a lower cost; 2.) improved tax receipts; 3.) improved visual quality and 4.) improved recreational opportunities. Hardwood utilization and management is today in California a pressing issue that requires a responsible and timely resolution effort by both the private and public sectors. Improved multiple use land management of California's hardwood lands can occur with better utilization and product marketing.

REFERENCES

California Board of Forestry. 1985. Issues and Strategies for the Development of the Centennial Action Plan. Proceeding of the Centennial II Conference, December 4 - 5, 1985. Sacramento, California.

Plumb, T.R.; McDonald, P.M. 1981. Oak Management in California. USDA Forest Service Gen. Tech. Report PSW-44.

Pillsbury, N.H.; Kirkley, M.L. 1982. Hardwood Biomass Inventories in California. In: Proceedings of the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22 - 26, 1981. San Diego, California. Gen. Tech. Report PSW-58, Berkeley, CA. PSW, USDA-FS, pp. 171-178.

Pillsbury, N.H.; Brockhaus, J.A. 1979. Tree Photo Volume and Weight. Tables for California's Central Coast. Central Coast Consortium and Development Area. Salinas, CA. 45 pp.

O'Keefe, T.G. 1982. Hardwood Utilization: A Down East View Fuel or Fiber? Hardwood Utilization and Marketing Opportunities Maritimes Forest Research Center, New Brunswick, Canada. pp 11-13

APPENDIX

<u>Partial List of Important Domestic Hardwood Associations</u>

1. National Wood Pallet and Container Association
2. Associated Cooperage Industries of America, Inc.
3. Hardwood Dimension Manufacturers Association
4. Southern Hardwood Square Association
5. Maple Flooring Manufacturing Association
6. National Oak Flooring Manufacturers Association
7. Hardwood Research Council
8. Maine Hardwood Association
9. National Association of Furniture Manufacturers
10. Furniture Manufacturers Association of Calif.
11. Hickory Handle Association
12. Appalachian Hardwood Manufacturers, Inc.
13. The Hardwood Institute
14. National Hardwood Lumber Association
15. Indiana Hardwood Lumberman's Association
16. Northern Hardwood and Pine Manufacturers Assoc.
17. Southern Hardwood Lumber Manufacturers Assoc.
18. Southern Hardwood Manufacturers Club
19. Wood Turners and Shapers Association
20. Fine Hardwoods-American Walnut Association
21. Hardwood Plywood Manufacturers Association
22. Hardwood Veneer Association, Inc.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

An Agroforestry System for California and Other Semi-Arid Mediterranean Areas[1]

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Abstract: The purpose of this study was to describe the use, status and land use problems of semi-arid mediterranean lands worldwide and to suggest an appropriate agroforestry system. Experimental design and management recommendations for a proposed set of preliminary species/spacing trials and also two long-term demonstration projects were presented for two marginal rangeland sites in California's Central Coast region (San Luis Obispo County). Additionally, recommendations for the potential transfer of the California system were then made on the basis of information on the biological and physical characteristics and agroforestry research capacity of the semi-arid mediterranean areas.

To begin to understand the potential of agroforestry for California's hardwood lands, it is important to first gain an overview of land use in the entire semi-arid mediterranean geographic zone (hereafter referred to as the SAM Zone). Located primarily on the west coasts of continents, from approximately 30 to 45 degrees North latitude to 30 to 35 degrees South latitude, and receiving winter rainfall, SAM areas can be found in California, the countries in Europe, North Africa and the Middle East which surround the Mediterranean Sea, central Chile, southwestern South Africa, and three areas in Australia (the southwest corner of West Australia, the southern portion of South Australia, and the western half of the Victoria District) (Rumney 1968). Despite its limited size, the SAM Zone has had a strong influence throughout history on the economic and cultural development of adjacent humid and arid regions.

SAM areas have provided livestock range, cropland and fuelwood resources and have also accomodated both sedentary and migratory human settlement from adjacent areas. The demand for these products and amenities will increase in the future as population increases, yet the productivity of the SAM Zone has been reduced as a result of destructive land use practices such as over-grazing, over-cultivation and destruction of the woody plant species (Secretariat of the United Nations 1977). The many recent conferences and symposia (e.g. FAO 1976; Secretariat of the United Nations 1977) on land use and/or environmental degradation in the semi-arid areas have consistently recommended returning to selected traditional soil and water conservation measures, fallowing, intercropping and using drought-resistant species for wise stewardship of marginal dry lands. Other suggestions have promoted the use of new genetics technology to select or create plants with improved qualities such as drought-resistance, the ability to fix nitrogen, produce fodder, and/or grow in combination with other plants.

Agroforestry systems for the SAM Zone can incorporate many of these suggestions and could potentially provide food and energy in an ecologically-sound manner. As defined by Combe and Budowski (1979), agroforestry is:

> A group of land use management techniques implying the combination of forest trees with crops, or with domestic animals, or both. The combination may be either simultaneous or staggered in time and space. The goal is to optimize per unit of area of production whilst at the same time respecting the principal of sustained yield.

Incorporating the above concepts, a plan was developed for an agroforestry system suitable for use in the Central Coast region (San Luis Obispo County) of California's SAM Zone. The methodology of the International Council for Research in Agroforestry (ICRAF 1982) was followed. The plan for this system also includes an assessment of the potential for technology transfer since the geographically-separate areas of the SAM Zone have uniquely similar physical, ecological and land use characteristics. This assessment, based on a review of the research needs and limitations of other SAM areas (Australia, Chile, Greece, Israel, Morocco and Spain), was used to modify the recommendations made for the California system (Diamond 1987).

LAND USE IN THE CENTRAL COAST REGION OF CALIFORNIA

Grazing and dryfarming have been the predominant land use in the Central Coast region of California. A variety of horticultural crops, including walnuts, almonds, grapes, avocados and citrus have been grown successfully with and without irrigation. Since the early 1900's, tree plantations have been established which

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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incorporate eucalypts, pine and miscellaneous conifer species to provide shelter, fuelwood and other forest products such as Christmas trees. Native oaks have historically provided mast (acorns for livestock feed), fodder, shade, charcoal and firewood for residents of the area.

California's Central Coast is faced with many of the same economic pressures confronting other rural areas in the state. Subdivision of rangeland due to increasing urbanization, and a poor livestock market, have resulted in frequent overstocking of livestock and increased levels of degradation of the grazing resources of hardwood lands. Additionally, the oaks are being increasingly harvested to improve forage quality and quantity, to provide fuelwood and income from both local and major urban markets, and to clear land for irrigated farms and residences. Although the harvesting of oaks has occurred in the past for all of the above-mentioned reasons (Rossi 1979), harvesting has increased over the last five to ten years as a result of economic trends such as decreasing economic returns from livestock, greatly expanded fuelwood markets since the 1973 "oil crisis", and increasing rural populations. Given the inconsistent regeneration of some oak species and the threat to wildlife habitat, these continuing pressures on oaks are cause for concern and could be alleviated by more intensive, sustainable and economically-diversified use of already-cleared hardwood lands. Other hardwood land resource problems include the increased statewide occurrence of salinization, alkalinization and the reduction of groundwater levels as irrigated acreage increases. Each of these problems reduces the profitability of irrigated farming, livestock and forestry systems in California.

EXAMPLES OF AGROFORESTRY SYSTEMS RELEVANT TO CALIFORNIA

Examples of agroforestry systems from the past and the present can provide guidance for the development of an appropriate agroforestry system for California. As mentioned previously, mast of native oaks was frequently used to fatten sizable herds of livestock, from the time of the Spanish missions and ranchos until the middle of this century. Both mast feeding and cutting of branches for forage was also particularly common during difficult economic times. The Spanish missionaries also introduced mixed farming systems developed in the European SAM Zone to California. These systems included a variety of agricultural crops, horticultural trees and shrubs, and cattle, sheep and/or swine. Presently, there are ranchers and farmers within California and specifically within San Luis Obispo County who are practicing different types of agroforestry. Combinations generally include woodlots of fast-growing fuelwood trees or grape vines on ranch land, or multiple species of fruit and nut trees grown together, sometimes with annual crops below. Other examples of mixed use found statewide include grazing of National Forests in some areas and tree windbreaks on farms and ranches.

Indigenous agroforestry systems are quite common in the Mediterranean Basin countries and include the mixed garden systems brought to California by the Spanish missionaries with managed species of both native and introduced trees, agricultural crops and livestock; the "cork and pork" (dehesa) system of managing native cork oaks (*Quercus suber*), forage species and swine in the Iberian Peninsula (Parsons 1962) and the extensive use of native shrub formations such as maquis and garrigue (similar to California's chaparral) for grazing by goats and sheep.

Use of planted tree and shrub fodder species is also prevalent in the SAM areas of Australia and Chile. In both of these countries, New Zealand-style agroforestry plantations of widely-spaced Monterey pine (*Pinus radiata*), pasture species and sheep are commonly found. Due to their typically small farm size, both Chileans and Greeks have planted intensive, mixed-use systems which combine many tree, crop and livestock combinations including fodder trees and shrubs. The native shrub formations are grazed by livestock in all of the SAM areas.

NEW TECHNOLOGIES FOR A SAM ZONE AGROFORESTRY SYSTEM

Relevant research from both within and outside the SAM Zone can be incorporated into the design of an agroforestry system appropriate for the SAM Zone. Researchers in Texas (Felker 1981), Southern California (Felker *et al*. 1982), Oregon (Gordon *et al*. 1979; Wollum and Youngberg 1964; Tarrant 1983), Hawaii (Brewbaker and Styles 1982; MacDicken and Brewbaker 1984), and Illinois (Funk *et al*. 1979) have provided valuable information on the characteristics, management and potential of nitrogen-fixing tree and shrubs. Research on biomass tree farms in California has been undertaken by Ayers (1984), Pillsbury and Williamson (1980), and Standiford *et al*. (1983). The characteristics and management of fodder trees and shrubs have been investigated extensively in Australia (Everist 1972) and North Africa (Le Houerou 1978, Ibrahim 1981). Management of forest grazing has been researched many areas, including California (Kosco and Bartolome 1983) and the Southeastern United States (Linnartz and Johnson 1984). Furthermore, detailed plans for the management of livestock and legume pastures under widely-spaced forest plantations in New Zealand (Hawke *et al*. 1983a, 1983b) have been modified and applied to Australian SAM Zone conditions (Howes and Rummery 1978).

DESIGN AND MANAGEMENT RECOMMENDATIONS FOR A CALIFORNIA AGROFORESTRY SYSTEM

Although agroforestry components will vary in different SAM areas to include species and varieties which meet local needs, the design and management of the basic agroforestry system planned will be the same. Institutional and technical support for agroforestry research is adequate in all six of the areas (Australia, Chile, Greece, Israel, Morocco, Spain) selected as potential sites for the transfer of California agroforestry technology. However, with the exception of California and Australia, the financial constraints of the target population of small farmers in Chile, Greece, Morocco and Spain may preclude extensive irrigation, heavy use of commercial fertilizers, and capital-intensive equipment and management. For these reasons as well as environmental concerns, the proposed agroforestry systems -- even in the United States -- should incorporate water and soil conservation methods, drought-resistant environmentally-adapted plants, and alternatives to commercial fertilizer (e.g. manure) whenever possible. Additionally, the successful technology transfer of the proposed demonstration projects demands that the scale of the demonstration project be similar in size to the average land holding in that country.

The first step will be a species and spacing trial to determine which plant species at which particular plant spacing exhibit the best survival and growth after three years when grown alone and in mixed species, interplanted plots. The effectiveness of the site preparation and other cultural practices will also be evaluated for application in the demonstration project. The plants species which will be included in the proposed San Luis Obispo County trials were selected because of their compatibility with local environmental conditions (climate, soils, elevation), social suitability (the products provided, management required, cultural preferences), satisfactory growth in previous local trials and availability. A randomized split-block design, which is appropriate for small areas, will be used to compare growth and survival of seedlings at three intra-row spacings, 0.6, 1.2, and 1.6 meters (2, 4 and 6 feet). A uniform distance of 3.6 meters (12 feet) between rows will allow for the use of typical California farm equipment such as tractor mowers. Edge effects will be minimized by a 3.75 meter border width of trees (Zavitkovski 1981, MacDicken and Brewbaker 1984).

The woody perennial components of this design concept will include fast-growing trees which are harvested on short-rotation cycles for fuelwood, fiber, timber and local products such as Christmas trees or nuts. These drought-tolerant woody species should be planted using dryland soil and water conservation methods such as contour ploughing, micro-catchments and minimum tillage. Two species of eucalyptus which are indigenous to the SAM Zone, Eucalyptus camaldulensis Dehnh. (river red gum), and E. viminalis Labill. (manna gum) will be included in the agroforestry trials to provide fuelwood, fiber and timber. Two pine species which are also indigenous to the SAM Zone, Pinus halepensis Miller (Aleppo pine) and P. eldarica (Eldarica pine) will be intercropped with the eucalypts and also nitrogen-fixing fodder shrubs and will produce Christmas trees, fuelwood, fiber or timber. Both indigenous and exotic nitrogen-fixing woody species, will serve as long-term nurse crops for the pines and eucalypts and will produce fodder (and also fuelwood). In the San Luis Obispo County system, species trials tested will include Acacia saligna (Labill.) H. Wendl (willow acacia), Ceanothus cuneatus (Hook.) Nutt. (wild lilac), Ceanothus sanguineus Pursh. (red stem ceanothus), Elaeagnus commutata Berh. (silverberry), and E. umbellata Thunb. (autumn olive).

The agricultural components of the system will be both annual and perennial forages, including some species which fix nitrogen. Hordeum vulgare L. (barley) and Trifolium subterraneum L. (subterranean clover) will be planted in the San Luis Obispo County agroforestry system. The livestock component of these systems will be either cattle, sheep or goats, depending on which animal is traditionally used in each specific SAM Zone area. For the two San Luis Obispo Country trial sites, beef cattle will be used at the Cal Poly site and St. Croix sheep will be present at the San Miguel site.

Site preparation, seedling establishment and cultural practices will be the same for the species screening and the demonstration project. Weed control, by means of deep ripping, heavy grazing, mowing or use of pre-emergent herbicides, is critical both prior to seedling establishment and also after planting. The latter two methods are appropriate at regular intervals for one to two years after planting to decrease plant competition for resources and rodent populations. However, the use of pre-emergent herbicides may be appropriate only in areas with available technology and capital resources. Manual mowing and heavy grazing prior to planting, in addition to close initial spacing with thinning after seedling establishment, will be an appropriate method of weed control in most situations.

Planting at the beginning of the seasonal rainfall period (November-December) aids in establishment and allows for replanting and establishment in January or February, if necessary. Use of fertilizers at the time of planting has been shown to aid tree establishment and either a mixed nutrient, slow-release fertilizer tablets (Agri-form) or non-commercial fertilizers (e.g. manure) can be used (Ayers 1984). The need for a permanent irrigation system can be eliminated through the careful selection of plants which are drought-resistant and the use of soil and water conservation measures. However, supplementary irrigation should be applied monthly (or as needed) during at least the first, and possibly the second dry season after establishment. Fencing is necessary for one to two years after planting to exclude deer and rodents, and prevent livestock trespass. Predator perches and frequent weed control has helped to control rodent populations for the Cal Poly wood energy plantation in

San Luis Obispo County (Ayers 1984). Fencing and/or road establishment around the perimeter of the plantation, and frequent weed control will also help prevent fire damage.

Table 1 shows the management timeline for the 5-year preliminary species and spacing trials. Nine plant species (two eucalypts, two pines and five nitrogen-fixing fodder species) will be planted in December of Year 1 and 2 in monoculture plots at three spacings. Year 1 monoculture trials will be replicated in Year 1 and 2 to obtain additional growth and survival data. Each year, all plots will be replicated twice. Plantings from both years should provide a good estimate of the monoculture yields with which to standardize the yields attained for intercropping trials planted at the end of Year 2 (Mead and Stern 1980). The purpose of Year 1 and 2 trials is to determine which one of the eucalypt and pine species and which two nitrogen-fixing fodder shrubs exhibit the best survival and growth after two years of growth and at which spacing. Year 1 and 2 monoculture species plots will each have 108 plants (not including buffer plants) and each year, approximately 2,000 plants will be planted on 3.5 acres. Monocropped trials in Year 1 and Year 2 will each be removed 2 years after planting.

The purpose of Year 3 and 4 trials is to determine which of the two nitrogen-fixing fodder shrubs serves as the best nurse crop for the other two woody species (eucalypt and pine), and at what spacing. Each of the two nitrogen-fixing fodder species will be intercropped with the eucalypt and pine species in separate trials, using the three intra-row spacings used in monocrop trials in Year 1 and 2. A split-split randomized block design will be used with split plots for each nitrogen-fixing plant divided into three sub-plots for the three intra-row spacings. The nitrogen-fixing fodder species will be alternated within rows with eucalypts and pine (N-E-N-P-N-E-N). This arrangement should help to minimize potential allelopathic effects, if they should occur, of both the eucalypt and the pine species on the growth or nitrogen-fixation capabilities of the fodder species. Each set of trials in Year 3 and 4 (two replications and buffer rows) will cover 2.25 acres and include approximately 500 trees. Survival and growth measurements will be taken at three-month intervals during the first year of growth for single species and multiple species plantations, and at six-month intervals after the first year of growth. A brief weekly monitoring will be taken and project costs tallied annually.

All species and spacing trials will be removed in Year 5 and the demonstration project will be planted with the combination of nitrogen-fixing fodder species, eucalypt and pine trees which exhibited the best growth and survival. One-sixth of the total area will be planted each year with woody species and barley pasture, for six successive years, so as to provide a sustained yield of eucalyptus fuelwood and forage. By planting in this manner and restricting grazing until trees are 2-3 years old, rotational grazing can be practiced using proper fencing.

Eucalypts will be harvested for fuelwood in the spring of their sixth year of growth. Coppice management should be practiced thereafter, with subsequent cuttings occurring every 4-6 years until age 30. The pines will also be harvested at age six for Christmas trees or firewood. Alternatively, the pines could be allowed to continue

Table 1. Management for Species and Spacing Trials

Month	Activity
October	Year 1 - Deep ripping (one-time only)
November	Weed Control
December	Dig holes; Plant with fertilizer tablets
January	Replant, as necessary; Weed control
February	
March	Weed control
April	
May	Water; Weed control
June	Water
July	Water; Weed control
August	Water
September	Water; Weed control

YEAR 1	Monocrop 1 is planted.
YEAR 2	Monocrop 2 is planted.
YEAR 3	Monocrop 1 is removed, Intercrop 1 is planted
YEAR 4	Monocrop 2 is removed, Intercrop 2 is planted.
Years 1-4:	
Monitoring:	Bi-monthly, for trial duration (five years)
Data collection (survival and growth):	At 3, 6, 9, 12, 18, and 24 months after planting.
YEAR 5	Intercrop 1 is removed at the beginning of the growing season and Intercrop 2 is removed at the end of the growing season. Planting begins for the intercropped demonstration project using the combination of spacing and plant species which showed the best survival and growth.

growing, pruned and thinned to a spacing of 100 trees per acre (with excess trees being sold for firewood) and harvested for timber at 25-30 years of age. For either option, the pines will need to be replanted after cutting. The nitrogen-fixing plants will serve as dry season animal fodder and can be grazed directly or lopped for a cut-and-carry system after age 2 or 3 years.

Below the woody overstory, each section of barley pasture will provide a source of short-term income and cut-and-carry forage for the first two years. After this time period, the pasture will be converted to a sub-clover/barley mix to increase the available nitrogen in the agroforestry system and enhance livestock nutrition. Sub-clover should be planted at a rate of 10 to 20 pounds per acre with inoculum, just prior to, or during the first seasonal rains (November-December). Fertilization with phosphorus, potassium and sulfur is also recommended when available. The clover can be grazed as soon as the leaves develop (generally six months after planting), and animals should be removed when the soil surface and horizontal stems become visible. Therefore, approximately 2.5 years after tree and shrub establishment, closely-controlled direct grazing can be allowed with proper tree protection such as fencing and livestock repellants. The sale of livestock and their products can provide a new source of income to the system.

The variety of components in this system can potentially provide a number of sources of gross income. Preliminary best estimates were obtained for cost and return calculations using methods based on Australian and New Zealand economic analyses and information on the economics of California livestock, eucalyptus energy plantations and Christmas tree operations. It was assumed that the 18-acre site would be managed as either a cow-calf or sheep-ewe operation. Since herd sized are fairly small, animals would be bred annually by bringing in high-quality bulls or rams to the site and paying breeding costs. Economic calculations were based on a 1.2 x 3.7 meters (4 x 12 foot) plant spacing (900 woody plants per acre). All figures were calculated on a per-acre basis, for the 18-acre site. A discount rate of four percent was used, in addition to an investment period of seven years. It was assumed that the property was owned rather than rented and that all investment capital would be provided by the farmer-investor. Furthermore, it was also assumed that fencing, equipment and access roads were already available on the site. For these calculations, the land managers were assumed to possess the appropriate skills in livestock, pasture and woody species management. Additionally, only occasional outside labor would be hired for miscellaneous tasks.

Several additional assumptions were made about the San Luis Obispo County system's design, management and goals. The realistic target audience for this project are land owners and managers who have an off-farm source of income. Furthermore, these individuals will more than likely have other land use management goals such as ecological sustainability, economic diversification, stability and optimization (versus maximization) and self-sufficiencies for specific products (e.g. fuelwood) which may be as important to them as economic efficiency. These same caveats may also hold true for other SAM areas yet the system is also designed so that the choice of components and management intensity can be varied to fit other land use goals.

Using the microcomputer program, FORECON, the internal rate of return was calculated and used as the criteria for comparison of the two economic alternatives (cow-calf versus sheep-ewe operations). Both operations yielded a similar favorable return of 25 to 28 percent, if managed conservatively (low labor, time and capital requirements and used farm equipment), in addition to ecological and social benefits. Benchmark figures from Australia and New Zealand yielded somewhat lower returns, 7-13 percent, which may be the result of longer time frames (25-30 years) and the increased management costs from larger acreages and herd sizes (Ferguson and Reilly 1978, Bilbrough 1984).

CONCLUSIONS

Agroforestry can help to address the current needs of the hardwood rangelands of California, and other SAM areas, by producing a variety of goods in an intensive and sustainable manner which combines old and new technologies. Technology transfer of this system within the California SAM area can be accomplished by means of training sessions at the site for farmers, ranchers, land managers, extension agents and graduate students. Coordination of SAM zone trials is recommended and could be undertaken by the International Council for Research in Agroforestry.

One researcher, Dr. Michael Baumer, addressed the need for further research into the social, economic and political factors involved in the adoption of agroforestry systems:

> The problem is not to create agroforestry systems which will be suitable for application in Mediterranean iso-climatic region (olive trees and cereals exist there since several thousands of years, and many other agroforestry systems are typically Mediterranean, such as 'montado' in Portugal,'dehesa' in Spain, caroob (sic)-tree/sheep breeding/cereals in Cyprus or in Israel, 'hema' in Syria, etc.). The real difficulty is to let an appropriate system be adopted (or adapted and re-adopted) by concerned populations. (emphasis added) (Baumer 1985)

Together with new technology and appropriate social, economic, and political support, these traditional systems offer the SAM Zone, in California and beyond, new hope for increased productivity.

Acknowledgements: I thank Pam Muick and Lee MacDonald, University of California, Berkeley, for their editorial comments on this paper.

REFERENCES

Ayers, N. Establishment of a eucalyptus energy plantation of the central coast of California. Unpubl. M.S. thesis, California Polytechnic State University, San Luis Obispo; 1984.

Baumer, M. 1985. Senior Researcher in Agroforestry, International Council for Research in Agroforestry, Nairobi, Kenya (personal correspondence), March 1985.

Bilbrough, G.W., compiler. Proceedings of a technical workshop on agroforestry. Wellington: Ministry of Agriculture and Fisheries. Wellington; July 1984. 98 pp.

Brewbaker, J.L. and B.T. Styles. Economically important nitrogen fixing tree species. Document #2A. In: Nitrogen-Fixing Tree Association. Bellagio workshop: resource document on nitrogen-fixing trees, Bellagio, Italy. Waimanalo, Nitrogen Fixing Tree Association; Sept. 1982.

Combe, J. and G. Budowski. Classification of agroforestry techniques. In: De Las Salas, O., ed. Workshop Agro-forestry Systems in Latin America, Turrialba, Costa Rica, March, 1979. Proceedings. Turrialba, Costa Rica; 1979. pp. 17-47.

Diamond, N.K. An agroforestry system for San Luis Obispo County (CA.) and its potential for technology transfer to other semi-arid mediterranean regions. Unpubl. M.S. thesis, California Polytechnic State University, San Luis Obispo. 1987.

Everist, S.L. Use of fodder trees and shrubs. Division of Plant Industry Advisory Leaflet No. 1024. Queensland, Australia: Queensland Department of Primary Industries; 1972. 7 pp.

FAO--Food and Agricultural Organization of the United Nations. Conservation in arid and semiarid zones. FAO Conservation Guide 3. Rome, Italy; 1976. pp. 3-11.

Felker, P. Uses of tree legumes in semi-arid regions. Economic Botany 35 (2):174-186; 1981.

Felker, P., Clark, P.R., Cannell, G.H. and J.F. Osborn. Screening Prosopis (Mesquite or Algarrobo) for biofuel production on semiarid lands. In: Proceedings of the symposium on dynamics and management of Mediterranean-type ecosystems. Berkeley, California: Pacific Southwest Forest and Range Experiment Station; 1982. pp. 179-185.

Ferguson, I.S. and J.J. Reilly. The economics of joint agriculture/forestry enterprises. In: Howes, K.M.W. and R.A. Rummery, eds. Integrating agriculture and forestry. Proceedings of a workshop. Bunbury, West Australia, 26-30, September 1977. Perth, Australia: CSIRO, Perth; 1978. pp. 91-105.

Funk, D.T., Schlesinger, R.C. and F. Ponder, Jr. Autumn-olive as a nurse plant for black walnut. Botany Gazette 140:110-114; 1979.

Gordon, J.C., Wheeler, C.T. and D.A. Perry. Symbiotic nitrogen fixation in the management of temperate forests. Corvallis, Oregon: Forest Research Laboratory, Oregon State University; 1979.

Hawke, M.F., Percival, N.S. and R.L. Knowles. Forestry on farms: establishment and early management of agroforests. AgLink FPP 743. 2, Wellington, New Zealand: Information Services, Ministry of Agriculture and Fisheries; 1983a. 3 pp.

Hawke, M.F., Percival, N.S. and R.L. Knowles. Forestry on farms: managment of established agroforests. AgLink FPP 743. 3, Wellington, New Zealand: Information Services, Ministry of Agriculture and Fisheries; 1983b. 3 pp.

Howes, K.M.W. and R.A. Rummery, eds. Integrating agriculture and forestry. Proceedings of a workshop held at Bunbury, West Australia, Sept. 26-30, 1977. Perth, Australia: CSIRO; 1978.

Ibrahim, K.M. Shrubs for fodder production. In: Manassah, J.T. and E.J. Briskey, eds. Advances in food-producing systems for arid and semi-arid lands. Academic Press, New York; 1981. pp. 601-642.

International Council for Research on Agroforestry (ICRAF). The International Council for Research in Agroforestry. Nairobi, Kenya: ICRAF; 1982. 12 pp.

Kosco, B.H. and J.W. Bartolome. Effects of cattle and deer on regenerating mixed conifer clearcuts. Journal of Range Management 36 (2):265-268; 1983.

Le Houerou, H.N. The role of shrubs and trees in the management of natural grazing lands (with particular reference to protein production). In: Proceedings of the Eighth World Forestry Congress, Jakarta, 16-28 October, 1978, Forestry for Food, Volume III. Jakarta: World Forestry Congress, Jakarta; 1978. pp. 1147-1174.

Linnartz, N.E. and M.K. Johnson, eds. Agroforestry in the southern United States. Thirty-third Annual Forest Symposium. New Orleans: Louisiana Agricultural Experiment Station and Louisiana Cooperative Experiment Service; 1984. 183 pp.

MacDicken, K.G. and J.L. Brewbaker. Descriptive summaries of economically important nitrogen-fixing trees. Nitrogen-fixing tree research reports 2 (May 1984):46-54; 1984.

Mead, R. and R.D. Stern. Designing experiments for intercropping research. Experimental Agriculture 16:329-342; 1980.

Parsons, J.J. The acorn-hog economy of the oak woodland of southwestern Spain. The Geographic Review LII (2):211-235; 1962.

Pillsbury, N.H. and D.P. Williamson. The landowners guide for fuelwood marketing opportunities in the Central Coast. California Polytechnic State University, San Luis Obispo in cooperation with Forest Service, U.S.D.A., State and Private Forestry, San Francisco; 1980. 13 pp.

Rossi, R.S. Land use and vegetation change in the oak woodland-savanna of northern San Luis Obispo County, California (1774-1978). Unpubl.

Ph.D. dissertation, University of Callifornia, Berkeley; 1979. 337 pp.
Rumney, G.R. Climatology and the world's climates. New York: MacMillan Company; London: Collier-MacMillan Ltd.; 1968. pp. 103-111.
Secretariat of the United Nations. Desertification: its causes and consequences. United Nations Conference on Desertification, 29 Aug.-9 Sept. 1977. New York: Pergamon Press; 1977.
Standiford, R., Donaldson, D.R. and J.R. Breece. Planting eucalyptus for firewood. Leaflet 21297. Berkeley: University of California, Cooperative Extension, Division of Agricultural Sciences; 1983.
Tarrant, R.F. Nitrogen fixation in North American forestry: research and application. In: Gordon, J.C. and C.T. Wheeler, eds. Biological nitrogen fixation in forest ecosystems: foundations and applications. The Hague, Boston, London: Martinus Nijhoff/Dr. W. Junk; 1983. pp. 261-277.
Wollum III, A.G. and C.T. Youngberg. The influence of nitrogen fixation by nonleguminous woody plants on the growth of pine seedlings. Journal of Forestry, May 1964: 316-321; 1964.
Zavitkovski, J. Small plots with unplanted plot border can distort data in biomass production studies. Canadian Journal of Forest Resources 2(1): 9-12; 1981.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Relating Cordwood Production to Soil Series[1]

Dennis J. Lytle and Sherman J. Finch[2]

Abstract: Oak production data were gathered on 8 different soil series in support of soil surveys in Yuba and Sutter Counties, California. Cords per acre of blue oak (Q. douglasii) and interior live oak (Q. wislizenii) varied widely depending on past management, soil properties and climate. Soil properties that affected oak production were depth and available water capacity (AWC), presence of a "claypan" and type of underlying bedrock. Soil properties and their production and management limitations should be a consideration in hardwood management.

Oak production data is being included in National Cooperative Soil Surveys in California; principally because of its use for fuelwood, and because of the increasing importance and attention being paid to hardwoods. In this paper, data on cordwood volumes are reported for Yuba and Sutter Counties. Similar data are included in soil surveys in Lake, Mendocino, Sacramento and San Joaquin Counties.

DESCRIPTION OF THE STUDY AREAS

In Yuba County, the Blue oak-Digger pine forest cover type begins at about 38 m (125 feet) in the foothills of the Sierra Nevada mountains and extends to about 580 m (1900 feet) elevation. Figure 1 illustrates the relationships between elevation, moisture and the major vegetation types in Yuba County. The forest cover types are those described in "Forest Cover Types of the United States and Canada" (Eyre 1980).

We have further subdivided the Blue oak-Digger pine type into Blue oak-annual grass and Blue oak-interior live oak-annual grass. Digger pine (P. sabiniana) is a minor component in the blue oak types in Yuba County (table 1). Precipitation ranges from about 406 mm (18 inches) at the lowest elevations to about 890 mm (35 inches) at the highest elevations in the blue oak cover type (DWR 1966). Six soil series are mapped in the blue oak type in Yuba County (table 2). Depth to bedrock ranges from 25 to 64 cm (10 to 25 inches) or 50 to 100 cm (20 to 40 inches) depending on soil series. No soil series were mapped in the blue oak cover type that had bedrock at greater than 100 cm (40 inches). Underlying bedrock is metavolcanic (greenstone), amphibolite schist, granodiorite, or gabbro diorite (table 3).

In Sutter County, blue oak occur only on the north, east, and west aspects in the Sutter Buttes. Elevation ranges from about 23 to 640 m (75 to 2100 feet). Precipitation ranges from 432 to 483 mm (17 to 19 inches) (DWR 1970). Two soil series were mapped in the blue oak cover type in the Sutter Buttes (table 2). Depth to bedrock ranges from 25 to 50 cm (10 to 20 inches) or 50 to 100 cm (20 to 40 inches) depending on soil series. Underlying bedrock is andesitic lahar (mudflow) (table 3). Interior live oak was not found growing on these soils in Sutter County.

METHODS

The soil surveys in Yuba and Sutter Counties were made by five soil scientists, a forester, three range conservationists and a biologist from 1980 to 1986. As the surveys progressed, these scientists selected typical sites that represented the soil series, the overstory vegetation, and the understory vegetation. Table 1 lists the natural vegetation for each soil series phase in Yuba County. In soil surveys, vegetative production and species composition are used in the design and separation of soil series and soil mapping units. On forest land, changes in height over age, or site index, and changes in species composition are used by the soil scientist as one of the means to separate soil series and soil mapping units.

At 28 typical sites on 8 soil series, cordwood volumes for all trees were estimated. Cordwood volume was estimated by sample cruise or "zigzag" transect as used by the Soil Conservation Service (SCS). The procedure is defined in the SCS National Forestry Manual (SCS 1980). The process involved collecting data on 20 trees at each site. After heights and diameters were measured, cordwood volumes were determined from tables (Pillsbury and Stevens 1978). The volume data in table 3 represent observed volume not yield. Site index curves to determine yield were not available for blue oak, interior live oak or Digger pine at the time of our field work. Blue oak ages were obtained from 5 sites, but not in sufficient quantity to predict growth rates. For reference, the range in age was 86 to 125 years. These ages appear consistent with other studies (McClaren 1983, Neal 1980).

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, Nov. 12-14, 1986, San Luis Obispo, California.

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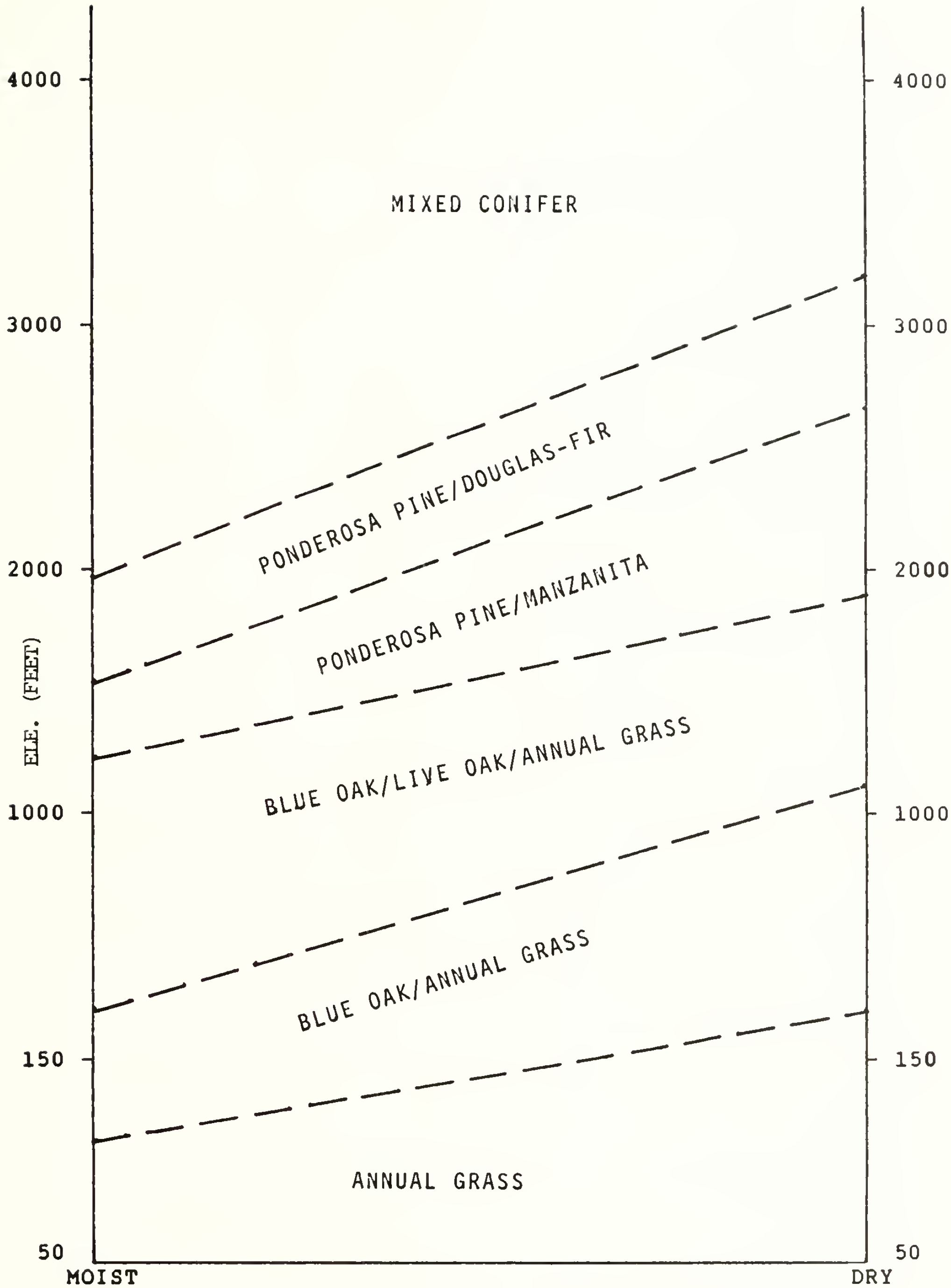

Figure 1--Schematic of vegetation, elevation and moisture in Yuba County, California.

Table 1--Natural Plant Communities

Soil Series Phase	Characteristic Vegetation: Common Name	Characteristic Vegetation: Scientific Name	Percent Composition [1] Dry Wt.	Percent Composition [1] Canopy
Auburn loam	Blue oak	Quercus douglasii		40
	Soft chess	Bromus mollis	40	
	Wild oat	Avena fatua	10	
	Ripgut brome	Bromus diandrus	10	
	Rose clover	Trifolium hirtum	5	
	Filaree	Erodium spp	5	
	Medusahead	Taeniatherum asperum	5	
Auburn gravelly loam	Blue oak	Quercus douglasii		40
	Interior live oak	Quercus wislizenii		5
	Digger pine	Pinus sabiniana		5
	Poison-oak	Taxicodendron diversilobum		5
	Soft chess	Bromus mollis	40	
	Filaree	Erodium spp	5	
	Rose clover	Trifolium hirtum	5	
	Foxtail fescue	Vulpia myuros	5	
	Ripgut brome	Bromus diandrus	5	
	Wild oat	Avena fatua	5	
Orose	Interior live oak	Quercus wislizenii		25
	Blue oak	Quercus douglasii		5
	Digger pine	Pinus sabiniana		5
	Whiteleaf manzanita	Arctostaphylos viscida		5
	California black oak	Quercus kelloggii		5
	Toyon	Photinia arbutifolia		5
	Poison-oak	Taxicodendron diversilobum		5
	Ripgut brome	Bromus diandrus	5	
	Blue wildrye	Elymus glaucus	5	
	Squirreltail	Sitanion hystrix	5	
	Soft chess	Bromus mollis	5	
Stohlman	Blue oak	Quercus douglasii		10
	Soft chess	Bromus mollis	25	
	Wild oat	Avena fatua	15	
	Ripgut brome	Bromus diandrus	5	
	Filree	Erodium spp	5	
	Clover	Trifolium spp	5	
	Purple needlegrass	Stipa pulchra	5	
Palls	Blue oak	Quercus douglasii		40
	Soft chess	Bromus mollis	25	
	Wild oat	Avena fatua	15	
	Mediterranean barley	Hordeum leporinum	15	
	Common geranium	Geranium dissectum	10	
	Filaree	Erodium spp	5	
	California melicgrass	Melica californica	5	
	Ripgut brome	Bromus diandrus	5	
	Clover	Trifolium spp	5	
Sobrante loam	Blue oak	Quercus douglasii		40
	Soft chess	Bromus mollis	30	
	Rose clover	Trifolium hartum	10	
	Mediterranean barley	Hordeum leporinum	5	
	Ripgut brome	Bromus diandrus	5	
	Foxtail fescue	Vulpia myuros	5	
	Filaree	Erodium spp	5	

Table 1--Natural Plant Communities--continued.

Soil Series Phase	Characteristic Vegetation		Percent Composition [1]	
	Common Name	Scientific Name	Dry Wt.	Canopy
Sobrante gravelly loam	Blue oak	Quercus douglasii		40
	Interior live oak	Quercus wislizenii		10
	Digger pine	Pinus sabiniana		5
	California black oak	Quercus kelloggii		5
	California buckeye	Aesculus californica		5
	Poison-oak	Toxicodendron diversilobum		10
	Buckbrush	Ceanothus cuneatus		5
	Soft chess	Bromus mollis	25	
	Wild oat	Avena fatua	10	
	Ripgut brome	Bromus diandrus	10	
	Clover	Trifolium spp	5	
	Filaree	Erodium spp	5	
	Silver hairgrass	Aira caryophyllea	5	
	Dogtail	Cynosurus echinatus	5	
Flanly	Interior live oak	Quercus wislizenii		30
	Blue oak	Quercus douglasii		15
	Digger pine	Pinus sabiniana		5
	California black oak	Quercus kelloggii		5
	Canyon live oak	Quercus chrysolepis		5
	California buckthorn	Rhamnus californica		5
	Whiteleaf manzanita	Arctostaphylos viscida		10
	Buckbrush	Ceanothus cuneatus		5
	Poison-oak	Toxicodendron diversilobum		5
	Toyon	Photinia arbutifolia		5
	Dogtail	Cynosurus enchinatus	5	
	Blue wildrye	Elymus glaucus	5	
	Wild oat	Avena fatua	5	
	Ripgut brome	Bromus diandrus	5	
Argonaut loam	Blue oak	Quercus douglasii		50
	Soft chess	Bromus mollis	25	
	Dogtail	Cynosurus echinatus	25	
	Wild oat	Avena fatua	10	
	Ripgut brome	Bromus diandrus	10	
	Foxtail fescue	Vulpia myuros	5	
	Rose clover	Trifolium hirtum	5	
	Medusahead	Taeniatherum asperum	5	
	Silver hairgrass	Aira caryophyllea	5	
Argonaut gravelly loam	Blue oak	Quercus douglasii		50
	Interior live oak	Quercus wislizenii		5
	Digger pine	Pinus sabiniana		5
	Poison-oak	Toxicodendron diversilobum		5
	Soft chess	Bromus mollis	25	
	Wild oat	Avena fatua	10	
	Ripgut brome	Bromus diandrus	10	
	Dogtail	Cynosurus echinatus	10	
	Filaree	Erodium spp	5	
	Rose clover	Trifolium hirtum	5	
	Silver hairgrass	Aira caryophyllea	5	

Table 1--Natural Plant Communities--continued.

Soil Series Phase	Characteristic Vegetation		Percent Composition[1]	
	Common Name	Scientific Name	Dry Wt.	Canopy
Verjeles	Interior live oak	Quercus wislizenii		25
	Blue oak	Quercus douglasii		5
	Digger pine	Pinus sabiniana		5
	California black oak	Quercus kelloggii		5
	Whiteleaf manzanita	Arctostaphylos viscida		10
	Toyon	Photina arbutifolia		5
	Poison-oak	Toxicodendron diversilobum		5
	Ripgut brome	Bromus diandrus	5	
	Blue wildrye	Elymus glaucus	5	
	Squirreltail	Sitanion hystrix	5	
	Soft chess	Bromus mollis	5	

[1]Percentage composition for grasses and forbs by dry weight. Percentage composition for trees and shrubs by percent canopy.

Table 2--Classification of the Soils (Soil Survey Staff, 1975)

Yuba County

Soil Series[1]	Classification
Argonaut	Fine, mixed, thermic Mollic Haploxeralfs
Auburn	Loamy, oxidic, thermic Ruptic-lithic Xerochrepts
Flanly	Fine-loamy, mixed, thermic Ultic Haploxeralfs
Orose	Loamy, mixed, thermic shallow Ultic Haploxeralfs
Sobrante	Fine-loamy, mixed, thermic Mollic Haploxeralfs
Verjeles	Fine-loamy, mixed, thermic Ultic Haploxeralfs

Sutter County

Soil Series[1]	Classification
Palls	Coarse-loamy, mixed, thermic Mollic Haploxeralfs
Stohlman	Loamy, mixed, thermic Lithic Mollic Haploxeralfs

[1]Soil Series descriptions are available on request from the Soil Conservation Service, 2121-C 2nd Street, Davis, Calif. 95616.

Table 3--Soil Vegetation Relationships Yuba and Sutter Counties, California, 1936

SOIL					VEGETATION			
Depth Class	Series Phase	Mean A.W.C.[1]	Bedrock	M.A.P.[2]	Cover Type	Av. Basal Area	D.B.H.[3]	Mean Volume
		(inches)		(inches)		(Sq. Ft.)	(inches)	cords/acre
Shallow (10 to 20 inches)	Auburn loam	2.75	amphibolite schist (hard)	18 to 22	blue oak	141	9	37
	Auburn gravelly loam	2.25	greenstone (hard)	22 to 26	blue oak-int. live oak	69	14	21
	Orose	1.5	granodiorite (soft)	26 to 35	blue oak-int. live oak	135	8	38
	Stohlman	1.5	andesitic lahar (hard)	17 to 19	blue oak	--	9	12
Moderately deep (20 to 40 inches)	Palls	3.0	andesitic lahar (hard)	17 to 19	blue oak	--	12	93
	Sobrante loam	5.0	greenstone (soft)	22 to 26	blue oak	160	10	43
	Sobrante gravelly loam	4.0	greenstone (soft)	26 to 35	blue oak-int. live oak	161	10	97
	Flanly	5.0	granodiorite (soft)	26 to 35	blue oak-int. live oak	258	8	85
Moderately deep with claypan	Argonaut loam	3.5	greenstone (soft)	22 to 26	blue oak	133	10	19
	Argonaut gravelly loam	2.75	greenstone (soft)	26 to 35	blue oak-int. live oak	141	10	47
	Verjeles	5.0	gabbro diorite (soft)	26 to 35	blue oak-int. live oak	165	6	83

[1]A.W.C. - Available water capacity. Amount of water in inches held between 1/3 bar and 15 bar suction. Average for whole soil.

[2]M.A.P. - Mean annual precipitation, range for series phase.

[3]D.B.H. - Average diameter at breast height (4.5 ft.).

Species composition data for each site were obtained by visual estimate and by clipping, sorting and weighing each grass and forb species to determine the percent composition on a dry weight basis (table 1). The procedure is defined in the SCS National Range Handbook (SCS 1976). Composition for trees and shrubs by percent canopy was determined by visual estimate. Estimates were periodically verified by using a spherical densiometer for trees.

DISCUSSION

The volume data in table 3 represent 28 samples on 11 soil types. Sufficient ground control or sample quantity was not taken to provide statistically reliable information, but several inferences can be drawn from table 3.

Soil Depth and Available Water Capacity

Shallow soil series with bedrock at 25 to 64 cm (10 to 25 inches) had consistently lower cordwood volumes than moderately deep (50 to 100 cm, 20 to 40 inches) soils without a claypan. Volumes on the shallow soils averaged 27 cords per acre, 34 percent of the 80 cords per acre average on the moderately deep soils without a claypan. Presumably this is the result of shallower rooting depth and lower available water capacity in the shallow soils. Part of the lower volume may be a result of prior harvesting of oaks or fire and a failure of the shallow soils to regenerate oaks because of low available water capacity. Resprouts of blue oaks were observed on moderately deep soils and in the more mesic sites such as north slopes in areas where precipitation exceeded 660 mm (26 inches). No advance reproduction of this species was noted. In short, the blue oak was not being successfully reproduced. The most striking example of the effect of soil depth on cordwood volumes is in the soils found in the Sutter Buttes. Cordwood volumes were 87 percent higher on the moderately deep Palls soils than on the shallow Stohlman soils.

Bedrock Type

Hard unweathered amphibolite schist under Auburn loam soils is extensively fractured and often tilted to a nearly verticle angle. Roots were observed penetrating the fractures. One study documented roots of blue oak extending to 13 m (42 feet) or more in fractured and jointed metamorphic rock (Lewis and Burgy 1964). Roots were observed in only a few small fractures in hard massive unweathered greenstone under Auburn gravelly loam soils. Cordwood volumes on Auburn soils over amphibolite schist were higher than volumes on Auburn soils over greenstone, even though precipitation was higher on the Auburn soils over greenstone (table 3).

Greenstone under Sobrante soils is weathered soft in the upper part, normally about 1 foot, and becomes increasingly hard and massive with depth. There are very few fractures below 1 foot. No roots were observed penetrating in hard bedrock under Sobrante soils. In soils formed over soft, deeply weathered granodiorite such as Flanly, roots were observed to several feet in fractures in the rock. No roots were observed penetrating the hard massive andesitic lahar under Stohlman or Palls soils in the Sutter Buttes.

There may be differences in soil fertility due to differences in lithologies and other factors, but these are probably unimportant relative to physical differences in the soils.

Claypan

Argonaut and Verjeles soils, though they are moderately deep to bedrock, had cordwood yields that were 38 percent less than the other moderately deep soils. Argonaut and Verjeles soils have a distinct clay layer (claypan) that normally starts at 38 to 76 cm (15 to 30 inches) below the surface. The claypan lessens the effective depth that many roots can penetrate. Few fine roots were seen penetrating the claypan, however some coarse roots were observed in the claypan. The clay layer has a much lower hydraulic conductivity than the rest of the soil. Water moves through it very slowly and may perch above it during heavy rains. This wetness may have a significant effect on root development and thus production. Blue oak are not found on poorly drained soils (Neal 1980). Also note the mean available water capacity is lower on Argonaut soils than Sobrante soils. Argonaut soils have a lower A.W.C. because of the lower amount of water available in the clay layer. Both Argonaut and Sobrante soils are moderately deep to soft greenstone. Oak volumes in similar precipitation ranges were significantly higher on Sobrante soils than on Argonaut soils.

Climate

Precipitation also had an effect on production. Not surprisingly, Sobrante and Argonaut soils in the blue oak cover type had lower production than Sobrante and Argonaut soils in the blue oak-interior live oak cover type. Very little interior live oak was found at lower elevations in the 560 to 660 mm (22 to 26 inch) precipitation zone. With increase in elevation and precipitation and corresponding decrease in evapotranspiration, interior live oak becomes the dominant species at the highest elevations on such soils as Flanly (table 2). At the higher elevations the higher precipitation and lower temperatures equate to more moisture for plant growth.

Vegetation is highly variable in the blue oak type (Vankat and Major 1978, Neal 1980). Past occurrences strongly influence present stand structure and diversity. Extensive areas of Yuba County were burned in the 1930's and before. We have no way of knowing how fire affected the sites because of the slow response of these types to past disturbances, but perhaps one can assume that all were disturbed at least to some extent. The data on cordwood production may not represent the true productive capacity of the soils. However, care was taken to select sites that showed a minimum of disturbance and that had a plant community that was as close as possible to our predetermined potential for the soil (table 2).

Very little data are available on correlating soil properties to oak growth. Many problems in management of oaks, seedling survival and resprouting may be explained by soil properties. Based on our observations of the study areas, the odds are slim that blue oak will regenerate on any of these soils. The relatively low available water capacity and intense competition for water by understory plants make regeneration nearly impossible. Livestock grazing, rodents, insects, wildlife and fire and their interaction must be considered when managing blue oak and interior live oak. Stand density and diversity are, in part, related to the type of soil. Rundel (1982) noted that soil depth and the related effects of depth on soil moisture availability are the critical factors in separating the chapparal and foothill woodland communities in Sequoia National Park.

CONCLUSIONS

Soil properties are related to oak production. Soil properties are related to plant species occurrence. Soil properties and their limitations to oak growth should be identified first before more detailed steps are taken to manage oaks or conduct research on them. Soil survey information is available in nearly every county in California to help identify soil properties, including those that strengthen or lessen the likelihood of successful blue oak growth and regeneration. If during research the soil properties are identified, and the soil is classified according to "Soil Taxonomy", the results can be transferred to other areas of like soils with similar site characteristics.

Acknowledgements: We wish to thank Warren E. Peden, Soil Conservation Service, U.S. Department of Agriculture, for assistance in gathering and correlating data on vegetative composition and production.

REFERENCES

DWR--Department of Water Resources. Lines of Average Yearly Precipitation in the Central Valley, North Half; State of California; 1966.

Eyre, F. H., editor. Forest Cover Types of the United States and Canada. Society of American Foresters; 1980. 148 p.

Lewis, D. C.; Burgey, R. H. The relationship between oak tree roots and ground water in fractured rock as determined by tritium tracing. J. Geophys. Res. 69: 2579-2588; 1964.

McClaran, M. P. Quercus douglasii stand age structure on grazed and ungrazed sites in Tulare Co., California. Report to the Sequoia Natural History Association, Three Rivers, CA; 1983. 14 p.

McDonald, P. M. Silvicultural Characteristics of Blue Oak. Unpublished manuscript. Redding, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture. 28 p.

Neal, D. L. Blue Oak - Digger Pine. In: Forest Cover Types of the United States and Canada. Society of American Foresters; 1980; 126-127.

Pillsbury, N. H.; Stevens, J. A. Hardwood volume and weight tables for California's central coast. Sacramento, CA: California Department of Forestry; 1978; 2nd printing, 1980. 54 p.

Rundel, P. W. Ecological relationships of Foothill Woodland and Chaparral communities in the Southern Sierra Nevada, California. Ecologa Mediterranea. T. VIII. Fasc. 1/2 Marseille Definition et localuation des Ecosystemes mediterraneens tenesures. Saint-Maximin 16-20/11/1981; 1982; 461-471.

SCS--Soil Conservation Service. National Forestry Manual. Washington, D.C.: U.S. Department of Agriculture; amended 1982.

SCS--Soil Conservation Service. National Range Handbook. Washington, D.C.: U.S. Department of Agriculture; 1976.

Soil Survey Staff. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agricultural Handbook 436. Washington, D.C.: U.S. Department of Agriculture; 1975. 754 p.

Vankat, J. L.; Major, J. Vegetation changes in Sequoia National Park, California. J. Biogeography 5:377-402; 1978.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Economic Forces Affecting California's Hardwood Resource[1]

Sam C. Doak, Bill Stewart, and Paul Tuazon[2]

Abstract: California's hardwood resource is affected by a range of economic forces that influence the availability of related benefits in different ways. Demand for hardwood products such as firewood may influence removal of hardwoods not only directly but also indirectly through land management activities that are aimed at increased production of other land-based commodities. Residential and agricultural expansion into hardwood areas may result in changes to the hardwood resource that, although not always immediately apparent, may be more permanent in nature.

THE HARDWOOD RESOURCE

Strong and growing market pressures, primarily from the firewood market, have been assumed to be promoting hardwood removal, but there has been little data on the actual influence of these markets or on possible future trends. This paper is based on a study designed to identify and analyze the major economic forces affecting California's hardwood resource.

Concern over California's hardwood resource has focused primarily on the removal of trees and the inability of some species to regenerate adequately. But the hardwood resource includes the environmental and societal benefits hardwoods provide as well as the trees themselves. These benefits are diverse and are related to the particular types of vegetative structures that comprise the wildland hardwood resource. Some of these benefits are realized in the production of wood products such as firewood, lumber, and pulpwood. Others are nonconsumptive and include wildlife habitat, visual quality, shade, and water protection. Effective hardwood resource policy must address the biological, social and political relationships associated with this broad range of hardwood-related benefits.

Several economic forces affect the distribution, availability, and flow of hardwood-related benefits. Like the benefits themselves, these forces are connected, often in complex patterns. They act both in concert and individually, and result in changes to the resource. For purposes of discussion, three types can be identified: 1) those operating directly through the demand for hardwood products; 2) those operating directly through land management decisions and indirectly through hardwood product demand; and 3) those operating directly through land use decisions with little or no connection to hardwood product demand. The first category includes the markets for hardwood firewood, pulp chips, lumber, and biomass. The second group includes management activities such as range and timber stand improvement. The last includes agricultural conversion and residential (and commercial and industrial) expansion.

HARDWOOD PRODUCT DEMAND

Hardwood products such as lumber, firewood and pulpwood are consumptive benefits of the hardwood resource. Because demand for hardwood products is manifested in tree removals, it is the most obvious force affecting the hardwood resource.

Firewood

Hardwoods are cut for firewood wherever they grow in the state. The oaks (*Quercus* spp.) generally command the highest price in the retail market, but several other native species are also burned, including madrone (*Arbutus menziesii*), tanoak (*Lithocarpus densiflorus*), bay (*Myrica californica*), and alder (*Alnus rubra*). Residential consumption of firewood, fueled largely by two major energy crises, increased dramatically in the 1970's.[3] As prices rose, new firewood cutters entered the market, previously unmarketable trees gained stumpage value, and hardwood removals increased. Such trends have led to a growing concern that demand for firewood is driving the widespread removal of indigenous hardwoods across the state, resulting in the loss of other benefits associated with their retention.

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[3]Regression analysis indicated a close correlation between gasoline prices and seasonal oak firewood prices in the *San Francisco Chronicle* from 1972 through 1985.

Although demand for firewood is an important force, its effect on the indigenous hardwood resource is mitigated by several factors. Native California hardwoods constitute only a small portion of the total firewood market. Although a relatively greater proportion of hardwood firewood than softwood is sold through retail markets, the majority of firewood consumed in the state is softwood. Much of this is cut for personal use from National Forests or private forestland. Growth in retail demand has prompted the development of other supplies of firewood including exotics such as eucalyptus, orchard wood (especially almond, walnut and citrus), and imports (both hardwood and softwood) from Arizona, Oregon, and even British Columbia.[4] This increased diversity of supply sources tends to buffer any effect that changes in firewood demand may have on indigenous hardwoods. Market indicators such as prices and numbers of firewood dealers in newspaper ads, and volumes of truck and rail imports from out of state, indicate that demand for hardwood firewood has stabilized considerably.[5] Additionally, the predominance of oak in retail firewood markets appears to have waned as softwoods and other hardwoods have gained greater consumer acceptance.[6] If demand for firewood remains stable, then the pressures on indigenous hardwoods for firewood are likely to stabilize as well.

[4]Southern Pacific records indicate an increase in firewood imports from the Northwest from approximately 148 cords in 1982 to over 6,000 cords in 1983. Pest Exclusion Unit records indicate over 7,500 cords imported by truck in 1983 via Interstate-5.

[5]Pest Exclusion Unit records showed decreasing volumes of truck shipments of firewood from the Northwest from 1982 through 1985. Rail shipments were found to be more erratic, but indicated an overall decline in volume from 1983 through 1985. Combined truck and rail volumes decreased only slightly from 1982 to 1985, with a high of 23,000 in 1983.

Analysis of newspaper firewood advertisements revealed that both the price of oak firewood and the number of advertisements decreased between 1980 and 1984. Based on a weighted sample of seven major newspapers, the real (inflation-adjusted) price of oak in December decreased by 92 percent from 1980 to 1984 while the number of firewood advertisements decreased by 78 percent.

[6]In 1980, 48 percent of all newspaper firewood advertisements analyzed were for oak while 20 percent were for orchard wood. In 1984 the share of oak advertisements decreased to 37 percent while orchard wood increased to 42 percent.

The proportionate share of hardwood shipped by truck via Interstate 5 decreased from 37 percent in 1982 to 7 percent in 1985.

Lumber

The hardwood lumber industry holds a small but constant share of total native hardwood consumption. The industry in California is currently limited to a single full-time hardwood mill.[7] The major hardwoods used for lumber are black oak, tanoak, and madrone. These are all found primarily on commercial timberlands. Any change in consumption in this sector, however, will have an indirect effect on rangeland hardwoods through horizontal linkages with the firewood market. Increased demand for black oak, tanoak and madrone sawlogs will tend to reduce their availability for firewood, shifting pressure towards other sources of supply, including the hardwood-rangelands.

Pulpchips

There are currently four operational wood-pulp mills in California. Although these mills rely on softwood chips, a small percentage of hardwood is often used in their total chip mix. Tanoak is used by two of these mills, both of which are on the North Coast where supplies are abundant.[8] The other two mills use eucalyptus and alder.[9] In late 1979, as a result of a shortage of softwood mill residue, overseas demand for tanoak chips rose considerably, and prices nearly doubled. Large quantities were shipped to Japan. Since the 1979 chip crisis, Japan has developed more reliable sources of fiber, and tanoak has not been exported from California for several years. Any increased consumption in the pulp and paper sector will, like the hardwood lumber sector, have an indirect effect on other hardwoods through horizontal linkages with the firewood market.

Energy production

There are currently 72 biomass projects in California using forest or mill residues to generate power. Sixty-six of these are co-generation plants, the remaining 6 producing only electricity. Six other facilities are under construction and nine more are in the planning stages (California Energy Commission, 1985).

[7]Cal Oak Lumber Company in Oroville, produces approximately 5,000,000 board feet annually.

[8]Tanoak cannot be utilized in production of higher-grade papers. Interviews with chip buyers indicate that approximately 60,000 cords of tanoak are consumed annually by the domestic pulp and paper industry.

[9]Eucalyptus and alder provide fiber highly desirable for the production of linerboard.

While the vast majority of these plants rely on softwood mill residues, some in-woods whole-tree chipping operations supply limited amounts of fuel. These in-woods operations occur on National Forest and private lands as precommercial thinnings, stand type conversions, or increased utilization during harvest operations. Thinnings and coversions are generally completed at a negative return to stumpage. Current chip prices barely cover chipping and transportation costs, and far exceed the costs of other fuels such as sawmill residue.

Although harvesting methods may become more economical, it is doubtful that delivered prices at biomass plants will translate into hardwood stumpage prices higher than those currently paid by firewood cutters. In some areas, demand for biomass will be in direct competition for orchard wood. This may reduce the supply of orchard firewood on the market, and subsequently increase demand for native hardwood firewood stumpage.

LAND MANAGEMENT

The removal of hardwoods is not always driven entirely by their value in commodity products such as firewood or sawlogs. Removals are often desired as part of land management objectives directed at other resource outputs such as softwood lumber or grazing for livestock. Range managers may want to improve the forage production of hardwood-rangeland by removing some or all of the hardwoods. Forest managers often remove individual hardwoods to release more valuable conifers, or convert entire hardwood stands to conifer plantations. Stumpage values can, however, play an important role in land management decisions by facilitating desired removals.

Range improvement

Range improvement through hardwood removal is an intensification of an existing use. It was historically undertaken to increase forage and livestock production. In this context the removal of hardwoods for range improvement is dependant on the profitability of the livestock industry and the net costs of removal to the landowner. Any increase in the profitability of the livestock industry or lowering of removal costs would likely result in increased hardwood removal. (Conversely, a decline in profitability or a rise in removal costs would likely lead to a decrease in hardwood removal.)

Firewood values have become increasingly relevant to hardwood-rangeland managers. The costs of past removals were often prohibitively expensive for an individual landowner, promting government assistance. Rising demand for firewood has lowered the costs of removal and aided in the accomplishment of desired range improvement objectives. As stumpage values rise beyond the costs of removal and clean-up, the incentive to remove hardwoods extends beyond any returns realized through range improvement alone. Much greater weight is placed on the stumpage value of hardwoods relative to both increased livestock production and hardwood retention value (for the production of such benefits as soil stability, wildlife habitat, aesthetics, etc.). If firewood stumpage prices rise, incentives to remove hardwoods will grow as the opportunity costs of their retention increase.

Declines in the profitability of the livestock industry place increased financial pressures on hardwood-rangeland owners. In these situations removal is more likely a short term "survival" response rather than an investment in range improvement. Immediate cash flow problems may be most easily solved through capital liquidation in the form of hardwood stumpage sales. Although operating costs may be reduced due to resulting range improvements, the positive stumpage values and the need to survive play an important role in the decision.

Timber stand improvement

Intensive silvicultural practices that promote the removal of hardwoods from commercial timberland are also an intensification of an existing use. The main goal is increased production of softwood sawtimber. As with range improvement, the demand for hardwood firewood, lumber, and pulp chips can act as catalysts for these silvicultural activities. In some cases the revenue from these other markets may even become the primary objective. But hardwood stumpage values in commercial timberland are still relatively insignificant compared to softwood sawtimber values, and the return to hardwood stumpage generally has a minor effect on management direction decisions. The greatest removal pressures on hardwoods in commercial timberlands lie in those areas from which the combined costs of harvest and transportation to demand centers is lowest.

LAND USE CHANGES

While land management decisions such as range and timber stand imrovement may be influenced by hardwood stumpage values, other land use decisions affecting hardwoods are not. Conversion of hardwood-woodland to intensive agricultural use or to residential, commercial and industrial development are changes in land management direction. Decisions leading to use changes are related only to the expected value of the proposed use relative to maintaining the current management direction. Although hardwood stumpage may be sold in resulting clearance operations, the value of that stumpage is not a factor in the decision process.

Agricultural conversion

Agriculture is one of the largest sectors of California's economy. Expansion of this sector often occurs in the hardwood-rangelands bordering existing agricultural lands. Soil, topography, climate, and technology limit the potential for development.

Conversion of hardwood-rangelands to intensive agricultural production continues in certain areas of California. San Diego County has the largest number of acres being converted to intensive agriculture. The rapid expansion of avocado orchards is removing many acres of wildlands within the potential range of Engelmann oak. Agricultural counties such as Monterey and Tehama are predicting large increases in intensive agricultural acreage. Much of this expansion will occur in hardwood-rangeland.

The introduction of drip irrigation technology has reduced production costs enough to allow increased agricultural development of many grazing areas. In Tulare County it played a significant role in allowing expansion of citrus orchards into the hardwood-rangelands on the perimeter of the San Joaquin Valley. Drip irrigation, along with high grape prices, increased the introduction of small vineyards in the hardwood-rangelands of Monterey, Sonoma, Napa, and Mendocino Counties. Fruit orchards have recently been introduced into the hardwood-rangelands in the Sierras and in Mendocino County.

Parcelization and residential expansion

Like agricultural conversion, residential expansion into hardwood areas is a permanent change in use that, although it may provide firewood, is not influenced by firewood or other wood product demand. Residential expansion may entail some loss of hardwood cover, but parcelization and residential expansion also result in a permanent change in management direction, with new owners and managers using the land quite differently from managers of larger commodity producing land units.

Residential development is affected by economic and social forces with very little connection to the commodity markets for wood products or livestock. The land supporting hardwoods is valued for its location and production of amenity values. The dynamics manifest themselves in the land market. Because of rapidly increasing population and changing lifestyles, greater numbers of people desire to live in rural areas. The hardwood- rangelands provide an ideal environment for this new population. These lands are largely privately owned and relatively less expensive to develop than areas closer to urban centers. They are also closer to urban work centers than commercial timberlands, while still providing the amenities of living in a rural area. It is unclear what the real effects of parcelization and changing land use patterns are on the hardwood resource, although the allocation of benefits associated with hardwoods will change over time.

Residential expansion into hardwood-woodlands is most noticable in many of the Sierra foothill counties such as Nevada, Placer, El Dorado, Amador, and Calaveras. Other counties with high growth in hardwood areas include Monterey, Sonoma, Lake and San Diego. Practically every county in the state with any expanse of hardwood-woodland is experiencing some degree of change brought on by residential growth in those areas.[10]

CONCLUSION

There are a wide range of economic forces having an equally wide range of effects on California's hardwood resource. These effects are manifested not only in the removal of hardwoods, but in changes in land use and management direction that have differing degrees of permanance.

The mere existence of hardwoods does not dictate the structure and magnitude of the biological and societal benefits associated with them. The production and availability of hardwood-related benefits can be significantly affected by forces that may have little or no effect on the existence of individual trees. Demand for hardwood products such as firewood can act to remove a multitude of benefits while in effect cashing in on one. But other forces, such as the demand for residential parcels, can greatly alter the availability of hardwood-related benefits even while ensuring the retention of the trees themselves. The process of changing ownership, parcel size, and residential occupation may result in a reduction in the number and extent of oaks and other hardwoods through land clearance and firewood production. But more importantly, the character of the land is altered by multiple new owners and their often inconsistent activites. Land is removed from large scale commodity production, state fire protection costs increase,

[10]The Central Sierran counties of Nevada, Placer, El Dorado, Amador, Calaveras, Madera, Tuolumne and Mariposa, with an average annual growth greater than or equal to five percent, were all in the top twelve high growth counties in the state between 1970 and 1985. All of these counties are characterized by extensive privately owned hardwood woodlands. During this same fifteen year period a total of 172,617 acres in these eight counties were subdivided into 59,587 lots, an average of 2.9 acres per lot (California Department of Real Estate). These figures include only formal subdivisions. Informal subdivisions of four lots or less are more difficult to track although they may cover more territory.

wildlife requirements and management become more complicated, and future patterns of water requirements are affected. Unlike firewood production which may temporarily remove hardwoods (and their associated benefits) from the land, land use changes such as residential expansion are essentially permanent.

Acknowlegements: This study was funded by the Forest and Rangeland Resource Assessment Program, California Department of Forestry.

REFERENCES

Albin-Smith, Teresa K.; Raguse, Charles A. Environmental effects of land use and intensive range management: a Northern California example. University of California, Davis: California Water Resources Center; 1984. 35p.

California Department of Real Estate. Subdivision records, 1970-1984. Sacramento, CA.

California Energy Commission. Biomass project tracking list. Sacramento, CA. 1985.

Doak, Sam C.; Stewart, Bill. A model of economic forces affecting California's hardwood resource: monitoring and policy implications. University of California at Berkeley, Department of Forestry and Resource Management; 1986. 148 p.

Lee, Glenn. A report on California's firewood marketing. Sacramento, CA: Forest and Rangeland Resources Assessment Program, California Department of Forestry. Unpublished report; 1984. 29 p.

Fortmann, Louise; Huntsinger, Lynn. California's oak lands: owners, use, and management. University of California at Berkeley, Department of Forestry and Resource Management; 1985. 78 p.

Gasser, Don; Stewart, Bill. Market dynamics of Bay Area firewood. In Proceedings, fuelwood production conference; 1985 July, 22; Santa Cruz, CA: University of California Extension; 1985; 41-46.

McClaran, Mitchell P.; Bartolome, James W. The importance of oaks to ranchers in the California foothill woodland. Rangelands, 7(4): 158-160; 1985.

Parsons, James J. Slicing up the open space: subdivisions without homes in Northern California. Erkunde, 26(1): 1-8; 1972.

Pillsbury, Norman H.; Timmons, J.; Mayer, K.; Libeau, H.; Plumb, T.; Marsh, B.; Del Porto, N.; Wade, R.; Phillips, P.; Slack, H. California's hardwood resource: preliminary report of the hardwood task force; 1983 December. 67 p.

Skog, Kenneth, E.; Watterson, Irene, A. Residential fuelwood use in the United States. J. For. 712-747: 1984, December.

United States Department of Energy. Estimates of U.S. Wood Energy Consumption from 1949 to 1981. Washington, D.C: National Information Information Center; 1982. 149 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Recognizing Hardwood Quality: Key to Increased Profits?[1]

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Abstract: In order to maximize the dollar return from California's hardwood resources, that industry must allocate the resource to its best end use and strive to increase the utilization of all material presently considered waste. To achieve the proper allocation of this resource to its best end use, you must be able to recognize and accurately classify the quality characteristics of standing timber, cut logs, and end products. Quality classification and grading systems allow us to segregate the tree or its parts into groups, all with similar characteristics. This enables the individual to determine value and predict the volume of end products. Although most hardwood systems have been developed for eastern hardwoods, they have also been applied to western hardwood species. These systems are essential for timber appraisal, timber inventory, and quality control during processing. The accurate prediction of end product yield and value allows the individual or company to be more confident of their management and marketing decisions.

When we think in terms of timber quality, we usually consider one of two aspects: channeling the log, tree, or stand to its best end use or uses; or maximizing the total dollar value. These two may or may not be the same. But as our national supply of high-quality hardwood timber decreases, we must make better use of the resource; that is, we must allocate our timber supply more efficiently and find additional uses for those parts of the log or tree that traditionally were discarded as waste. To accomplish this we need classification and grading systems that can accurately measure the quality characteristics of trees and logs. Such systems aid in minimizing the biological variation inherent in a group of logs or trees by segregating the tree or its parts for specific uses and into various classes based on each use. Therefore, as Brisbin (1985) states, an accurate evaluation of quality is especially important in potentially high-value hardwoods where the differential in price between high-quality and low-quality end products is large.

The West Coast hardwood industry must either adopt the East Coast lumber and log grading rules, or modify them to fit their needs or requirements. For only through the use of such grading systems will you be able to define and measure the resource as well as design the proper mills to utilize it. Studies by the University of California's Forest Products Laboratory have shown that the USDA Forest Service hardwood log grade specifications (Rast et al. 1973) were suitable for use in segregating tanoak (Dickinson and Prestemon 1965), golden chinkapin (Prestemon et al. 1965), and Pacific madrone (Dickinson et al. 1965) logs into quality classes showing distinct differences on grade yield of hardwood factory lumber. Only California white oak (Dost et al. 1966) required modification of the USDA Forest Service standard grades for hardwoods. Probably additional studies in all species are needed since the number of logs in the individual studies ranged only from 53 to 93. Studies in the East normally had a minimum of 300 to 500 logs in each species sawn at several different mills.

For years, the attitude was that hardwoods were a weed species or a nuisance that just increased the cost of logging or reestablishing softwoods. This attitude must be changed as well as the attempt to try to harvest and saw hardwoods like softwoods; that is, 16-foot logs or to the closest 2 foot.

There have been conflicting reports on the quality and availability of hardwoods, particularly in the East, but the same is probably true for hardwoods on the West Coast. While some lament the decline in quality, others insist that the general quality is improving. Market conditions, coupled with availability, have a great influence on people's opinions. But as buyers and sellers of timber, there is one

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thing we can all agree on--that hardwood timber varies greatly in quality and value, not only within species, but also within geographic areas and individual stands.

USERS OF GRADING SYSTEMS

There are four groups who can benefit from an understanding of timber quality and a knowledge of grading systems (Brisbin 1985). These include timber managers, timber appraisers, loggers, and primary processors of forest products. Grading systems enable land managers and foresters to estimate the present and future value of individual trees in a stand. This allows them to make sound silvicultural and economic decisions on which trees to mark for cutting and which to leave. Also, timber management practices cannot be evaluated adequately without a means of measuring their effect on both the quality of the residual stand and the quantity of wood produced. And timber appraisers can use classification and grading systems to estimate the value of a tract of timber for purchase or sale.

Loggers obviously play an essential role in producing high-quality products from trees. The decisions that a feller makes during the felling, and especially bucking of a tree, can greatly affect the dollar return of the resulting end products. The following are some of the variables that the feller should consider in addition to bucking for grade (USDA Forest Service 1975):

1. Proper stump height. Unless rot is present, some of the highest quality wood is in the area of the stump. Not cutting at the proper height for a particular tree can cause a considerable loss in log volume and affect the grade of the log by lowering the diameter at the small end of the log.

2. Proper log length. Cutting a log shorter than the standard length or without proper trim usually means that the mill scaler will scale it as a shorter length log or reject the log. Excess trim also means a loss of volume in the other logs bucked from that tree. Log grade must be considered when discussing length since an 8-foot log cannot be grade 1 by USDA Forest Service grade standards.

3. Proper end cuts. Diagonal cuts on the end of logs lead to a reduction in the log length at the mill or an unnecessary loss of log length on subsequent logs in the tree.

4. Proper bucking for crook and sweep. By cutting to minimize crook and sweep, scale and grade can be improved. The best bucking position usually is at the point of maximum crook and sweep. Although a jump-cut (cutting out an unmerchantable section) will reduce total tree volume, sometimes this can be more than compensated for by an improvement in the grade of the log.

5. Proper placement of defects. After diameter, defects are the primary factor in determining log grade. The person bucking the log must consider defect placement during bucking, that is, try to place defects near the end of short logs and near the center or end of long logs.

Primary processors need grading systems not only to purchase raw material, but also to allocate logs to their best end use. Grading systems also are useful for estimating expected volumes of the different end products that a processor may produce from a given group of logs.

Finally, the use of grading systems helps owners and managers of private, nonindustrial woodlands determine the volume and value of their timber holdings. Such evaluations could result in a more productive use of these woodlands where timber production is compatible with owner objectives.

EVALUATING QUALITY

Englerth (1966), in his evaluation of qualitative relationships in wood utilization, states that only after end products to be produced are defined can timber quality be estimated, since product end use and performance requirements must be related to tree and wood characteristics. Most quality classification and grading systems in use today were developed using tree and wood characteristics that significantly increase their ability to predict actual volume and value of the desired end products.

As Brisbin (1985) states, relatively few tree and wood characteristics of a given species affect the end-use requirements of most products. The most important ones are:

1. Growth rate and bole form of the tree
2. Specific gravity
3. Knots and limb-related defects
4. Decay and insect damage
5. Size of tree

Slow and uniform growth of a tree is probably the most desired from the manufacturer's standpoint for processing and drying. Particularly in veneer, erratic growth causes problems in slicing and, more importantly, in drying. Abnormal growth also affects the grain pattern in both veneer and high-quality factory lumber. Abnormally fast growth affects the uniformity of chips, causing potential problems in such products as orientated-strand board and structural particle board. Crook or sweep in a tree affects its suitability for most solid wood products. It also affects volume recovery and increases harvesting and production costs. The strength of structural products as well as the yield of pulp fiber are adversely affected by low specific gravity. Growth rate, tree age, and specific gravity are all interrelated. Almost all solid or reconstituted products are adversely affected by knots, limbs, decay, and insect damage. Tree size, mainly diameter, is probably the most important quality indicator for most solid wood products.

Because wood is a biological material and no two trees are exactly alike, it is difficult to predict the exact effect that specific tree and wood characteristics will have on the end products. The primary purpose of quality classification and grading systems is to reduce this biological variation by segregating the tree or its parts for specific uses. The grades are a measure of quality. As such, they become the basis for nearly all processing decisions. Economics and market demand may determine the value of a particular grade for a given set of circumstances, but the wood characteristics alone should determine the actual grade (Brisbin 1985).

Specifically, quality classification and grading systems are useful for (1) classifying young growing-stock hardwood stands to relate present quality characteristics to future product potential, and (2) predicting the quality of trees and logs that have potential to be converted immediately into primary products.

HARDWOOD LOG AND TREE GRADES

Many grading systems have been developed and used over the years to facilitate the buying and selling of logs and trees. To be effective, a grading system must be developed from a carefully selected data base, provide consistent results, be easily understood and applied by a wide range of individuals, and predict accurate yields of end products. The Forest Service Standard Hardwood Log Grades meet all of these requirements. Approximately 20,000 logs sawed at more than 75 sawmills throughout the Eastern United States made up the data base for this grading system. The grading specifications are closely correlated with those for standard factory lumber grades (Cassens and Fischer 1978) published by the National Hardwood Lumber Association (NHLA 1982). The yields are expressed as a percentage of NHLA grade yields (Hanks et al. 1980). The grading factors to be considered in applying Forest Service Log Grades are (Rast et al. 1973):

1. Position of log in tree (butt or upper)
2. Log diameter
3. Log length
4. Number and location of grade-reducing defects
5. Amount of crook and sweep
6. Amount of cull (rot, holes, etc.)

Although the grading specifications seem complicated to the inexperienced log grader, we have found that most people learn the grades with a little practice. Also, there are several publications that can help the grader recognize defects (Marden and Stayton 1970; Shigo 1983; Rast 1982; Rast and Beaton 1985). Two of the more important conditions for learning to grade are practice grading and observing graded logs being sawed. Hanks et al. (1980) provided lumber grade yield tables by log grade and scaling diameter for 16 species and two groups of lowland oak species. By applying current lumber prices to the predicted yields, you can estimate the value of the lumber that can be sawed from the graded logs. Therefore, by deducting appropriate costs (logging, hauling, milling, etc.), you can estimate the value of a group of logs. Yaussy and Brisbin (1983) developed multivariate regression equations to predict expected board volume by lumber grade. This form is more compatible with computer applications.

Log grade systems are useful for determining board-foot yields, lumber grade recovery, and subsequent log value, but are awkward for estimating the quality of standing timber. Tree grades for predicting factory lumber yields were developed by Hanks (1976); yield equations were developed for northern red, black, white, and chestnut oak; red and sugar maple; yellow and paper birch; basswood; black cherry; yellow-poplar; and aspen. Tree grades, like log grades, group trees by high, medium, and low quality based on predicted lumber grade yields. Many of the same factors used in log grades also apply to tree grades--size, surface characteristics, straightness, and soundness. Since many of the steps used to grade a tree are used to determine volume, the added cost of tree grading during cruising is minimal.

Little work has been done on using log grading systems to predict veneer products. Each manufacturer's requirements usually depend on the customer's specification. Most company and independent log buyers have specifications that are tailored to meet a particular end product. As a result, it will be difficult to develop a standardized veneer grading system. Veneer log specifications have been published (Northern Hardwood and Pine Manufacturers Association 1976; Rast 1975), but do not include expected product yields for veneer. However, these grading systems can still be used by foresters, timber buyers, and timber sellers to estimate the volume of veneer in logs that meet general veneer specifications.

Because of changing market conditions and the species composition of many stands, emphasis is being placed on production and market acceptance of structural lumber from hardwoods. Denig et al. (1985) have completed preliminary work on log grades for estimating yields of structural dimension lumber from yellow-poplar sawlogs. Their modification of the existing softwood log grades provides statistically sound predictions of hardwood structural lumber. Since hardwood log grades for factory lumber are based on the amount of clear wood in the board, these grades are unacceptable for grading structural lumber because structural lumber utility is based on strength-reducing characteristics. For example, a board with a single large knot (whose diameter is less than one-third of the surface measure) may still qualify as an FAS board in factory lumber, but it may be unsuitable as a structural board. Grade and span tables are available for yellow-poplar framing lumber (Allison et al. 1985).

Although most hardwood log grading systems are based on the yields of one end product, namely factory grade lumber, most hardwood trees are suitable for conversion into two or more products. As an example, a white oak tree may be processed to produce fancy face veneer, stave bolts, high-grade lumber, special structural timbers, railroad ties, posts, or pallet lumber.

It is now possible to appraise hardwood timber for these multiple products by applying separate log grade product specifications individually to the sample tree. But research is in progress to develop multiproduct grading systems for sawtimber-size trees. Blinn et al. (1983) described a method for estimating the multiproduct value of hardwood timber stands that is based on making product suitability decisions about each sample tree in that stand. The measurements and estimates are then aggregated for the stand to calculate volume and value per acre for each potential product.

Yaussy and Sonderman (1984) developed a preliminary model for partitioning the total tree cubic volume into a maximum of four round product groups. The only measurements required to predict volume by product group are d.b.h., total height, number of limb-related defects in the butt 16-foot section, and an estimate of epicormic branch severity. The four product groups for which volume predictions are made are veneer logs, Forest Service grades 1 and 2 sawlogs, Forest Service grade 3 and construction grade logs, and fuel and fiber. The model demonstrates the feasibility of predicting product yields from several easily measured tree characteristics.

Information is available for all of the previously mentioned grading systems, and slide-tape programs are available that explain and demonstrate the use of both the hardwood log and tree grades, but one of the most effective methods of learning to apply hardwood log or tree grades is attending a grading workshop. In the East, these courses are offered by universities and through state forest organizations; hopefully as hardwoods become a more utilized resource on the West Coast, this will become a standard practice in your area.

QUALITY CLASSIFICATION FOR FUTURE PRODUCT POTENTIAL

Young hardwood growing-stock stands represent a large portion of the hardwood stands in the East. If we are to practice good timber management and economics, we need a system for predicting the future product potential of these young stands in which we plan to apply cultural treatments. Although considerable research has been conducted on the effect of timber management practices on tree growth rates, there has been only a limited amount of work on timber quality development. In dealing with medium- and high-value hardwoods, quality change over time is as important, if not more important, as growth rate.

No industry can be static and remain viable over a long period of time, and the forest products industry is no exception. As this industry changes, we can expect to see end-product specifications change as well as a competition develop for the limited forest resource used for end products. Therefore, a tree-quality classification system for young hardwood growing-stock trees must not be tied to specific current product specifications, but be more biologically descriptive of the tree.

Assuming that we have selected the appropriate tree characteristics, described them by an array of numerical values, and aggregated them for a given stand, it should be possible to interpret these at any point in terms of current or newly developed product standards.

Sonderman and Brisbin (1978) and Sonderman (1979) investigated different potential quality-related tree characteristics and examined their occurrence and variation in natural and culturally treated young stands. Dale and Sonderman (1984) and Sonderman (1984a,b) described the response of several tree quality characteristics in young hardwood stands to various levels of thinning treatments. This research showed that thinning treatments significantly affect the number and size of limb-related defects in the more valuable butt portion of hardwood trees. Thinning below the

B level (60 percent stocking) usually is detrimental because it stimulates epicormic sprouting and retards natural pruning.

Individual-tree growth and quality responses to intermediate thinnings are being integrated into comprehensive computer programs for many forest types. These programs allow users to study the effects of the type, timing, intensity, and frequency of thinnings on growth and quality development. For example, Dale and Hilt (1986) used OAKSIM (Hilt 1985a,b), an individual-tree growth and yield simulator for even-aged upland oak stands, to test various thinning strategies for oak stands growing on medium and good sites (black oak site indices 60 and 80, respectively). Results indicate that 80-year rotations are not feasible on medium sites because only a few trees are large enough (16 inches) to qualify as grade 1 trees, even if thinning is applied. Longer rotations are required. Thinning on good sites, however, can produce 20 to 30 grade 1 trees per acre at age 80.

These kinds of computer simulation studies can be run for a wide range of age, site, stand, and thinning conditions. This information, coupled with economic analyses, is extremely valuable for making long-term decisions on how to grow high-quality timber.

SUMMARY

We believe that most landowners are interested in increasing profits from their investment in forest lands. It may not be the prime reason for owning forest lands, but it is almost always compatible with other objectives if the proper management plan is selected and care is taken in selecting a logger. To achieve your goals, you must first be able to recognize and utilize the timber quality available by applying a grading and quality classification system. These can be used in appraisal, inventory, quality control, and mill design.

Obviously there are many factors to be considered in management strategies by landowners or managers, such as current and future prices, markets, landowner objectives, and transportation. However, if the combination of product yields that are physically possible from a stand of timber or group of logs can be predicted accurately, then all of the management and marketing alternatives can be evaluated adequately and informed decisions made.

REFERENCES

Allison, R.C.; Deal, E.L.; John, L.G. Grades, design values and span tables for yellow-poplar framing lumber. AG 351. North Carolina State Univ.; 1985. 11 p.

Blinn, C.R.; Sinclair, S.A.; Ek, A.R. A method for estimating the multi-product value of hardwood timber stands. For. Prod. J. 33(3): 49-54. 1983.

Brisbin, R.L. Quality hardwoods--what a forester needs to know. In: Proceedings of the 1985 Pennsylvania State Forest Resources Issues Conference. Pennsylvania State Univ., University Park, PA. 1985. (In press)

Cassens, D.L.; Fischer, B.C. Hardwood log grades and lumber grades: is there a relationship? FNR 84. Purdue University; Depart. For. and Nat. Resour. 1978. 4 p.

Dale, M.E.; Hilt, D.E. Thinning pole and small sawtimber mixed oak stands. In: Proceedings guidelines for managing immature Appalachian hardwood stands, 1986 May 28-30; Morgantown, WV. Morgantown, WV: West Virginia University Books 1986, 99-117.

Dale, M.E.; Sonderman, D.L. Effect of thinning on growth and potential quality of young white oak crop trees. Res. Pap. NE-539. Broomall, PA: Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture. 1984. 12 p.

Denig, J.; Wengert, E.M.; Brisbin, R.; Shroeder, J. Structural lumber grade and yield estimates for yellow-poplar sawlogs. For. Prod. J. 35(1):26-32; 1985.

Dickinson, F.E.; Prestemon, D.R. Tanoak log grades and lumber yield. No. 41. Univ. California, School of Forestry, For. Prod. Lab.; Calif. Forestry and For. Prod. Report. 1965. 4 p.

Dickinson, F.E.; Prestemon, D.R.; Dost, W.A. California white oak log grades and lumber yield. No. 43. Univ. California, School of Forestry, For. Prod. Lab.; Calif. Forestry and For. Prod. Report. 1965. 5 p.

Dost, W.A.; Dickinson, F.E.; Prestemon, D.R. California white oak log grades and lumber yields. No. 45. Univ. California, School of Forestry, For. Prod. Lab.; Calif. Forestry and For. Prod. Report. 1966. 6 p.

Englerth, G.H. Framework of qualitative relationships in wood utilization. Res. Pap. FPL-45. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1966. 17 p.

Hanks, L.F. Hardwood tree grades for factory lumber. Res. Pap. NE-333. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1976. 81 p.

Hanks, L.F.; Gammon, G.L.; Brisbin, R.L.; Rast, E.D. Hardwood log grades and lumber grade yields for factory lumber logs. Res. Pap. NE-468. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1980. 92 p.

Hilt, D.E. OAKSIM: An individual-tree growth and yield simulator for managed, even-aged, upland oak stands. Res. Pap. NE-562. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1985a. 21 p.

Hilt, D.E. User's guide to OAKSIM. An individual-tree growth and yield simulator for managed, even-aged, upland oak stands. Gen. Tech. Rep. NE-104. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, 1985b. 22 p.

Marden, R.M.; Stayton, C.L. Defect indicators in sugar maple--a photographic guide. Res. Pap. NC-37. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 1970. 29 p.

National Hardwood Lumber Association. Rules for the measurement and inspection of hardwood and cypress lumber. Nat. Hardwood Assn. Memphis, TN. 1982. 115 p.

Northern Hardwood and Pine Manufacturers Association. Official grading rules for northern hardwood and softwood logs and tie cuts. North. Hardwood and Pine Manu. Assn., Green Bay, WI. 1976. 17 p.

Plumb, T.R., Tech. Coor. Proceedings of the symposium on the ecology, management, and utilization of California oaks. Gen. Tech. Rep. PSW-44, Berekely, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 1979. 38 p.

Prestemon, D.R.; Dickinson, F.E.; Dost, W.A. Chinkapin log grades and lumber yield. No. 42; Univ. of Calif., School of Forestry, For. Prod. Lab.; Calif. Forestry and For. Prod. Rep. 1965. 5 p.

Rast, E.D. Preliminary hardwood log veneer grades for yellow birch and sugar maple face veneer. In: Proceedings 3rd Annual Hardwood Symposium. Hardwood Research Council, Cashiers, NC. 1975. 84-89.

Rast, E.D. Photographic guide of selected external defect indicators and associated internal defects in northern red oak. Res. Pap. NE-511. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1982. 20 p.

Rast, E.D.; Beaton, J.A. Photographic guide to selected external defect indicators and associated internal defects in black cherry. Res. Pap. NE-560. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1985. 22 p.

Rast, E.D.; Sonderman, D.L. Gammon, G.L. A guide to hardwood log grading. Gen. Tech. Rep. NE-1. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1973. 32 p.

Shigo, A.L. Tree defects: a photo guide. Gen. Tech. Rep. NE-82. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northerastern Forest Experiment Station. 1983. 167 p.

Sonderman, D.L. Guide to the measurement of tree characteristics important to the quality classification system for young hardwood trees. Gen. Tech. Rep. NE-54. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1979. 12 p.

Sonderman, D.L. Quality response of even-aged 80-year-old white oak trees after thinning. Res. Pap. NE-543. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1984a. 6 p.

Sonderman, D.L. Quality response of 29-year-old even-aged central hardwoods after thinning. Res. Pap. NE-546. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1984b. 9 p.

Sonderman, D.L.; Brisbin, R.L. A quality classification system for young hardwood trees--the first step in predicting future products. Res. Pap. NE-419. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastrn Forest Experiment Station. 1978. 7 p.

U.S. Department of Agriculture, Forest Service. How profits are left in the woods. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeast Area, State and Private Forestry. Information Leaflet. 1975. 5 p.

Yaussy, D.A.; Brisbin, R.L. Multivariate regression model for predicting lumber grade volumes of northern red oak sawlogs. Res. Pap. NE-536. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1983. 11 p.

Yaussy, D.A.; Sonderman, D.L. Multivariate regression model for partitioning tree volume of white oak into round-product classes. Res. Pap. NE-317. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1984. 4 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Cal Oak—Staying Afloat in the California Hardwood Lumber Business[1]

Richard Wade and Guy Hall[2]

Abstract: Cal Oak Lumber Company of Oroville, Calif., has operated for 21 years as the state's largest manufacturer of goods made from native California hardwoods. The Company's history and current operations are described to illustrate two decades of evolution in the utilization of California hardwoods. Problems and opportunities in producing and marketing lumber, firewood, and pulp chips from seven hardwoods indigenous to northern California are outlined. Changing market conditions for these products has caused Cal Oak to revise production goals and strategies, to improve manufacturing techniques, and to attempt to expand the uses of and markets for native hardwood products.

The prospect for success in manufacturing lumber and other products from California's native hardwoods does not rest entirely upon such technical aspects as having an adequate raw material supply, or the suitability of the wood for making lumber. Assuming that these conditions are given, the manufacturer must also be able to produce quality goods with economic efficiency, to compete with more established species in hardwood markets, and to be responsive to changing and emerging markets.

Cal Oak Lumber Company of Oroville, Calif., has taken the step from simply recognizing the potential uses of California hardwoods to actually utilizing the resource in the manufacture of an array of products. Having met for 21 years the above criteria for survival, Cal Oak stands as an example of durability and longevity in a business most noted for its failures.

The experience of Cal Oak will serve here to illustrate many practical aspects of large scale, diversified utilization of the native hardwood resource. In this discussion, I will first briefly relate Cal Oak's history as it reflects an evolution in the utilization of the native hardwood resource. The current market conditions for California hardwood products will be described from Cal Oak's perspective. I will then outline Cal Oak's recent efforts to remain competitive in these markets through changes in production strategy and end product outputs, and through innovation in the use of native woods.

In conclusion, general characteristics of the California native hardwood business and some elements necessary for a firm's successful venture into this arena will be identified.

HISTORY

Cal Oak Lumber Co. was begun in 1965 by forester Guy Hall, who entered into a joint venture with a local sawmill operator to move and redesign an existing sawmill to cut oak in Oroville, Calif.

At that time, there was little utilization of native hardwoods for any purpose. Considerable knowledge had been gained by researchers indicating the potential suitability of California hardwoods for lumber, but such conclusions had been largely untested outside the laboratory. Isolated, large scale processing of hardwoods had occurred over the years, with the use of tanoak (Lithocarpus densiflorus) for flooring and of other hardwoods for lumber, but there was no ongoing hardwood-based industry. In the Sierra, many forestland managers, primarily public, saw the loss of conifer growth due to hardwood competition, and actively pursued the trees' destruction by poisoning and girdling.

Early Utilization by Cal Oak

Most of the lumber sawn during Cal Oak's early years was sold as pallet shook. Then, as now, the primary species was California black oak (Quercus kelloggii), although irregular cutting of tanoak, madrone (Arbutus menziesii), valley oak (Quercus lobata), sycamore (Platanus racemosa), and other species occurred. Recovery of upper grade boards was not a primary goal, although some were sold as rough, green FAS grade. At this time, only the clear main bole of large, sound and straight trees was brought to the mill, and all limbs were left in the woods. Mill residues were disposed of by burning.

Emerging Markets

During the 1970's, market conditions and improvements in processing technique allowed diversification into products other than industrial grade lumber. These factors included a.) an increasing demand for firewood and for pulp quality wood chips for export; b.) a growing ability by Cal

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, California Polytechnic State University, San Luis Obispo, Calif.

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Oak to produce and sell kiln dried, surfaced lumber from many native species, including short, clear boards recovered from pallet cuttings; and c.) an end to the burning of mill wastes, forcing Cal Oak to find other means of disposing of residues.

In light of these developments, Cal Oak made several major changes.

The Mini Mill--To increase lumber production and recovery to meet market demands, a second "mini" mill was designed and built. While the original mill, refitted with a bandsaw headrig, continued cutting large logs up to 16 feet long, the "mini" mill sawed logs from crooked boles and limbs to make pallet shook and short clear boards. It also employed a bandsaw headrig to reduce the residue and greatly increased the utilization of an individual tree.

In 1972, a pallet line was built capable of producing some 1200 pallets per day. This was a first step to diversify into secondary manufacturing and achieved a modest vertical integration.

Slabs and ends from the mills were diverted from the now obsolete teepee burner, cut to length, dried, and sold as firewood. The first boxed firewood product was introduced by Cal Oak in 1976, utilizing this slabwood as a portion of its contents.

In 1974, the "big" mill was sold. The "mini-mill" had been modified to saw logs to 54" in diameter, and 40" to 8 feet long, so as to recover both upper grade and pallet lumber. A new chipper added to the "mini-mill" to process either its residues, or to chip whole logs independently of the mill's operation.

A detailed history of the Company and its makeup by the late 1970's is in Cal Oak's report to the 1979 Oak Symposium at Claremont (Hall and Allen 1980).

CAL OAK TODAY

Cal Oak in 1986 can best be described as an integrated hardwood processing facility. Facilities include the sawmill, which still uses the carriage system to cut short logs, Kockums chipper, lumber remanufacturing facilities such as a cutup/rip line, resaw, and new equipment to produce decorative boxes, wood splitters, and a firewood packaging line, plus warehouses for firewood and lumber storage.

In 1985, about 50,000 tons of logs were procured. Sawmill output included the production of 3.3 million board feet of lumber, of which 1.4 million was upper grade (#2 Common & Better), 5,000 tons of pulp quality wood chips, and 5,000 tons of sawdust and other residue. Approximately 10,000 cords of firewood were inventoried and/or processed, ranging in form from logs to a fumigated box of kindling.

In retrospect, there has been a constant evolution of the type and relative amount of goods produced at Cal Oak, a reflection of their ability to create and develop a niche for native species in hardwood lumber markets, while diversifying production to capitalize on opportunities in the markets for firewood and pulp chips. As markets grew and hardwood products became more diverse, it became increasingly important to allocate incoming logs and to adjust production to outputs which would maximize returns relative to production costs. While overriding factors such as limited investment capital, raw material availability, technical limitations or advancements, and litigation have influenced product output at Cal Oak, it is the relative market values of hardwood lumber, firewood, and pulp chips which have largely dictated the mixture of outputs.

CURRENT MARKETS

The following section describes, from Cal Oak's perspective, the current standing of native hardwood products in the markets for hardwood lumber, firewood, and pulp (or fuel) chips. For each end use, Cal Oak's recent attempts to remain competitive in the market will be identified.

The Hardwood Lumber Market

Furniture, flooring, millwork, pallets, timbers, and ties are a few of the many end uses of the approximately 83 major commercial hardwood species growing in the United States (U.S. Forest Products Laboratory 1974). In 1985, production of hardwood lumber in the United States was about 6 billion board feet, most of which was produced east of the Mississippi River. Industries which utilize high grade domestic hardwood lumber are largely oriented by history and tradition to the use of eastern lumber species, with a few exceptions, such as red alder (*Alnus rubra*). This is true even of hardwood lumber consumers in California, which in 1982 ranked second only to North Carolina in the U.S. furniture industry by value added by manufacture (Hoover 1986).

From Cal Oak's standpoint, the market for native hardwood lumber is divided into 2 broad categories; that which is used for furniture, flooring, moulding, and other high end uses, and that for industrial uses such as pallets, dunnage, and timbers.

The Upper Grade Lumber Market

Within Cal Oak's procurement area, about a 120 mile radius from Oroville, grow 7 species from which upper grade lumber is recovered by the Company. These include California black oak, valley oak, California sycamore, black walnut (*Juglans hindsii*), Fremont cottonwood (*Populus fremontii*), tanoak, and madrone. All are kiln dried, surfaced, and graded according to National Hardwood Lumber Association grading rules or to specifications developed by Cal Oak for short lumber.

The major characteristics which dictate the marketability of each species is a.) its substitutability for lumber of eastern hardwood species in the marketplace, b.) the degree of difficulty in producing a quality board or adapting the wood to a given use, and c.) the availability of the raw material in consistent volume.

Impediments to Marketing of California Natives--Despite any inherent qualities of these woods, and Cal Oak's ability to routinely produce quality lumber, the sheer size and diversity of the eastern hardwood industry is a great advantage to eastern manufacturers. For example, many secondary manufacturers are reluctant to promote a product line utilizing a native species when there are so few producers of that lumber. The limited production of western hardwood lumber severely limits the variety of lumber dimensions available. The many eastern producers, each striving for a niche in the market, ensures that a broad range of thicknesses, widths, and lengths of eastern hardwood lumber is available.

Despite transportation costs to the West Coast, lumber prices of eastern species comparable to western natives are often extremely competitive here. Although Cal Oak's production capacity is similar to that of an eastern hardwood sawmill, middlemen in the east often consolidate the production of many mills to increase the efficiency of kiln drying, grading, marketing, and transporting lumber (Hoover 1985).

There is a lack of matching products for native California hardwoods, such as veneers and moulding stock. Although complementary products can be found, this deters many manufacturers who use such components from using California natives.

Many early attempts at making lumber from indigenous woods were poorly done, resulting in lumber which was not properly dried, and thus tended to warp or check while in service. Some residual prejudice is found for that reason.

Advantages of California Species--Notwithstanding these general impediments to marketing California natives, there are obvious advantages to the California producer, including low transportation costs to local markets, better customer service, and the ability to sell smaller quantities at wholesale. The unique appearance and lumber quality of each California species is the major selling point.

Status of Individual Species

The following is a brief description of the current status of the upper grade lumber of the 7 species milled at Cal Oak:

California Black Oak--This species produces a red oak lumber which is the mainstay of Cal Oak's operations, about 80 percent of the Company's annual upper grade production. Red oak lumber, produced from at least a dozen eastern oak species, is preeminent in American furniture and woodworking industries. Lumber from California black oak, while closely resembling Appalachian red oak in some logs and Northern red oak in others, has superior machining qualities and a tighter, distinctive grain pattern with more figure which make it desirable for many uses. Current major buyers of black oak lumber are woodworking and cabinet shops, building contractors, and hobbyists, using the lumber for furniture, cabinets, boxes, and other applications.

Raw material is available in good quantity and careful processing makes technical problems with the lumber very rare. As will be discussed further, Cal Oak is expanding the application of this lumber to flooring, paneling, and doors.

White Oak--An attractive, very durable white oak lumber is cut from the valley oak, which compares favorably with and is easily substituted for its eastern counterparts. However, the lumber is produced in small, irregular quantities due to limited raw material. Valley oak presents a variety of challenges in all phases of lumber manufacturing, including a propensity for fungal stain in the lumber, and a tendency to collapse while drying.

Because of its generally high quality and Cal Oak's success in controlling these problems, much more native white oak lumber could easily be sold than is produced.

Sycamore--Lumber of good quality is produced from this species, with few technical problems. California sycamore lumber is easily substituted for eastern sycamore and is in modest demand for drawer sides and for woodworking. As this is a riparian species and logs are seldom generated, the supply of the lumber is erratic. Since whatever is sawn at Cal Oak is usually quickly sold, there has been little effort to expand the uses and markets for sycamore.

Black Walnut--The market for material from this species, including gunstock blanks, and burls and veneer bolts for export, is very lively the State. Lumber from California species closely resembles eastern walnut, although the color is often more varied. Sources of logs, including orchard grafts, old plantings along roads and around homes, and riparian areas, all offer difficulty in obtaining raw material for lumber, so quantities produced at Cal Oak are modest. The grade recovery in lumber is often low due to poor logs from open grown trees.

Fremont Cottonwood--When sawn, this species produces lumber which, while not having the strength characteristics of dense hardwoods, is often laced with birdseye and other attractive grain patterns. Characteristics which impair its marketing for upper grade uses are several, prominent of which is the tendency for torn grain. The lumber has limited substitutability. The supply of raw material is limited to some degree due to its riparian nature.

Since Fremont cottonwood mill residues and low grade logs have little value for firewood, the successful sawing is especially dependent upon a strong market for the pallet shook invariably generated, even when sawing for upper grade. The absence of a strong demand for pallet lumber made this species impossible to cut profitably in 1986.

Tanoak and Madrone--These species, while differing in appearance and wood characteristics, are similar to one another in their current utility and marketing strengths. Although difficulties in lumber manufacture are inherent, due to tree form and wood characteristics, Cal Oak routinely produces quality upper grade lumber from them. Tanoak and madrone are not immediately substitutable for eastern species; however, favorable characteristics indicate that each can become a major commercial species. Madrone has an attractive and unique appearance, outstanding machining properties, and is durable. Tanoak is very stable when processed properly, has excellent strength, and an oaklike appearance.

The availability of raw material is not a serious limitation. The major current use of upper grade tanoak and madrone lumber cut by Cal Oak is for furniture, and their use for flooring is increasing.

The Low Grade Lumber Market

Equally importance to California hardwood lumber producers is the market for low grade lumber, consisting of shook for pallets, timbers, dunnage, and other industrial uses where strength, not appearance, is needed. By nature, California hardwoods yield a high percentage of low grade lumber due to poor tree form and the high incidence of knots and such defects as rot and shake. Irrespective of the production goals, this low grade lumber will always be a significant portion of output.

Over the past several years the market for pallets and shook has been unfavorable. In the late 70s, large grocery retailers came to accept pallets using red alder, previously felt too weak for exchange pallets. Although alder pallets are still considered inferior by industry standards, demands for the more durable, yet more expensive, California oak and tanoak pallets has suffered. In a pallet exchange system, the ownership of an individual pallet soon is impossible to discern. Therefore, the manufacturer has little incentive to buy a more expensive and durable oak pallet.

Under these conditions, Cal Oak has had difficulty selling pallets and shook at a profit.

Cal Oak's Response to Market Conditions

From the mid 70s into the 80s, Cal Oak's strategy was to saw black and white oak to recover upper and lower grades, while tanoak and cottonwood and madrone were sawn mainly for pallet shook, with upper grade recovery minor. Upper grade lumber was sold to small secondary manufacturers who could efficiently cut their required dimensions out of Cal Oak's basic product. Recovery of pallet shook was desired for use in Cal Oak's pallet line and for sale in a relatively strong market.

In 1984, the slump in the oak pallet market and lack of growth in upper grade sales led to major changes. In an attempt to increase the economic viability of lumber production, goals were set to lower production costs, reduce the output of industrial grade lumber, and increase the value and demand for upper grade lumber products.

Production Changes

Prior to 1984, Cal Oak had operated 2 mill shifts, largely milling low grade logs which yielded mostly pallet grade lumber. In April 1984, 1 mill shift was eliminated, and sawlog quality standards upgraded. Log grade sawlogs were now split for firewood. This new strategy resulted in a decrease in the recovery of low grade lumber, with a corresponding increase in upper grade yield. Lumber production per shift increased by almost 50 percent.

The increasing value of firewood during this period aided in the change, for those logs no longer considered sawlogs could now be split profitably.

In 1985, after 10 years of building pallets, the pallet assembly line was shut down and later dismantled. In its place, a resaw was installed to improve grade recovery and sawmill production. A planer was added to surface upper grade lumber.

The Door Program

In 1984, Cal Oak was approached by a large door manufacturer to provide the material for a rail-stile door made almost entirely from California black oak. By 1985, most of Cal Oak's upper grade production was earmarked for that purpose. In order to provide the many parts needed to assemble the variety of sizes and patterns of doors, a cutup/rip line was installed, where defects are "chopped out" of standard lumber to produce smaller, clear boards cut to a specific dimension.

New Uses for Black Oak--With this door program came innovations. Specially cut oak boards were sliced into veneer by the door manufacturer. This veneer was adhered to an engineered pine core to produce the stile and rail components of the door. After trial and error with gluing procedures, glued solid oak panels were mass produced to become the solid panel portion of the door.

Edge band and ovolo was sawn to complete the door components. In addition, all parts such as jambs, casing, and moulded trim, were to be supplied by Cal Oak. Cal Oak experimented with different cut patterns to find the most attractive and stable.

Results--From a technical standpoint, the program to enter the door market with California black oak was successful. It was a "natural", seizing the positive characteristics of the species, while minimizing the negative influence. However, factors unrelated to the properties or acceptance of the oak, nor to Cal Oak's performance, have since curtailed this program.

In this instance, the reliance of Cal Oak upon the commitment of one large customer, and the use of large amounts of capital resource and production in expectation of fulfillment of that commitment, proved to be highly deleterious. Cal Oak, while resolving to avoid new "eggs in one basket" situations, has had to find ways to reduce the negative impacts of the curtailment of this program.

Expansion of the Product Line

Over the last 3 years, Cal Oak has made many efforts to extend the use of native hardwoods to products which have a higher end value than lumber, or which complement the lumber and increase sales by meeting the more complex material requirements of secondary manufacturers and builders.

Rotary Cut Veneer--An experiment to produce rotary cut veneer from California black oak was initiated in the summer of 1985. Logs were chosen for their apparent suitability to be rotary cut and shipped to an Oregon veneering plant. They were peeled without any problem attributable to wood properties or log form. The veneer slices were sorted and glued both to a medium density fiberboard core and a plywood core.

The operation was generally successful, but the grade recovery and corresponding value of the veneer was not sufficient to continue on a regular basis. While this attempt to create a veneer product which would complement black oak lumber failed on economic grounds, we have found that certain substitute veneers are quite compatible with California black oak lumber, when juxtaposed in furniture or cabinets.

Flooring--Although black oak, madrone, and tanoak have desirable characteristics for flooring, and have been used for that purpose, the availability of flooring from these species has been sporadic. As a result, the consistent use of and demand for native hardwood flooring has never developed.

Since 1984, Cal Oak has had flooring manufactured by contract from blanks cut at Cal Oak, making these products consistently available in the product line. Offsite millwork is costly, but the manufacture and selling of flooring allows Cal Oak to utilize short clear cuttings and narrow width boards generated by its cutup line, and to provide a product which complements and increases sales of its lumber. Since tanoak and madrone are well suited for flooring, there is the potential that sales of these species can increase substantially.

Native hardwood flooring products now face serious price competition from eastern oak and other species.

Paneling--Cal Oak has experimented extensively with different patterns, widths, and thicknesses for paneling and wainscoting, and has brought into its product line black oak wainscoting and paneling, manufactured under contract from blanks cut at Cal Oak. With the increasing importance of flooring and paneling, and to reduce manufacturing costs, a moulding machine will be installed in the spring of 1987.

Varying Thicknesses--The difficulty of kiln drying native California hardwoods increases greatly with increasing thickness of the boards. Until recently, Cal Oak's upper grade production was largely 4/4 lumber. Since furniture manufacturers need a variety of thicknesses, particularly 5/4, 6/4, and 8/4, this impaired the marketing of Cal Oak lumber. By mid-1986, the kiln drying of black oak boards of these thicknesses with acceptable losses was achieved through experimentation with kiln schedules. This increased variety of available thicknesses may let Cal Oak more competitive with eastern oak suppliers.

Secondary Manufacturing

The Wood Box--In 1986, Cal Oak launched a program to produce and sell a box made entirely from California black oak, designed specifically to complement Cal Oak's boxed firewood. Materials are supplied largely from #1 and #2 Common black oak lumber, cut and ripped to eliminate unacceptable defects and to create the different components.

The intent of the wood box program is to integrate vertically and to diversify products, thereby using part of the production capacity created for Cal Oak's role in the door program. Also it hopes to create an internal demand for dimension stock without depending on performance by others. In producing the wood box, less desirable upper grade lumber which often does not sell well can be cut up and utilized, while creating an attractive complementary product to enhance the sales of Cal Oak boxed firewood products.

The wood box program has recently been expanded to include other types of decorative boxes, such as for wine, electronic accessories, and planting boxes.

The Market for Firewood

The growth in California's firewood consumption since 1974 is well known, although estimates of annual consumption vary. An analysis of California markets by Doak and Stewart (1986) notes that while native hardwood firewood is a premium commodity, it is minor in the total consumption, and substitute woods have entered the market as native hardwood prices have risen. A study of Bay Area trends by Gasser and Stewart (1985) indicates that overall demand may be stabilizing or declining, and that factors such as rainfall and consumers' perception of energy costs influence annual consumption.

Cal Oak's production and sale of firewood, once simply a means to be rid of residues and substandard logs, has grown with demand, and is now an integral and substantial part of the Company's business. Logs are actively procured to provide material for boxed firewood products, for splitwood sold in bulk, and for local retail sales.

Cal Oak's View of the Market

Prior to these recent analyses of firewood markets, Cal Oak has had to draw conclusions about market characteristics and make marketing decisions based upon observation and experience. These conclusions are as follows:

Consumer Objectives--The objectives of the California firewood buyer range from those depending entirely upon wood for heat to those enjoying the fire's aesthetic benefits. The latter consumer's concept of wood is as a convenience or luxury item, and cost has less interest or meaning to him.

Local Markets--Consumer choice on firewood type varies geographically, with the preference for hardwood firewood strongest in the Bay Area, Central Valley, and Sierra foothills. Buyers close to a wood source, particularly in rural areas, tend to buy the local wood is available, regardless of species.

Wood Quality--Consumers will pay a premium for wood that is dry, clean, and of good measure, rather than spend less for an unknown commodity.

Continuing Demand--Cal Oak has presumed a growing demand for native hardwood firewood. Consumption by urban, convenience oriented buyers is presumed less related to economic factors, such as the cost of wood stoves or other heating fuels, than is consumption by utilitarian wood users.

Response to Markets

Cal Oak's marketing strategy is to stress sales to urban consumers who purchase for convenience and aesthetics, while using less effort in selling wood for heating. Cal Oak's boxed firewood products are designed primarily to meet this urban demand.

Boxed Wood--Cal Oak's first boxed firewood product, made in 1976, was a 1 cubic foot mix of split oak wood and slab mill byproduct cut to length. The success in selling the box in grocery stores was a marketing breakthrough, since firewood sold by conventional means is messy and difficult to handle. The box provided a clean, easily handled product, simple to distribute and sell.

The boxed firewood market has grown to be very competitive. Adjustment and upgrading of the product line is a constant necessity, and Cal Oak currently has several sizes and types of product available. Marketing chores have in part been contracted to professional food brokers well versed in the arcane protocol of the grocery business.

Processing Considerations--The efficiency of the splitting operation is very important, due to steady increases in the costs of raw material, labor, and insurance. Cal Oak's method of buying raw material in log form requires conventional logging methods, and a part of the log, purchased by weight, becomes splitting residue with negative value. Both logs and split wood must be stored, which is costly. Thus, Cal Oak's material costs are higher than firewood producers who process firewood where trees are cut.

Cal Oak has attempted with only moderate success to make splitting more efficient with less waste, and to capture whatever waste is generated. This is one of the weakest aspects of our firewood business.

The Market for Chips

In the last 10 years there have been 3 major uses for pulp quality hardwood chips. Exporters buy both hardwood logs and chips for sale in the Far East. Domestic paper manufacturers use softwood chips, but buy some hardwood chips for specific uses. Recently, biomass energy producers have desired clean, burnable mill residues, including chips.

The current demand for pulp quality hardwood chips is low, and no major changes are expected. Although some exporting of hardwood pulp chips occurs regularly, there is no export demand for hardwood chips within Cal Oak's operating area. For several years, the Louisiana-Pacific paper mill in Antioch has used some hardwood chips, most recently eucalyptus. The demand for mill residues to fuel biomass powered energy plants grows incrementally with each new plant.

Cal Oak's Response--Cal Oak can produce chips both from mill residues and from small whole logs, independent of sawmill operation. From 1978 and 1981, whole logs were chipped in response to high export demand. Since 1981, the value of split firewood from a given log has been greater than that of chips from that log. Cal Oak makes chips only from mill residues and from parts of logs which cannot be manufactured into a firewood product.

Since 1985, a biomass fueled power plant in Oroville has been buying Cal Oak chips for fuel, providing an alternative to the sale of chips to the Antioch paper mill. The relatively low value of either use has made transportation costs the deciding factor in the end use of this material.

Efforts to market the hardwood chips in different ways have been minimal but do offer promise. Some potential uses for the hardwood chips include garden products, a mushroom growing medium, and barbeque fuel.

Other Byproducts--Cal Oak produces about 25 tons of sawdust and shavings from milling and planing operations each day. This material is currently sold to the nearby biomass fueled plant in a mixture of sawdust and chips. Some minor volumes are sold as mulch and as bedding for stables. As with the wood chip, other efforts to market this material have been few.

SUMMARY

Since its inception, Cal Oak has both reflected and facilitated a broad diversification of uses for native California hardwoods. The Company's evolution, from pallet shook mill to long term producer of high grade hardwood lumber and supplementary products, is the result of a striving to attain the highest value product from native woods, while making the sale of low value products and byproducts viable.

Recent actions by the Company have strengthened this trend. Major changes in production and manufacturing ability have favored high value outputs, such as dimension stock for hardwood doors, over low value products, such as pallets. Since 1984 concerted efforts have been made to increase the marketability of lumber products by providing a variety of lumber dimensions, black oak plywood, glued panels, and moulded products. An expanded use of oak, tanoak, and madrone for flooring and paneling has been accomplished.

The diversification of manufacturing capability and increasing vertical integration is likely to continue at Cal Oak. Improving the efficiency of production and increasing the physical recovery of residues and the end value of low grade products and byproducts will also be of high priority.

CONCLUSION

Cal Oak's experiences provide a unique opportunity to examine the practical aspects of large scale, multiple product utilization of native California hardwoods, and to draw conclusions regarding the nature of that enterprise.

The technical and economic feasibility of producing lumber from California hardwoods is well proven. However, there are few traditional applications for these woods. When marketing native lumber products for a given use, eastern lumber products usually must be displaced in the marketplace.

To compete with suppliers of traditional species, the California hardwood lumber producer must attempt to upgrade and diversify the product line so that the full range of products necessary for commercial applications is available to secondary manufacturers.

Over the long term, there have been large changes in the values of native hardwood lumber, firewood, and wood pulp chips. California hardwood processors must observe changes in the values of these and all other products potentially derived from native hardwoods, and must modify output of products to minimize losses or to gain new revenue sources.

The aggregate value of all the end products yielded from an operation like Cal Oak's is low. While some upper grade lumber and firewood production may be profitable, many of the products yielded are currently sold at a loss. The value of each product attained must be maximized.

A given hardwood log must be properly allocated to that use which will maximize the ratio between the value of the products derived and the cost of processing.

REFERENCES

Doak, Sam C.; Stewart, Bill. A Model of Economic Forces Affecting California's Hardwood Resource: Monitoring and Policy Implications. Department of Forestry and Resource Management, University of California, Berkeley; March 1986; 148 p.

Gasser, Donald P.; Stewart, Bill. Market Dynamics of Bay Area Firewood, in: Proceedings, Fuelwood Production Conference. University of California, Santa Cruz; June 22, 1985; 41-46.

Hall, Guy H.; Allen, Richard. Wood Products from California Oaks, Cal Oak Lumber Company Style, in: Proceedings of the Symposium on the Ecology, Management, and Utilization of California Oaks. Pacific Southwest Forest and Range Experiment Station General Technical Report PSW-44. November 1980; 362-368.

Hoover, William L. Structure of the Hardwood Lumber Industry, in Department of Forestry and Natural Resources Bulletin #180. Purdue University. May 1985; 22.

Hoover, William L. Indiana's Forest Products Industry--Comparative Status as of 1982, in Department of Forestry and Natural Resources Bulletin #183. Purdue University. January 1986; 26.

U.S. Forest Products Laboratory. Wood Handbook: Wood as an engineering material. USDA Agricultural Handbook 72. 1974.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

California's Hardwoods--What Potential?[1]

Kenneth L. Delfino[2]

There is one thing that I have learned at this conference during the last 2 days. I have had a misunderstanding about hardwoods for the last 25 years. I always thought that the term "hardwoods" and "softwoods" referred to the relative characteristics of the wood. That does not appear to be true. I found out over the last 2 days that the "hard" in "hardwood" means something else completely. It is "hard" to grow' it is "hard" to sell; it is "hard" to count the rings and it is "hard" to get any consensus on how to manage hardwoods.

I would like to discuss tonight a couple of subjects that California Department of Forestry and fire Protection is becoming involved in and some initiatives that we are taking in marketing and utilization.

We have heard a lot about marketing in the last couple of days. The Forest Service, U.S. Department of Agriculture, had an item in their budget for fiscal year 1988 for about $5 million for a marketing effort. Unfortunately, it died in the final conference committee. They were given $100,000 to work with National Forest Products Association and came up with a marketing program.

Although this program is not specific to hardwoods, it will have some spin-off benefits. Regardless of the loss of the Forest Service funds, CDF is undertaking a major effort. Under our California Forest Improvement Program, we are currently working on a marketing program. We just completed the first phase with a report by the Sierra Resources Consulting Group entitled, "Marketing California's Forest Product." The primary objective of that study is to identify ways in which CDF can assist the California Forest Products Industry to increase sales and profits, hence to bolster economic development in the State's.

The project has three key elements. The first is an identification of the existing and potential markets for California's wood products. The second is the identification and assessment of the way in which CDF could productively involve itself in marketing. The third is the identification and documentation of the detailed steps for implementing the most promising programs identified in the first two steps. A coordinated statewide effort in a marketing program for certain of the State's forest products could produce some substantial benefits for the forest products industry in the State's rural areas. The are specific opportunities for export markets which we are investigating. I recently learned that the State of Washington has a major marketing effort called the Evergreen Partnership. It's a cooperative effort among state government, private industry and others, and they are very optimistic that the marketing effort will provide substantial benefits for the State of Washington. You can assume that the State of Washington would like to get into our markets. So if other states are getting into this process, I think California must do likewise to remain competitive.

Our first major activity under this marketing program is a symposium which will be sponsored by CDF on March 16, 1987, in Sacramento. This marketing effort is not designed specifically for hardwoods. It incudes all forest products. But I guarantee that after this symposium and with some of the things were have learned and heard here is these 3 days, we will be making some major efforts in the hardwood area as part of that marketing program.

The second initiative I want to talk about is utilization. We have several excellent papers this afternoon on the various problems involved with utilization.

Both of the keynote speakers, Harold Walt and Zane Smith, made reference to utilization. Zane Smith said that hardwoods were hard to mill. Hal Walt said that hardwoods were hard to dry. Both of these statements are true when we are dealing with a softwood mentality that currently exists on the West Coast. However, I contend that neither of those statements are necessarily true about eastern hardwoods. Hardwoods in California represent different kinds of challenges, but the technical issues are probably no more complex than those of the east. I think that was affirmed by some of the speakers we heard this afternoon in the utilization session.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

[2]Deputy Director, Resource Management, California Department of Forestry and Fire Protection, Sacramento.

The Board of Forestry has been looking at the hardwood issue for several months before this symposium. During the Board of Forestry field trips, we learned that hardwoods, in some areas, are not being managed properly. Part of the reason that I think we have seen some of the misuse or possible abuse of hardwoods is that they have as relatively low economic value. The same thing happened to softwoods in the early part of this century in California, particularly Douglas-fir. When a forest product or any kind of a natural resource product has a relatively low value, there is not a great deal of respect for its value and consequently the use or misuse of the resource can take place. There is no great incentive to manage or grow it because it has marginal value. Some of the activities we see in the foothills of the Sierra where hardwoods were being cleared is due to this low value. Hardwoods were incidental to other land management objectives. The premise is that if these hardwoods had higher value, they would be better managed. If the hardwoods had an intrinsic or economic value, landowners would manage those woods. One of the purposes of our utilization and marketing programs is to bring the values of those hardwoods up high enough so that they could be managed.

I believe that East and Midwest had some of the same problems. Probably 50 or 60 years ago, their hardwoods were considered low value. They developed techniques, markets, and processing, and now have high value products. You certainly don't see them treating their hardwoods as we treat many of ours. In California, most of our madrone and tanoak stands in the conifer hardwood forest are not being utilized. Some outstanding trees are being pushed over, cut, poisoned or otherwise destroyed. They are viewed as a weed specie because our foresters have a softwood mentality. Landowners have the softwood mentality and they don't realize that there may be some potential value in those woods.

To prepare for this talk, I did some extensive market research. Before coming to San Luis Obispo on Tuesday, I stopped at our local Lumberjack store. They have three native American species of hardwood in their lumber rack: red oak, birch, and red alder. The red oak and birch I would assume came from the East and Midwest. The red alder, I assume, came from the Pacific Northwest.

This extensive nonscientific marketing survey came to a very dramatic conclusion. Red oak, in the Lumberjack store, sells for $3,500 to $4,000 per thousand board feet. Birch sold for $4,200 per thousand board feet. The alder, that species that we try to kill, was selling for $1,600 per thousand board feet. I looked a the rest of the lumber racks. They had redwood, pine, fir, and all kinds of other softwood species. The three hardwood species, disregarding the mahoganies and some exotics, were the highest priced pieces of lumber in that entire store. I believe that our California hardwood species could command these prices if marketed properly. The average buyer would purchase California black oak, or other hardwood species, if they were available. They would probably even buy tanoak and madrone if the price was right.

To make my point, I'd like to use a few statistics out of a report done by Bill Sullivan of Humboldt State University in a report entitled, "The Economic Potential of Tan Oak Timber in the North Coast Region of California."

The report does two things. First, deals with the quality and quantity distribution of tanoak logs and lumber in the north coast; second it represents an overview of the economics of the hardwood industry in the State on Michigan for comparison to what could occur potentially in California. I know many of you would say that there can be no direct comparisons between Michigan and what might occur in California because there is no comparison between the woods or the economic conditions. There are significant differences but the potential for some of the species in California is great. The real difference between softwood and the hardwood industry in California, according to Sullivan, is the magnitude of the added value of the product. A dry surfaced softwood board leaves the region, wherever it's harvested and milled, as a final product. A dried surfaced hardwood board is a raw material for future manufacture which could be done within the region where it is grown and originally milled.

As we heard yesterday, California is the second largest furniture manufacturer in the United States. Most of that industry is in southern California because there transportation into California is the cheapest for all the wood that comes from the East. If we develop California hardwoods we could just as easily locate some of those furniture industries up in the more economically impacted communities in northern California.

In the Michigan study, for 1980, Sullivan found that about 200 million board feet of hardwood sawlogs were cut and they had a value at the mill of about $50 million. They employed about 2,500 people in that process. The value added in secondary manufacture in the State amounted to $750 million with 28,000 jobs. That is a fifteenfold increase in the value and a tenfold increase in jobs. Those increases are phenomenal.

There are some great differences as I said earlier between California and Michigan. Michigan has about 28 billion board feet of inventory of hardwoods. The four northwestern counties of California, in the conifer-hardwood mix according to Bolsinger, has about 7.5 billion board feet of hardwoods. Unlike California, Michigan destroyed most of their conifer forest and did not replant it.

About 70 or 80 years ago, they decided to manage their hardwood forests and develop a hardwood industry. Michigan is actually working with lower grade sawlogs than we have in California tanoak. Michigan has a well developed hardwood technology and process in place. Ours is almost nonexistent. However, it's been proven that it can be done in California. Michigan is using well known and accepted species. Tanoak has a bad reputation for drying, for market acceptance, and for consumer acceptance. Past efforts at getting a viable tanoak industry have failed. However, tanoak has potential as a cabinet wood and as we heard today it has physical characteristics that are about the same as red oak. Tanoak is a little bit stronger and harder and has a greater shrinkage rate. The average value for tanoak lumber in Sullivan's study was $406 per thousand board feet, while red oak was selling at the time for about $725 per thousand board feet in Michigan. Values for tanoak are somewhat speculative since there is no accepted market. Cal Oak of Oroville, the only scale hardwood mill in California, in 1984 quoted some prices of $800 per thousand board for finished tanoak and $1,200 per thousand board feet for black oak.

We heard yesterday about the softwood mentality in the west. The industry here is geared to large volumes and high production rates. The softwood mills in California have a capacity of 30 to 150 million board feet per year. Hardwoods are difference. The mills, at least in the East, are usually very small, about 5 million board feet a year. This is truly, as Zane Smith said the other day, a cottage industry.

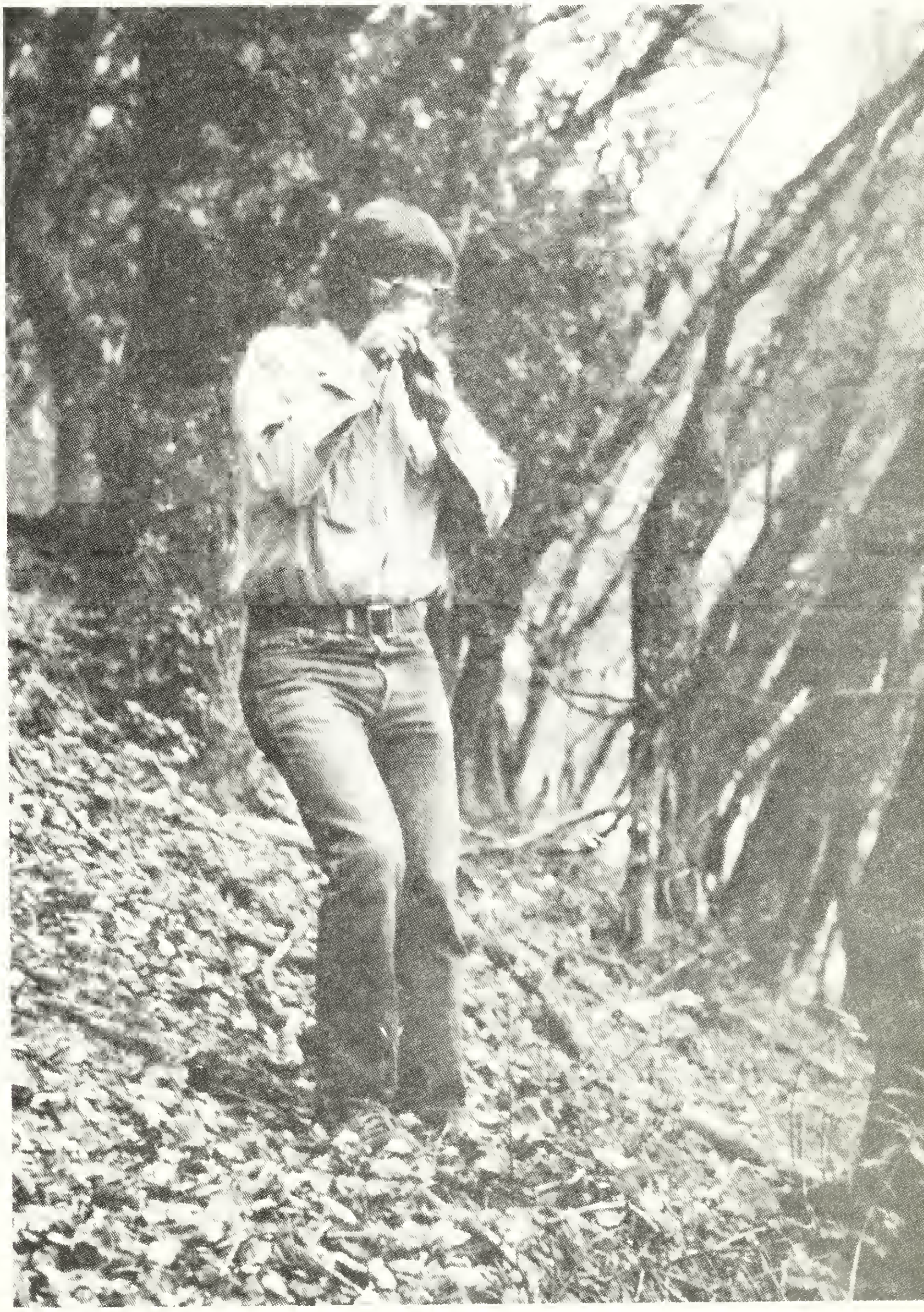
In California, we are faced with making a noncommercial species into an asset. According to Sullivan, a 10-inch tanoak log is superior to a 10-inch redwood log in lumbar value and far superior in the upper diameter classes. Now in terms of gross revenue per thousand board feet, tanoak offers much greater potential than second growth conifers. You will again note that I said potential. It has no real value at this time, but it does have potential.

One of the most significant problems lies in the market acceptance, or even in the awareness of the existence of west coast hardwoods. Most manufacturers are unaware that they grow here. We do have some excellent species. The dominant in California is California black oak, followed by tanoak, Pacific madrone and California laurel.

All of these species and several more at one time paneled the interior of the forestry building at Humboldt State. They were truly beautiful woods. I think—market acceptance aside—if people could see those woods in their finished state, in paneling or furniture, there would be market acceptance. I think all of these prejudices we have are probably ours and not the consumers.

I'm going to conclude with a little biblical proverb. In the opinion of many philosophers, an important part of our contemporary environmental problems are derived from the injunction stated in the sixth chapter of Genesis. "Go, multiply, and subdue the earth and take dominion over every bird of the air and every fish of the sea and every living thing that moves on the surface of the earth." That's been a tenet of western philosophy for the last one thousand or so years. I think with our current sense of awareness, if Genesis had to be rewritten, it might be more modestly put as follows: "Go and multiply with caution—bearing in mind the carrying capacity of the land and seas of the earth. Take a responsible dominion over the renewable and the nonrenewable resources of the earth—remembering that the health and prosperity of the people will be determined by the sustainable productive capacity of the lakes and streams and the fields and forests and the oceans of the earth."

Inventory-Measurements



Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Hardwood Inventory and Measurements--Passing the Three-R Test[1]

Charles L. Bolsinger[2]

Although good decisions are not always made by those who have good information, the odds favor the well-informed. It stands to reason that good information about California's hardwood resources will generally lead to good decisions. This is true whether such decisions concern the scheduling of firewood cutting on a small property, managing wooded grasslands on a large ranch, preserving oak stands in a heavily used park, assessing wildlife habitat in a county or region, or developing statewide hardwood policy guidelines.

A physical inventory, while by no means the only kind of information needed, is essential to most resource-related decisions. The kind of inventory information needed depends on the purpose, but generally will fall into one or more of four categories: quantity, quality, dynamics, and location. Quantity and location of hardwoods may be relevant to a commercial firewood company, while quality considerations would be equally important to a company looking for a hardwood mill site. Public policy-makers may be concerned with all categories of information, but not at the resolution needed by land owners and companies. A land owner would need detailed information on stands, and may even want to know the location of every large tree; on the other hand, policy-makers need generalized information at the county or state level. The usefulness of an inventory also depends on its reliability, which includes not only an acceptable standard error, or high correlation coefficient, but how carefully measurements were made, whether or not there is bias, how consistently classifications were made, how accurately species were identified, and whether or not the best models were selected and used properly.

Inventory needs have been changing, and California's hardwood resources present some unique challenges. New concepts and methods have been added to the expanding storehouse of inventory techniques; for most needs there is a technique that will do the job. For needs not covered, there is a good chance that if they are posted appropriate methods will soon be available.

The following papers address a range of hardwood inventory problems, and present a variety of methods, models and results, which for specific sets of questions, pass the 3-R test of relevance, resolution, and reliability.

[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, California Polytechnic State University, San Luis Obispo.

[2] Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Portland, Oregon.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Major Findings of a Statewide Resource Assessment in California[1]

Charles L. Bolsinger[2]

Abstract: Highlights of a statewide hardwood resource assessment are presented. The total area of hardwood types is about 9.6 million acres; total area of hardwood occurrence is 21.4 million acres. Total volume of hardwoods is 12.5 billion cubic feet. Growth of hardwoods on timberland is about twice the rate of conifer growth and removals less than 0.5 percent of volume and 10 percent of growth. Estimated tree cutting on woodland amounts to about 0.1 percent of volume. Stand characteristics vary by type, and regeneration seems to be adequate for most species, except blue oak and valley oak. Since 1945 hardwood types on timberland have increased 760,000 acres. Oak woodland has decreased over 1 million acres. Before 1973 rangeland clearing was the major factor. Since 1973 urban development and road building have become major factors.

At the Symposium on the Ecology, Management, and Utilization of California Oaks in 1979 (Plumb 1980), the need for a comprehensive statewide inventory of hardwoods was posted. The emergence of hardwood-related issues in various parts of the State since 1979 accentuated the need for a statewide hardwood assessment. Such an assessment has recently been completed. Its highlights are summarized here, with emphasis on the kind of information needs identified at the 1979 symposium and by people involved with current hardwood policy issues.

METHODS AND SOURCES OF INFORMATION

The assessment is based primarily on a forest inventory of lands outside National Forests conducted by the USDA Forest Service's Forest Inventory and Analysis Research Work Unit of the Pacific Northwest Research Station. The inventory design follows Cochran's (1963) double sampling for stratification. In addition, plots established in a previous inventory were reclassified to estimate growth and mortality and forest conversion rates. About 85,000 aerial photo plots were classified by broad type, stand condition and ownership; then subsampled by 5,048 ground plots in all land classes. Hardwood trees were tallied on 1,033 plots. A total of 1,777 plots established in the previous inventory were reclassified to determine land class change; 565 of these plots were in timberland and 379 were in oak woodland. Other information was obtained from National Forest Systems in Ogden, Portland, and San Francisco; National Park Service; State of California; and other organizations. A discussion of the methods used in the inventory is presented elsewhere in this symposium (McKay these proceedings), and a detailed report will soon be published.[3]

HARDWOOD AREA

Hardwood forest types cover 9.6 million acres

Hardwood types cover 9.6 million acres, including 2.2 million acres of timberland and 7.4 million acres of woodland. This amounts to about 25 percent of the total forest land area in California.[4] Hardwood types on timberland tend to be concentrated in the northern part of the State. Hardwoods on woodland are more widely distributed. Of the 2.2 million acres of timberland, 2.0 million acres were determined by sampling, with a confidence interval of 109,000 acres or 5.3 percent (68-percent probability). Of the 7.4 million acres of woodland 5.8 million were determined by sampling, with a 116,000-acre confidence interval, or 2.0 percent. The remaining areas were determined by compiling results of numerous type maps with varying resolution and accuracy.

Over 70 percent of hardwood area in private ownership

About 6.9 million acres of hardwood types are on privately-owned land. Of the 2.7 million acres in public ownership, about 0.5 million acres are in parks and wilderness:

Ownership category	Timberland	Woodland	Total	Percent
	Thousands of acres			
Private	1,857	5,060	6,917	72.0
National Forest:				
Unreserved	184	1,070	1,254	13.1
Reserved	12	274	286	3.0
Total	196	1,344	1,540	16.1
Other public:				
Unreserved	183	715	898	9.3
Reserved	16	232	248	2.6
Total	199	947	1,146	11.9
All categories	2,252	7,351	9,603	100.0

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986.

[2]Principal Resource Analyst, Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, Portland, Ore.

[3]Draft by Charles L. Bolsinger, Pacific Northwest Research Station, Portland, Oregon.

[4]Forest land is at least 10 percent covered by trees crowns, or 50 percent covered by chaparral and not converted to nonforest. Timberland is capable of producing 20 cubic feet or more per acre per year. Woodland is not capable of growing 20 cubic feet per acre per year.

Hardwoods occur on about 21 million acres

In addition to hardwood forest types, where one or more hardwood species predominates, individual hardwood trees, or clumps, groves, or stringers, occur in conifer forests, chaparral, and grassland. Estimates of the area of these inclusions are shown in the following tabulation:

Category	Million acres	Percent
Hardwood forest types	9.6	44.9
Hardwood trees in conifer forest	8.2	38.3
Hardwood trees in chaparral	1.8	8.4
Hardwood trees in rangeland	1.8	8.4
Total	21.4	100.0

Oak types predominate

Forest types are based on the plurality of basal area of the dominant species present. Most hardwood stands on timberland occur on conifer sites, and originated following logging. Woodland hardwood types are in most cases the original or climax cover. Species of oak are prominent on both timberland and woodland, accounting for 79 percent of the area in hardwood types:

Forest type	Timber-land	Wood-land	Total	Percent
	Thousands of acres			
Oak group:				
Blue oak	4	2,907	2,911	30.3
Canyon live oak	344	777	1,121	11.7
California black oak	591	303	894	9.3
Interior live oak	63	821	884	9.2
Coast live oak	39	789	828	8.6
Oregon white oak	97	361	458	4.8
Valley oak	8	266	274	2.8
Engelmann oak	--	39	39	.4
Unclassified	--	180	180	1.9
Total	1,146	6,443	7,589	79.0
Nonoak group:				
Tanoak	810	51	861	9.0
Pacific madrone	151	311	462	4.8
California buckeye	--	208	208	2.2
California-laurel	71	93	164	1.7
Eucalyptus	trace	96	96	1.0
Bigleaf maple	22	60	82	.9
Cottonwoods	9	49	58	.6
All others	43	40	83	.8
Total	1,106	908	2,014	21.0
All types	2,252	7,351	9,603	100.0

HARDWOOD VOLUME

Total volume exceeds 18 billion cubic feet, growing stock 12 billion

The total estimated volume in hardwood trees on timberland and woodland outside parks and wilderness in California is 18.4 billion cubic feet. This includes wood and bark from ground level to the tips of branches of trees 5.0 inches in d.b.h. and larger. Growing stock, including sound wood in straight sections at least 8 feet long to a 4-inch top outside bark above a 1-foot stump in trees 5.0 inches in d.b.h. and larger, amounts to 12.5 billion cubic feet, or 68 percent of total tree volume. Sawlogs, straight sections at least 8 feet long to a 9-inch top in trees 11.0 inches and larger, account for 5.3 billion cubic feet, or 29 percent of total hardwood tree volume. By-tree component volume is distributed as follows:

Tree component	Billion cubic feet	Percent
Sawlogs	5.3	29
Poles, upper sawtimber boles (to 4 inches)	7.2	39
Terminals, limbs, stumps, cull sections	5.9	32
Total volume	8.4	100

Hardwood volume on timberland exceeds that on woodland

About 61 percent of the total hardwood volume is on timberland, even though woodland area is greater. As with area, private landowners hold the majority of the hardwood volume, as shown in the tabulation:

Ownership	Timber-land	Wood-land	Total	Percent
	Million cubic feet			
Private	4,732	3,635	8,367	66.7
National Forest	2,398	832	3,230	25.8
Other public	551	387	938	7.5
Total	7,681	4,854	12,535	100.0

The confidence intervals of the volume estimates for lands outside National Forests are 4.3 percent for timberland and 10.4 percent for woodland (68-percent probability). Confidence intervals are not computable for National Forests, but the estimates are assumed to be of comparable reliability.

Hardwood volume is concentrated in a few species

Although more than 30 hardwood species grow in California, 89 percent of the volume is in 8, and 64 percent is in 4:

Species	Timber-land	Wood-land	Total	Percent
	Million cubic feet			
California black oak	2,254	277	2,531	20.2
Canyon live oak	1,302	731	2,033	16.2
Tanoak	1,887	51	1,938	15.5
Pacific madrone	1,116	401	1,517	12.1
Blue oak	1	1,112	1,113	8.9
Coast live oak	126	755	881	7.0
Oregon white oak	211	389	600	4.9
Interior live oak	45	508	553	4.4
California-laurel	273	154	427	3.4
Eucalyptus	10	221	231	1.8
Valley oak	34	164	198	1.6
Alders	163	4	167	1.3
Bigleaf maple	150	6	156	1.2
Giant chinkapin	50	--	50	0.4
Cottonwoods	10	32	42	.3
Quaking aspen	20	9	29	.2
California buckeye	1	24	25	.2
All other hardwoods	28	16	44	.4
All species	7,681	4,854	12,535	100.0

California's hardwoods average larger than those in the eastern U.S.

Total hardwood growing stock on timberland in California amounts to only 3 percent of the total in the United States, but volume in trees over 29 inches in d.b.h. in California amounts to 19 percent of the total for that diameter class in the Nation (U.S. Department of Agriculture 1982).

Hardwoods on timberland are larger on the average than those on woodland

As might be expected, growing-stock volume is concentrated in larger trees on timberland than on woodland. 28-percent of the volume on timberland is in trees 21.0 inches in d.b.h. and larger, compared with 19 percent on woodland.

	d.b.h. in inches			
	5.0-10.9	11.0-20.9	21.0-28.9	29.0+
	Percent of growing-stock volume			
Timberland	27	45	18	10
Woodland	34	47	13	6

Timberland hardwoods have better form for utilization

Tree form of California hardwood species is extremely variable. Timberland species such as tanoak, giant chinkapin, and alders are often straight and single-stemmed with small limbs on the lower bole. Woodland species are less well formed, as shown in the following tabulation:

Hardwood tree form class	Timberland	Woodland
	Percent total volume	
1. Straight bole (no cull); little taper; small limbs	25	8
2. Up to 20 percent cull due to form; large limbs	29	18
3. More than 20 percent cull due to form	39	60
4. 100 percent cull due to form	7	14
Total all classes	100	100

HARDWOOD GROWTH AND HARVEST

Timberland hardwoods have higher growth rates than conifers

Gross annual growth of hardwoods on timberland[5] is estimated to total 246 million cubic feet. Average annual mortality of hardwoods is estimated to total 24 million cubic feet. Net annual growth (gross growth minus mortality) is 222 million cubic feet or 2.9 percent of growing stock. This is almost twice the growth rate for conifers (1.6 percent).

Tanoak, madrone, and laurel have higher growth rates than oaks

Growth and mortality rates for hardwoods on timberland were estimated from tree measurements on two occasions on permanent inventory plots. As shown in the following tabulation, growth and mortality vary considerably by species, reflecting the innate characteristics of species, the sites on which they occur, and current stage of development:

Species or groups	Gross annual growth	Mortality	Net annual growth
	Percent of inventory		
Tanoak	4.04	0.54	3.50
California-laurel	3.70	0.19	3.51
Pacific madrone	3.40	0.26	3.14
California black oak	2.70	0.27	2.43
Canyon live oak	2.69	0.19	2.50
Other oaks	2.72	0.20	2.52
Other hardwoods	3.38	0.24	3.14
All species	3.20	0.31	2.89

Hardwood harvest is a small fraction of inventory and growth

Data from remeasured plots outside National Forests indicate that hardwoods were harvested (trees cut down and logs removed) on about 7,100 acres of timberland per year, and culturally killed (by herbicides, girdling or burning; or pushed over) on an additional 5,500 acres per year. The volume removed as determined from plot

[5]Hardwood growth was not measured on woodland, but plots were established as the basis for future growth measurements.

data, averaged 9.2 million cubic feet per year. (The volume of hardwoods cut, as reported by the State Board of Equalization, averaged 6.5 million cubic feet; estimates from plots include total growing stock volume in trees cut, while the reported figures include only wood removed from the woods). The volume of culturally killed hardwoods averaged 8.2 million cubic feet per year.

Data from one-time visits to plots in woodland indicate that hardwood tree cutting has occurred on about 60,000 acres per year. Intensity of cutting ranged from one tree per acre up to 90 percent of the stand. It was not possible to measure the volume cut in these areas. At the rate of 1 cord per acre--roughly 85 cubic feet--the volume cut per year would be approximately 5 million cubic feet.

Estimated annual hardwood removals as related to area, volume and growth are shown below:

Category	Thousand acres	Percent of area	Million cubic feet	Percent of volume
Timberland:				
Harvested	7.1	0.35	9.2	0.17
Killed	5.5	0.27	8.2	0.15
Total	12.6	0.62	17.4	0.32
Woodland:				
All removals	60.0	1.00	5.0[6]	0.12

Hardwood volume on timberland has increased; conifer volume has decreased

Statewide, hardwood volume has increased about 23 percent on timberland outside National Forests in the past 10 years, while conifer volume has decreased about 3 percent. This is a continuation of a 30-year trend, most notable in the north coastal counties, but evident in some interior counties as well (Bolsinger 1980). Conifers were harvested and hardwoods left to grow and seed in surrounding areas on several hundred thousand acres.

HARDWOOD STAND STRUCTURE

Density of hardwood stands varies

Stand density within a given type varies considerably because of site, stage of development, and stand history. Statewide, however, density is clearly related to type, despite other factors. Tanoak and Pacific madrone stands are the densest; blue oak and valley oak are the sparsest. The following tabulation shows basal area classes for trees 1.0 inch in d.b.h. and larger for major hardwood types:

Forest type	Square feet of basal area per acre			
	0-49	50-99	100+	Total
	Percent of forest type			
Pacific madrone	9	24	67	100
Tanoak	17	29	54	100
California-laurel	29	26	45	100
Canyon live oak	22	44	34	100
Coast live oak	34	22	34	100
California black oak	37	36	27	100
Oregon white oak	36	43	21	100
Interior live oak	78	16	6	100
Blue oak	75	21	4	100
Valley oak	81	19	0	100

Mean stand diameter is less than 11 inches for most hardwood types

Quadratic mean diameter (the diameter of the tree of average basal area) is a stand descriptor used in forest prescriptions, wildlife habitat assessment, and other applications. As shown in the following tabulation, coast live oak, valley oak, and tanoak stands are the largest in terms of mean diameter (more than 50 percent in stands 11.0 inches and larger). Oregon white oak is the smallest of the major types (Engelmann oak, a minor type, is not included because of the light sample):

Forest type	Quadratic mean stand diameter in inches at breast height			
	11.0 and larger	5.0 to 10.9	less than 5.0	Total
	- - Percent of forest type - -			
Coast live oak	74	11	15	100
Valley oak	52	48	0	100
Tanoak	51	37	12	100
Pacific madrone	48	43	9	100
Blue oak	43	26	31	100
Canyon live oak	41	41	18	100
California black oak	40	33	27	100
California-laurel	30	41	29	100
Interior live oak	30	25	45	100
Oregon white oak	26	51	23	100

Stand volume is highest for madrone, tanoak, and laurel; lowest for blue oak

For each stand sampled volume was averaged over five subplots (each subplot was about 1/5th acre in size) distributed over 5 acres and expressed on a per-acre basis. Hardwood volume in some "clumps" exceeded 10,000 cubic feet per acre, but average density over 5 acres rarely exceeded 5,000 cubic feet. The stand with the greatest hardwood growing stock volume was in tanoak type, but mean stand volume was higher in Pacific madrone. The largest hardwood tree tallied also was a madrone. Of the several oak types, the greatest mean volume was found in canyon live oak type. The largest oak tallied was also a canyon live oak (see following tabulation).

[6] This is hypothetical, based on an assumed average rate of 1 cord per acre.

Forest type	Mean volume	Maximum volume	Largest tree Tallied
	Cubic feet per acre		Inches in d.b.h.
Pacific madrone	1,705	4,519	73.3
Tanoak	1,679	6,900	59.2
California-laurel	1,677	3,125	45.2
Canyon live oak	1,503	4,128	58.3
Coast live oak	1,300	4,038	39.6
California black oak	1,213	4,000	53.6
Oregon white oak	1,099	4,498	37.0
Valley oak	994	2,180	42.5
Interior live oak	612	3,779	42.6
Blue oak	381	1,767	39.3

Associated vegetation and incidence of grazing

At each subplot location on lands outside National Forests a "vegetation profile" was tallied. All woody plants (shrubs and vines) were recorded by name, height, percent cover, and stage of development. Total cover for both forbs and grass-like plants was recorded, but species were usually not identified. Over 90 woody plant species were recorded, including some like *Baccharis pilularis* DC found mostly in one type (coast live oak), and ubiquitous species like *Rhus diversiloba* T.& G. Woody plant cover was densest in tanoak type (all plots had at least 50 percent cover) and canyon live oak (83 percent had 50 percent cover); and sparsest in valley oak (only 24 percent had 50 percent cover), interior live oak (27 percent had 50 percent cover) and blue oak (29 percent had 50 percent shrub cover).

Each woodland plot location was classified as to whether or not grazing had occurred within the past year (grazing was rated for specific locations, not the general ownership; some locations had not been grazed because of inacessability to cows and horses even though the owners said they grazed their properties). As expected, the incidence of grazing varied greatly by type and was closely related to the predominance of grass cover:

Forest type	Percent cover in grass-like plants	Percent of plots grazed
Blue oak	77	64
Valley oak	62	73
Interior live oak	54	72
Oregon white oak	45	62
Coast live oak	37	56
California black oak	18	28
Canyon live oak	18	8

Engelmann oak, California buckeye, and other minor types had also been grazed; the plot sample in these types was too weak to include in the above tabulation.

HARDWOOD REGENERATION

Hardwood seedlings are fairly abundant, except for valley oak and blue oak

Seedling-size trees (6 inches high to 0.9 inch d.b.h.) were tallied on all plots outside National Forests (most plots consisted of 5 subplots). The following tabulation shows the total area in which seedlings were found within each type and in other types, and figure 2 shows percent of area in major hardwood types by seedling stocking class:

Forest type and species	Area with seedlings within type	Area with seedlings in other types
	Thousand acres	
Coast live oak	307	171
Canyon live oak	656	1,460
Interior live oak	561	767
California black oak	381	2,000
Oregon white oak	226	232
Valley oak	0	39
Blue oak	894	263
Tanoak	786	1,500
Pacific madrone	241	1,700
California-laurel	155	1,100

Regeneration of Engelmann oak, a tree of restricted range in southern California, is considered by some to be inadequate to maintain the species. The species was tallied on two woodland plots, one of which had seedlings present (scattered Engelmann oak trees were also tallied on a plot in dense chaparral).

Regeneration of several minor hardwood species, including red alder, quaking aspen, black cottonwood, bigleaf maple, California buckeye, and giant chinkapin, appeared to be adequate, although the sample for these species was light.

CHANGE IN HARDWOOD AREA--1945 TO 1985

Hardwoods types on timberland have increased about 760,000 acres

A comparison of area estimates made in 1945 by Wieslander and Jensen (1946) with the current statistics indicate an increase of hardwood types on timberland in Del Norte, Humboldt, Mendocino, Shasta, Sonoma and, Trinity Counties. The comparative statistics agree with Bolsinger's 1980 timber investment study which showed that 700,000 acres of conifer types converted to hardwoods following logging. By 1985 the estimated area of conifer stands converted to hardwoods totaled 760,000 acres.

Woodland loss from 1945 to 1973: 990,000 acres; 90 percent range clearings

Between 1945 and 1973, over 1.9 million acres were cleared of trees and shrubs in rangeland clearing projects (State of California 1943-1973). An estimated 890,000 acres of these clearings were oak woodland. During the same period about 100,000 acres of oak woodland were estimated to have been cleared for reservoirs, roads, powerlines, and residential and commercial development (Bolsinger 1980). The total rate of loss was about 35,000 acres per year.

Since 1973, 199,000 acres lost: 85 percent to urbanization and road building

Reclassified plot locations were used to estimate that since 1973 about 199,000 acres of oak woodland were converted to nonforest (this estimate excludes southern California and San Luis Obispo, Santa Barbara, and Ventura Counties). Rangeland clearings, which had been the predominant cause of woodland loss before 1973, became the least important:

Cause of conversion	Percent	Acres per year
Residential-commercial development	46	7,400
Road and freeway construction	39	6,300
Rangeland clearing	15	2,400

Blue oak was the major type converted

The plot sample indicated that 54 percent of the woodland area converted since 1973 was blue oak type; valley oak accounted for 20 percent, interior live oak 15 percent, and canyon live oak 11 percent.

Residential-commercial clearings remove about 20 percent of the trees

Road and freeway construction and rangeland clearing removed all of the trees from the land sampled, but residential-commercial developments left an estimated 80 percent of the trees. Although trees in urban developments often decline and some ultimately die (Rogers 1980), they are not being eliminated as fast as the conversion data might suggest.

Firewood cutting was not identified as a cause of woodland conversion

None of the oak clearings sampled were classified as fuelwood operations, although some that were called rangeland clearings were probably encouraged by the marketability of the wood. Several plots had been cut by fuelwood operators, but enough trees had been left for the land to be classified as woodland.

Woodland conversions-in-process exceed area converted since 1973

About 279,000 acres of woodland were being developed for residential and commercial use when plots were measured. Such areas were still woodland by definition, but development activities in the same tracts indicated that they would probably be converted in the near future. By type these conversions-in-process were distributed as follows:

Forest type	Percent of conversions-in-process	Percent of current area in type
Blue oak	57	6
Coast live oak	18	7
Eucalyptus	13	36
Valley oak	12	13

"Natural" attrition of woodland

In woodland fringe areas in the lower foothills and valleys, oaks appear to be gradually disappearing. Stands seem to be thinning out as old trees die without being replaced by regeneration. At the point where crown cover has been reduced to less than 10 percent the land would be classified as nonforest. Although such areas appear to be common, they were sampled by none of the 379 reclassifed plots in oak woodland. If such attrition is indeed occurring its effect is implicit in the aerial photo stratification, and it will be quantified in future inventories. That none of the ground plots sampled this phenomenon suggests it is progressing too slowly to be detected over a 12-year period, or is not as extensive as casual observation would indicate.

DISCUSSION

California has a vast and varied hardwood resource. Unlike the State's conifer forests, the majority of the hardwoods are in private ownership. Oaks predominate, accounting for the majority of area and wood volume; although some species other than oak are important, especially in coastal timberland areas.

Large hardwood trees are common in California, which suggests there may be untapped possibilities for industrial uses. Tree form and quality, however, may limit the use of some species. The greatest value of some large trees may be as wildlife habitat, watershed protection, and landscape enhancement.

Annual removals of hardwoods on timberland are a small fraction of volume and growth. Both area and volume of hardwoods on timberland have increased dramatically in the past 3 to 4 decades, the result of (1) logging practices that favored hardwoods, and (2) the high innate productivity of several timberland hardwood species.

The area of hardwood woodland decreased by more than 1 million acres since 1945. Up until about 1970 rangeland clearing was the major factor; but since then urban expansion and road building have become more important. Although an increasing volume is being cut for firewood, it appears that most fuelwood cutting results in thinned stands rather than woodland conversions.

Stand characteristics vary considerably depending on species mix, site, and stand history. Extensive areas of blue oak, interior live oak and valley oak are sparsely stocked. In some cases the sparse stocking is natural; in other cases it is the result of land management practices. As expected, stands of timberland hardwoods were denser than woodland hardwoods; conversely, grass cover and use of sites by grazing animals were greater in the woodland stands.

Regeneration of most hardwood species seems to be adequate. Blue oak seedlings were scarce in drier parts of the species' range, and valley oak seedlings were not found on any plots in valley oak type (a few were found in other types on moister sites). This seems to suggest that the oak woodlands might be retreating upslope to moister environments. The "natural" attrition of oaks in the lower fringe area (observed, but not quantified) would support this idea.

The potential for developing economic uses for the "unwanted" hardwoods on conifer sites, and the potential for losing a sizable portion of the unique oak woodlands, are both real. The majority of the hardwoods belong to many individuals and corporations with diverse interests, resources, and capabilities. Decisions that affect the way these owners treat their land and trees will have a profound effect on the future of the State's hardwood resources.

LITERATURE CITED

Bolsinger, Charles L. California forests: trends, problems, and opportunities. Resour. Bull. PNW-89. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 138 p.

Cochran, W.G. Sampling techniques. 2nd ed. New York: John Wiley and Sons; 1963. 413 p.

McKay, Neil. How the statewide hardwood inventory was conducted. Presented at the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986. San Luis Obispo, CA.

Plumb, Timothy R., technical coordinator. Proceedings of the symposium on the ecology, management, and utilization of California oaks; June 26-28, 1979; Claremont, CA. Gen. Tech. Rep. PSW-44; Berkeley CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 368 p.

Rogers, Paul A. Measure that can help offset the detrimental effects that urban development has on oak trees. In: proceedings of the symposium on the ecology, management, and utilization of California oaks; June 26-28; Claremont, CA (Timothy R. Plumb, technical coordinator). Gen. Tech. Rep. PSW-44, p. 167-170; Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980.

State of California. Brushland range improvement, Sacramento, CA: Division of Forestry; 1953-1974. (annual reports).

USDA Forest Service. An analysis of the timber situation in the United States--1952-2030. Forest Resour. Rep. No. 23; U.S. Department of Agriculture; Washington DC, 1982. 499 p.

Wieslander, A. E. and Herbert A. Jensen. Forest area, timber volume, and vegetation types in California; Forest Survey Release No. 4; Berkeley, CA: California Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1946. 66 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

How the Statewide Hardwood Assessment Was Conducted[1]

Neil McKay[2]

Abstract: Forest Inventory and Analysis (FIA) inventories in California focused on conifer stands prior to 1980. Since 1970, the public and many organizations have become concerned about a variety of hardwood topics. In response, FIA expanded its efforts to inventory California's hardwood resources. In a 1981-83 statewide assessment, the unit extended its permanent two-phase sampling design into non-National Forest hardwood woodlands and designed the inventory to describe the hardwood resources present on all lands. The assessment provides information about forest areas and volumes, current stand conditions, land use patterns, environmental factors and wildlife habitats. FIA can monitor change in the hardwood resources by reevaluating and remeasuring photo and field plots.

The Forest Inventory and Analysis Research Unit (FIA) of the USDA Forest Service, Pacific Northwest Research Station recently completed a comprehensive forest inventory of California. Previous assessments by FIA and by other organizations provided information about the hardwoods present in timberland areas, but did not sample the vast hardwood woodlands.[3]

This new survey represents the first assessment specifically designed to provide data about the extent and characteristics of the State's hardwood resources on both timberland and other forest acreage. What has been the historic role of FIA in extensive forest assessments? Why did FIA intensify its efforts in inventorying the state's hardwood resources? How were the inventory design and methods modified to provide a more comprehensive hardwood assessment? This paper addresses these topics.

FIA INVENTORIES PRIOR TO 1980

FIA assessments have evolved in response to changing information needs since 1928. In that year, the Congress passed the McNary-Sweeney Act which mandated the USDA Forest Service to conduct periodic forest inventories across all ownerships nationwide. This agency, in turn, directed each regional research station to undertake this task within its respective area. By the mid-1930s, the California Forest and Range Experiment Station[4] had initiated its first inventory of California's timber resources.

This effort, which focused on the available supply of conifer sawtimber, met the current needs of planners and managers. Forest area estimates--specified by forest type, stage of development and stocking level--were derived from type maps. Gross and net volumes were estimated from local cruise reports and correlated with the area estimates for conifer sawtimber types present on timberland. Results of this inventory were published in 1946 (Wieslander and Jensen).

The first inventory had two shortcomings: (1) estimates of sampling errors could not be calculated for area and volume statistics, and (2) the design did not provide the basis for estimating growth and mortality in subsequent inventories. To remedy these problems, FIA, then known as Forest Survey, discontinued using local cruises and installed 1,527 randomly selected volume plots on timberland across all ownerships. Each plot consisted of a series of concentric fixed-radius subplots, a configuration primarily suited to determine sawtimber volume. Since the plots were referenced, they could be relocated and remeasured to assess change during later inventories. FIA completed its second inventory of California in 1954 using this design (USDA FS 1954). Eight years later, 215 plots were remeasured to provide estimates of growth, mortality and removals; this information was applied to update the 1954 report (Oswald and Hornibrook 1964).

By the late 1950s, as the State's old-growth reserves dwindled and support for sustained yield forestry grew, cutover and immature conifer stands were recognized as the future timber supply. Concurrently, a major Forest Service study demonstrated that regional FIA inventories did not describe adequately the current forest conditions required to evaluate these future stands (USDA FS 1958). In response, FIA units began to apply inventory designs that were not only sample-based and permanent, but able to estimate a wide range of forest conditions.

The Forest Survey unit of the Pacific Southwest Forest and Range Experiment Station used a double sampling design on the non-National Forest ownerships when it began a new inventory of California in 1964.

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[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resource, November 12-14, 1986.

[2] Forester, Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, Portland, Oreg.

[3] Forest land is land capable of supporting at least 10 percent stocking of trees and is not developed for nonforest use. Timberland is forest land capable of producing 20 cubic feet or more per year per acre of industrial wood. Other forest land, which includes hardwood woodlands, is forest land that does not qualify as timberland.

[4] The California Forest and Range Experiment Station is now the Pacific Southwest Forest and Range Experiment Station.

(For the National Forests, the unit relied on data collected by each Forest.) A grid of photo points was established directly on aerial photography. Interpreters classified each point by broad land class: timberland, other forest or nonforest. Points identified as timberland were assigned owner and volume classes; the volume stratification served to improve the precision of timberland volume estimates.

A subset of the photo points was designated as field plots. These plots were selected randomly and distributed proportionally by the number of photo points in each stratum. Plots verified as timberland were referenced and measured; each timberland plot consisted of 10 points and sampled 1 acre. At each point, a crew used a variable-radius plot to select trees 5 inches in d.b.h. (12.5 cm) and larger and a fixed-radius plot to sample smaller trees. The 10-point design provided both volume estimates and information about the magnitude and variability of attributes--stocking, composition, and structure--which described forest conditions within the plot area.

In 1966, the Forest Survey unit of the Pacific Northwest Forest and Range Experiment Station assumed responsibility for the inventories of California. Based on the 1964-72 inventory, the unit released a detailed analysis of the State's timber resources in 1980 (Bolsinger).

THE STATUS OF HARDWOODS IN PREVIOUS INVENTORIES

Low commodity values fostered by the perception of small log size, inferior quality, and limited supplies historically have limited industrial utilization of California's hardwoods. These reasons coupled with a focus on old-growth and, more recently, on young-growth conifer stocks led both FIA and the National Forest system to collect relatively little information about the vast hardwood woodlands in inventories completed prior to 1980; these woodlands were classified into broad ecosystems, but otherwise were not inventoried. During the inventories of 1953, 1962 and 1964-72, FIA did sample hardwoods present on timberland plots, but the volume tables available poorly represented many of the species tallied and several were declared noncommercial regardless of individual size, shape or soundness. In the National Forest inventories incorporated into these assessments, the hardwoods present on timberland often were ignored entirely.

WHY FIA DECIDED TO INVENTORY HARDWOODS MORE INTENSELY

Interest in nontimber forest resources increased significantly following the 1964-72 inventory. In the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) and the Forest and Rangeland Renewable Resources Research Act of 1978, Congress directed the Forest Service to widen the scope of FIA inventories to include the evaluation of these resources. In California, a host of nontimber issues emerged which focused on the State's hardwood resources. These included (1) rangeland clearing, (2) the lack of State regulation on hardwood cutting and regeneration practices, (3) wildland conversions, (4) the potential impact of biomass energy plants, (5) the loss of wildlife habitat associated with hardwood types, (6) the possibility that several oak species were regenerating inadequately, (7) hardwood removals for firewood, and (8) impaired esthetics due to hardwood removals. The California legislature enacted the Forest Resources Assessment and Policy Act of 1977 which created a statewide assessment program within the California Department of Forestry; in part, this legislation was a response to these hardwood-related issues.

FIA began planning for a new inventory of California in late 1978. An initial step, a needs assessment, was undertaken to determine the data needs of major users of FIA information and to identify topics that FIA could help address by applying its extensive, sample-based inventory design. As this process began, Charles Bolsinger, the analyst heading the inventory, attended the Symposium on the Ecology, Management, and Utilization of California's Oaks. Participants at this conference emphasized the need for a major hardwood research program which included a comprehensive statewide inventory of hardwoods (Plumb 1980). Subsequently, this concern was reiterated as FIA reviewed written inputs and attended a series of meetings with various organizations: California Department of Forestry, United States Soil Conservation Service, California Board of Equalization, University of California, California Forest Protection Association, and several others. Based on these inputs and on legislative direction, FIA added a comprehensive appraisal of the State's hardwood resources as a major inventory objective.

Specifically, the unit decided to:

1. Extend the inventory into other forest lands (specifically, oak and pinyon-juniper woodlands) in order to provide estimates of volume and other attributes for these areas.

2. Improve hardwood volume estimation techniques.

3. Improve the data base on firewood cutting, conversions, grazing, and other human and natural impacts.

4. Estimate the area of hardwood savanna in nonforest areas.

5. Estimate the area of hardwood occurrence in chaparral types.

6. Assess the presence of hardwood regeneration by species and type.

7. Gather and calibrate data for an analysis of wildlife habitats on other forest land as well as on timberland.

8. Determine the extent of hardwood mistletoe by host species.

INVENTORYING THE NON-NATIONAL FOREST LANDS

In the recent inventory, FIA sampled directly all ownerships except National Forests and National, State, regional, county and municipal parks. These data were combined with the most recent National Forest inventories to provide a comprehensive assessment of California's forest resources.

The design for non-National Forest lands approximated double sampling with stratification: a primary sample of photo points subsampled by a set of field plots (Cochran 1963). Both samples were selected systematically to ensure that all geographic areas of the State were proportionally represented. For the first time, the primary sample was referenced so that in future inventories FIA could reexamine it for change. At field plot locations selected for measurement, a new plot design was installed that provided better resolution for analyzing current stand conditions. FIA also initiated sampling for nontimber data in order to analyze wildlife habitats.

THE PRIMARY SAMPLE

Selection of the primary sample was partially automated. A computer-generated grid partitioned the State into "squares" 0.85 miles (1.4 km) on a side and 462 acres (187 ha) in area. Within each square, a random number generator program identified a sample point. The location of each point was referenced using the Universal Transverse Mecator coordinate system. Points were computer-plotted on U.S. Geological Survey quadrangle maps and located by hand on recent aerial photography.

Primary sample points were assigned several classifications. Points were stratified into three land classes: timberland, other forest, or nonforest. Other forest points were delineated by broad vegetation type; for example, oak woodland, chaparral, or pinyon-juniper. Timberland points were stratified into stand volume classes to increase the precision of timberland volume estimates; for other forest points, this step was not necessary due to the lack of absolute variation in stand volumes. Using tax assessors' records, each forest point was assigned to a broad ownership class: public, forest industry, or farmer and miscellaneous private.

Interpreters estimated the percent of tree cover occurring on forest and nonforest rangeland points. When present, the tree cover was typed as hardwood, Digger pine, juniper, or other conifer. This information permitted making area estimates defined by percentage classes of tree cover present in each type. Because tree cover data were collected for points on nonforest lands, FIA was able to estimate the area of hardwood savanna in the State.

The primary sample was also stratified into four development zones: (1) wildland, primarily timberland; (2) wildland, primarily other than timberland; (3) low density residential or industrial development; and (4) high density development. The zones were based on tract size, proportion of timberland area within a tract, proximity of roads, and frequency of nearby nonforest developments. Area estimates by zone aid in determining to what extent forest lands are affected by nonforest land uses.

The number of primary points outside the National Forests, by category, are:

Total number of points	85,174
Number of points in forest (excluding chaparral)	37,999
Number of points in chaparral	10,125
Number of points in chaparral with scattered hardwoods present	2,169
Number of points in nonforest with scattered hardwoods present	3,455

THE FIELD PLOTS

Field plots were used to determine the accuracy of photo stratifications and to obtain detailed information about individual trees, nontree vegetation, and plot area descriptors.

Field plot selection was done as follows: every fourth point in every fourth row on the primary grid was identified as a potential field plot location. FIA replaced 57 percent of these locations with nearby field plots sampled during the previous inventory; these old plot locations were assigned UTM coordinates and became part of both the primary and field samples. New field plots were designated at the remaining potential locations. The field plot grid interval averaged 3.4 miles (5.5 km) after these steps.

Crews ground-checked a plot if its land classification was in doubt. All timberland plots on the 3.4 mile (5.5 km) field grid were measured; each plot represented an average of 7,400 acres (2,996 ha). On other forest lands, plots were measured at every other grid location (6.8 miles/ 11 km) with each plot representing 29,600 acres (11,984 ha) on the average. Plot visits occurred between early 1981 and late 1983.

A NEW FIELD PLOT LAYOUT

The crews installed a plot of new design at each location selected for measurement. At timberland locations, the crews also remeasured the old 10-point plots when present. The new layout consisted of a cluster of five subplots distributed in a standardized pattern across 5 acres (2 ha). While the old 10-point, 1-acre (.4 ha) plot could cross classification boundaries, the new plot was established entirely in the same land class, owner group, and stand condition. With the new layout, the wider spacing between subplots better allowed FIA to detect and interpret the magnitude and variation in stand conditions present within a plot area. Thus, the new layout improved the ability of FIA to make area estimates for silvicultural treatment opportunities.

An exception to this new plot configuration occurred in chaparral communities; instead of the five-point plot, the crews installed a one-point plot with a 55.8-foot (17 m) fixed-radius to sample the vegetation and to record information describing the plot area.

The number of field plots outside the National Forests, by category, are:

Number of plots examined to verify land classes (5-point plots)	5,048
Number of measured timberland plots (5-point plots)	1,132
Number of measured other forest plots (5-point plots)	325
Number of measured plots with hardwoods present (5-point plots[5])	1,033
Number of measured other forest plots in a hardwood type (5-point plots)	168
Number of remeasured timberland plots (10-point plots)	557
Number of remeasured timberland plots with hardwoods present (10-point plot)	375

FIELD PLOT DATA

On the five-point plots, crews collected three categories of information: plot area descriptors, tree data, and vegetative profiles. Area descriptors collected at the plot location included slope, aspect, physiographic class, presence of damaging agents, past and present disturbances and uses, type and degree of erosion, and factors affecting stocking. Other plot-level data such as precipitation and elevation were obtained from external sources.

To identify tally trees, fixed and variable-radius sampling was applied at each subplot. Trees less 5.0 inches in d.b.h. (12.5 cm) were selected if located within 10.8 feet (3.3 m) of subplot center. Larger trees were selected using a variable-radius plot calibrated with a basal area factor (BAF) of 30.49 square feet (7 m/ha). This BAF allowed the detection of stocking variations affecting stand growth but ignored insignificant variations in tree spacing. Individual tree data recorded included species, measures of size, vigor and position, age, cull indicators, and the presence of damaging agents.

Vegetative profiles provided inputs for analyses of silvicultural treatment opportunities and wildlife habitats. At each subplot, crews tallied the major plant species present on a 16.4-foot (5 m) fixed-radius plot. For each species, a height class, percentage of cover, and, for shrubs only, stage of development were recorded.

On the old 10-point plots, the crews relocated trees sampled during the previous inventory. For each tree, data were collected on its current status (live or dead), size, vigor, position (crown class), and quality. These variables were used to develop regression estimators of growth and mortality which were applied to all trees tallied in the current inventory in order to estimate total growth and mortality.

[5]One-point plots in chaparral communities.

PROCESSING NON-NATIONAL FOREST DATA

FIA calculated area and volume estimates down to the county level from the data collected on the primary and field samples. Standard double sampling procedures were used to compute adjusted area estimates by owner class for timberland and other forest land (Cochran 1963). These statistics included area estimates by hardwood types. In compiling area estimates, the classification of ownership on the sample points was assumed to be without error.

Volume estimates were computed for each measured field plot by summing the volumes per acre (or hectare) that the merchantable tally trees represented. Individual tree volumes were based on volume equations specified by species. Adding the volume per acre for tally trees of a particular species provided the plot volume for the species. The mean volume of the plots actually falling in a primary sample stratum--defined by land and owner class and, if timberland, volume class--were expanded by the area estimate for the stratum to get total stratum volume.

NEW HARDWOOD VOLUME EQUATIONS

Prior to 1980, few volume equations were calibrated for native California hardwoods, and none, except for a red alder equation, were suitable for compiling the inventory due to varying merchantability standards and to suspected unreliability when used statewide. In response, FIA contracted Norman Pillsbury (California Polytechnic State University, San Luis Obispo) to develop volume estimators for 13 hardwood species (Pillsbury and Kirkley 1984). To construct these equations, Pillsbury applied a methodology he had developed earlier for analyzing the volume of standing trees with multiple stems and irregular forms (Pillsbury and Stephens 1978). Regression equations for each species were generated for three utilization standards: total volume (all stem and branch wood plus stump and bark); wood volume (all wood inside bark from stump height to a 4-inch (9.9 cm) top outside bark); and sawlog volume for trees greater than 11 inches (27.2 cm) in d.b.h. (straight sections from stump height to a 9-inch (22.2 cm) top outside bark).

INCORPORATING NATIONAL FOREST INFORMATION

FIA used the most recent National Forest inventories to represent the 21 National Forests within California in the statewide assessment. In each inventory, a National Forest was mapped into polygons defined by land class, broad forest type, stand size and stand density. Hardwood woodlands were usually identified only in broad terms such as "oak woodlands" or simply as "hardwoods." Ground checks verified that these forest types were classified correctly 85 percent of the time. Volume, which was not measured in these other forest hardwood types, was estimated as follows: FIA divided each broad type into more specific classifications (blue oak, canyon live oak...) by using a variety of sources--stand examinations, soil-vegetation maps, and personal contacts--and then extrapolated volumes from FIA plots in similar classifications on non-National Forest lands.

On timberland, the National Forests had installed samples of field plots to estimate volume by species and size class. Statistical precision was within ±10 percent of total volume (68-percent confidence level), but for the hardwood component in these stands, the confidence band was wider. Because the recent National Forest inventories did not assess hardwood growth and mortality on timberland, FIA estimated these statistics by adapting approximations from earlier National Forest surveys and from FIA timberland plots.

RELIABILITY OF HARDWOOD AREA AND VOLUME DATA

Statewide estimates of area, volume, and associated sampling errors are displayed for hardwood types on forest lands outside of the National Forests; sampling errors are expressed as confidence intervals stated for the 68 percent probability level:

	Area Estimate	Confidence Interval
	(Thousand acres)	
Area:		
Hardwood types in timberland:	2,040	±109
Hardwood types in other forest land:	5,775	±116

	Volume Estimate	Confidence Interval
	(Million cubic feet)	
Volume:		
Hardwood types in timberland:	5,291	±227
Hardwood types in other forest land:	4,018	±419

Confidence intervals vary according to the size and variance of an estimated statistic; for area and volume estimates for each group of counties comprising a FIA inventory unit, the intervals are usually broader than those for statewide estimates. Human error can not be quantified, but was minimized through training, rigorous quality control procedures, comprehensive written photo and field instructions, and extensive editing.

ASSESSING CHANGE

Estimates of change in the hardwood resources are possible by periodically reexamining the photo and field plots. The details of such monitoring will depend on funding and available technology. FIA has the ability to:

1. Relocate each photo plot and field plot on new photographs, satellite imagery or maps. Given current technology, changes in area by land class, ownership, vegetation type, development zone and percentage of tree cover can be monitored by reexamining the primary sample, a process limited only by available funds and by the degree of resolution provided by the medium. Determining ownership, a tedious job, could be done quickly if tax records were digitized on a computer.

2. Relocate each field plot on the ground. FIA has found 95 to 98 percent of previous established plots during this and other inventories. Most lost plots fall in clearings or burns, areas where the history of such plots is obvious. On relocated field plots, remeasurements describe many thousands of trees, information that FIA can use to determine growth, mortality, timber harvest, change in forest type, change in broad vegetation class, trends in opportunities and problems, and many other important facts about the dynamics of the forest.

DISCUSSION

Escalating concerns for the future of California's hardwood resources have spawned a variety of hardwood-related studies that use data from the recent FIA inventory. Some of this research has originated from within the FIA unit; to cite two examples: an overall analysis of California's hardwood resources (Bolsinger 1987, in press), and the development of a technique to link the inventory data and wildlife habitat models together to assess habitat capabilities statewide (Ohmann 1987).

Other agencies also have tapped this comprehensive supply of information. For example, the Forest and Rangeland Resources Assessment Program of the California Department of Forestry has integrated the FIA data into a geographic information system for use in forest resource planning. And in response to a request in 1983 from the California Board of Forestry, the University of California initiated a hardwood research program in which a number of studies have analyzed information compiled from the inventory. These and other organizations and individuals, public and private, have supported and relied on the recent FIA assessment for a variety of reasons. Among these reasons is an awareness that, for the first time, the analyst, researcher, and policymaker have a comprehensive and updatable source of information to use when addressing and evaluating the critical tradeoffs and opportunities that the State's hardwood resources represent.

ACKNOWLEDGEMENTS

FIA thanks the many organizations and individuals who contributed to this inventory. The California Department of Forestry underwrote the collection of ownership information, provided aerial photos for much of the State, and helped finance field data collection. The National Forest System, Pacific Southwest Region, funded the study to develop the hardwood volume equations and furnished inventory data for the National Forests. The Pacific Southwest Forest and Range Experiment Station helped to train field crews and assisted in defining vegetaTion type classifications. The California Forest Protective Association aided FIA in gaining access to field plots located on over 3,000,000 acres (1,214,575 ha) owned by its membership. The University of California Cooperative Extension publicized the inventory through its "news network." The Soil Conservation Service supplied photo maps, vehicles, and landowner contacts. Finally, FIA thanks the timber companies and other private owners for permission to visit plot locations on their lands.

LITERATURE CITED

Bolsinger, Charles L. California forests, trends, problems, and opportunities. Resour. Bull. PNW-89. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1980. 138 p.

Bolsinger, Charles L. Major findings of a statewide resource assessment in California. 1987 [These proceedings].

Bolsinger, Charles L. An assessment of the hardwoods of California timberlands, woodlands, and savannas. Resour. Bull. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; [in press].

Cochran, William G. Sampling techniques. 2nd ed. New York: John Wiley and Sons; 1963. 413 p.

Ohmann, Janet L. Wildlife habitats of California's hardwood forests--linking extensive inventory data with habitat models. 1987 [These proceedings].

Oswald, Daniel D.; Hornibrook, E. M. Commercial forest area and timber volume in California, 1963. Resour. Bull. PSW-4. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1984. 16 p.

Pillsbury, Norman H.; Stephen, Jeffery A. Hardwood volume and weight tables for California's Central Coast. Sacramento, CA: California Department of Forestry; 1978. 54 p.

Pillsbury, Norman H., Kirkley, Micheal L. Equations for total wood and sawlog volume for thirteen California hardwoods. Res. Note PNW-414. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1984. 54 p.

Wieslander, A. E.; Jensen, Herbert A. Forest areas, timber volumes, and vegetation types in California. Forest Survey Release No. 4. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station; 1946. 66 p.

U.S. Department of Agriculture, Forest Service. Timber resources for America's future. Resour. Pap.14. Washington DC; 1958. 713 p.

U.S. Department of Agriculture, Forest Service. Forest statistics for California. For. Surv. Release 25. Berkeley,CA: California Forest and Range Experiment Station; 1954. 66 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

The Distribution of California Hardwoods: Results of a Statewide Geographic Information System[1]

Abstract: The California Department of Forestry (CDF) has created and utilized a Geographic Information System (GIS) to estimate the distribution and ownership of various cover types, including hardwoods, by county, in the state. Acreage estimates of hardwoods are compared to estimates generated in other studies.

Nancy Tosta and Robin Marose[2]

Crucial to the creation of policies for the protection and use of California's hardwood lands is an understanding of the extent, ownership, silvicultural requirements, and condition of various hardwood species. Because local governments most often control land use and zoning, estimates of various hardwood species by county, and by ownership, are desirable.

To date, there have been relatively few efforts to systematically determine by county, the extent and ownership of California's hardwoods. Charles Bolsinger, as part of the most recent USDA Forest Service Pacific Northwest Research Station (PNW) Forest Inventory of California's private forestlands, located approximately 429 field plots on hardwood lands (Bolsinger, in preparation). One thousand and thirty-three of the total 1457 field plots established had hardwoods present. In addition, a photo interpretation sample of approximately 85,000 points statewide allowed extrapolation of acreage estimates to areas not field sampled. Bolsinger identifed eight oak forest types and ten other hardwood types in his report on the results of the inventory. The data on these types presented in his report are statewide estimates. Data on timberland or woodland hardwoods (not species) are presented by general regions in the state. Acreages by county could not be accurately estimated because of the limited number of field plots.

Another effort, not specifically aimed at hardwood coverage, was the CALVEG mapping of the US Forest Service (Parker and Matyas, 1979). These maps were created in the late 1970's, at a scale of 1:250,000, covering the entire state. They were generated from a manual interpretation of satellite imagery, with a minimum polygon size between 400 and 800 acres. Approximately 16 different hardwood types, identified by dominant species, were mapped in this effort. Acreage statistics were never published.

Two other recent statewide mapping projects have been described in the literature, although neither were designed specifically to map hardwood lands. A.W. Kuchler created a statewide map of the natural vegetation of California, defined as potential vegetation given the absence of human intervention (Barbour, 1977). Kuchler identified two broad-leafed formations, seven mixed broad-leafed/needle-leafed formations, and one oak savannah formation as potential hardwood cover types. This map was produced at a scale of 1:1,000,000. Acreage statistics were not published. In 1978, the California Department of Forestry (CDF), used a computer classification of satellite data to generate a statewide cover type map. Three classes containing hardwoods, differentiated by percent of hardwood canopy, were mapped. The unit of resolution was 1.6 acres. Photo classifications of the data were reproduced at 1:1,000,000 and 1:250,000 scales. Results were published as acreage statistics by county (CDF, 1979).

During the 1930's and 1940's, mapping efforts of the US Forest Service and the Pacific Southwest Forest and Range Experiment Station (PSW) produced large-scale maps of general cover types. Wieslander published a statewide, 1:1,000,000 scale map of cover types in 1945, including two classes containing hardwoods (Wieslander, 1945). He also published statistics of cover types by county (Wieslander, 1946).

None of these efforts have succeeded in characterizing the distribution of hardwoods by county and by ownership. However, through the utilization of Geographic Information System (GIS) technology, it is now possible to combine disparate data sets to yield new statistics. Estimates of cover types by owner class and other political boundaries can be easily generated.

GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY

Over the last fifteen years computer technology for overlaying and analyzing mapped data has become commonly available. The hardware for data capture and presentation, software for

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[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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manipulating mapped data, and the data itself comprise an automated form of a GIS. Data are usually captured by either manually using a cursor and digitizing tablet to "draw" polygons from a map base or by optically scanning mapped information.

The Forest and Rangeland Resources Assessment Program (FRRAP) within the CDF is utilizing a GIS for its periodic assessments of statewide forest and range resources. The data captured in FRRAP's GIS are listed in table 1. The data sources and original format of the data are indicated. These data layers were captured by optically scanning the mapped information. In some instances original data required significant editing and preparation before being digitized. Data layers within the GIS were standardized to US Geological Survey (USGS) quadrangles at a scale of 1:250,000. There are 30 USGS 1:250,000 quads that cover California. Hence, FRRAP's GIS is made up of 30 separate data bases, each representing one quadrangle with approximately 12 layers of mapped information.

All layers within the GIS are stored in cell (raster) format. Each of the original layers is divided by quad into an equal number of cells. Based on the original resolution of the data and FRRAP's data analysis requirements a cell size of approximately 300 acres was selected. This was achieved by dividing each quad into 16,000 cells in a matrix of 100x160 cells. Each layer within each quad was divided into an equal number of cells, with the cover type at the mid-point of each cell determining the cell label. Cell size varies by latitude within the state, ranging from 286 acres per cell at northern latitudes to 322 acres at southern, averaging 300 acres.

The GIS can be used to generate acreage counts of individual layers within the data base or of multiple overlaid layers such as county, cover type, and ownership. Other analyses include techniques such as distance or buffer zone calculations and mathematical modeling of layers.

GIS USE FOR COVER TYPE ESTIMATIONS

The CALVEG mapping was used as the basic vegetation layer within the GIS. The 16 CALVEG classes of hardwood species were aggregated into four broad hardwood cover types as defined by the Wildlife Habitat Relationships Program (WHR) (table 2) (Calif. Dept. Fish and Game 1987). Because of various inaccuracies in the original CALVEG data, including the mapping of relatively large polygons of plant communities, an effort was made to improve the vegetation classification. FRRAP overlaid the 85,000 photo interpretation points of the PNW Forest Inventory and generated new acreages of vegetative cover. These photo interpretation points did not indicate species of plants, but provided a site specific sampling of general class of vegetation (ie. various conifer volume classes, hardwood, chaparral). Photo interpretation points do not cover the US Forest Service lands, so the acreage adjustments that were made did not affect US Forest Service cover types.

To be mapped as hardwood, lands had to have at least ten percent canopy of hardwoods and hardwoods had to be dominant when conifer or shrub types were present. Predominantly conifer producing lands with hardwood understory were not included as hardwood acres in the FRRAP statistics.

An initial count of acreage by cover type, by county, and by owner class was derived using the GIS. These layers were recounted overlaid with the photo interpretation data. Based on the photo interpretation class, acres that had been misclassified on the CALVEG maps were allocated to

Table 1--Information Layers in FRRAP GIS

Data Layer	Original Source	Original Format and Scale
County Boundaries	BLM	Polygons - 1:750.000
Watershed Boundaries	DWR	Polygons - 1:1.000.000
CALVEG	USFS	Polygons - 1:250,000
Cover Types (Derived from CALVEG)		
Census County Subdivisions	US Census	Polygons - 1:600,000
Soil Associations	SCS	Polygons - 1:250,000
Timberland Production Zones	Counties	County Assessor Records
Williamson Lands	Counties/Doc	County Maps - 1:100,000
Photo Interpretation Points	PNW	Digital Coordinates
Field Plot Locations	PNW	Digital Coordinates
Ownership	BLM	Polygons - 1:750,000 and 1:100,000
Deer Herds/Migration	DFG	Polygons - 1:24,000

DWR - Dept. of Water Resources; BLM - Bureau of Land Management; USFS - Forest Service; SCS - Soil Conservation Service, DOC - Dept. of Conservation; PNW - Pacific Northwest Forest and Range Experiment Station; DFG - Dept. of Fish and Game.

Table 2--Classification of Hardwoods

CALVEG Type	WHR Cover Type
Coast Live Oak Interior Live Oak Blue Oak Valley Oak	Valley-Foothill Hardwood
Canyon Live Oak Madrone-Black Oak	Montane Hardwood
Tanoak-Madrone Black Oak Oregon White Oak	Montane Hardwood Conifer
Alder-Willow Mountain Alder California Sycamore Cottonwood	Miscellaneous Hardwood (Riparian sp.)

other cover types. For example, if 10 percent of the photo interpretation points in the mapped non-industrial private ownership, redwood cover type were found to be hardwoods, then 10 percent of the mapped redwood acreage would be allocated to one of the four hardwood cover types based on common vegetation associations found in that region of the state. The ownership would remain non-industrial private.

RESULTS AND DISCUSSION

FRRAP estimates of hardwood cover types by public and private ownership by county are presented in table 3. It is obvious from these numbers that most (71 percent) of the hardwood lands in the state are privately owned. Private ownership of the Valley-Foothill hardwood type is even more prevalent (81 percent). In 18 counties in the state, hardwoods make up more than 20 percent of the total land area within the county (fig. 1). In San Benito County hardwoods cover 48 percent of the total land area.

It is possible to compare the estimates of hardwood acres derived by FRRAP using various techniques within the GIS, with the original CALVEG acreages (as counted with the use of the GIS), and Bolsinger acreages (fig. 2). Comparison of acreage of all hardwoods statewide shows about a 10 percent difference between FRRAP and Bolsinger estimates with 10,676,000 and 9,603,000 respectively. Mapped CALVEG estimates at 10,826,000 acres show less than 2 percent from the adjusted FRRAP estimate. Estimates differ significantly on the ownership of hardwood lands, with FRRAP identifying 9 percent more of these lands as being in private ownership and 12 percent more of hardwoods in public ownership than Bolsinger. CALVEG identifies nearly 11 percent more private hardwood acres than FRRAP, and 21 percent less public acreage.

An examination of hardwood acreage by region points out some significant disagreements in estimates of the location of hardwoods in the state (fig. 3). (Comparisons are not made by ownership because Bolsinger does not report ownership acres by region.) Bolsinger estimates more hardwoods in the North Coast (28 percent more than FRRAP), North Interior (6 percent more than FRRAP), and San Joaquin regions (27 percent more than FRRAP). FRRAP estimates more in the Sacramento, Central Coast, and Southern California regions, with the Central Coast region being a significant 48 percent higher than Bolsinger's.

The differences in results likely point out differences in estimation techniques. Bolsinger utilizes a statistical approach based on a stratified double sample of field plots and photo interpretation point data. Relatively few sample plots, particularly regionally, are used to represent large areas. On the other hand, the mapping approach utilized in the CALVEG effort, with a minimum map unit size of more than 400 acres, overlooks normally occurring inclusions within mapped types. Mapping may tend to favor expected types on a regional basis. For example, in the North Coast, conifer types may be overmapped because hardwoods do not appear in blocks greater than 400 acres, although they tend to be a significant component of many conifer cover types. Conversely, in the Central Coast, large areas mapped as hardwoods may contain many inclusions of grass, shrub, or even conifer types, smaller than 400 acres.

Ideally, a system to determine extent and ownership of the state's hardwoods should build on known data. Geographic information systems offer a means to integrate numerous sets of diverse information for a specific geographic area. The state, as well as counties, can benefit by having the ability to examine different characteristics of any given area. By utilizing a GIS, FRRAP attempted to make the best use of several data sets collected for a variety of purposes. Whether the results are more accurate than other techniques can only be verified by further monitoring and more comprehensive inventories. A GIS provides a means to integrate existing information, but it does not replace the need for original mapped data. Current estimates of hardwood distribution should be utilized to allocate more intensive photo or field sampling for future hardwood mapping and monitoring. Better mapping and integration into geographic information systems should resolve some of the discrepancies is estimates of resource distribution, resulting in improved resource management.

Table 3--FRRAP Estimates of Hardwood Acreage in 1000's of Acres (by county and owner).

COUNTY	VALLEY FOOTHILL			OTHER HARDWOODS			TOTAL HARDWOOD ACRES		
	PRIVATE	PUBLIC	TOTAL	PRIVATE	PUBLIC	TOTAL	PRIVATE	PUBLIC	TOTAL
ALAMEDA	122	11	133	1	0	1	123	11	134
ALPINE	0	0	0	0	2	2	0	2	2
AMADOR	66	2	68	6	5	11	72	7	79
BUTTE	110	11	121	37	25	62	147	36	183
CALAVERAS	96	15	111	11	3	14	107	18	125
COLUSA	128	13	141	8	15	23	136	28	164
CONTRA-COSTA	83	19	102	0	0	0	83	19	102
DEL-NORTE	7	0	7	17	5	22	24	5	29
ELDORADO	67	13	80	49	31	80	116	44	160
FRESNO	445	157	602	15	10	25	460	167	627
GLENN	108	14	122	8	43	51	116	57	173
HUMBOLDT	106	20	126	272	39	311	378	59	437
IMPERIAL	0	0	0	0	0	0	0	0	0
INYO	0	0	0	0	3	3	0	3	3
KERN	322	115	437	93	15	108	415	130	545
KINGS	16	3	19	13	0	13	29	3	32
LAKE	129	26	155	23	90	113	152	116	268
LASSEN	1	1	2	20	16	36	21	17	38
LOS-ANGELES	13	3	16	7	22	29	20	25	45
MADERA	268	39	307	2	4	6	270	43	313
MARIN	43	6	49	5	6	11	48	12	60
MARIPOSA	182	51	233	5	13	18	187	64	251
MENDOCINO	165	30	195	463	105	568	628	135	763
MERCED	89	6	95	1	0	1	90	6	96
MODOC	6	0	6	1	14	15	7	14	21
MONO	0	0	0	0	11	11	0	11	11
MONTEREY	498	114	612	20	62	82	518	176	694
NAPA	125	18	143	32	5	37	157	23	180
NEVADA	105	7	112	34	15	49	139	22	161
ORANGE	4	3	7	0	1	1	4	4	8
PLACER	6	3	9	53	40	93	59	43	102
PLUMAS	1	0	1	29	52	81	30	52	82
RIVERSIDE	1	70	71	8	8	16	9	78	87
SACRAMENTO	10	0	10	0	0	0	10	0	10
SAN-BENITO	351	69	420	5	4	9	356	73	429
SAN-BERNARDINO	0	26	26	12	98	110	12	124	136
SAN-DIEGO	32	28	60	15	8	23	47	36	83
SAN-FRANCISCO	0	0	0	0	0	0	0	0	0
SAN-JOAQUIN	22	0	22	0	0	0	22	0	22
SAN-LUIS-OBISPO	302	38	340	9	40	49	311	78	389
SAN-MATEO	26	10	36	8	3	11	34	13	47
SANTA-BARBARA	155	7	162	0	131	131	155	138	293
SANTA-CLARA	240	24	264	23	9	32	263	33	296
SANTA-CRUZ	51	1	52	19	5	24	70	6	76
SHASTA	229	12	241	58	133	191	287	145	432
SIERRA	0	0	0	16	30	46	16	30	46
SISKIYOU	22	82	104	66	56	122	88	138	226
SOLANO	10	0	10	7	1	8	17	1	18
SONOMA	122	3	125	101	3	104	223	6	229
STANISLAUS	107	4	111	1	0	1	108	4	112
SUTTER	6	0	6	0	0	0	6	0	6
TEHAMA	425	78	503	11	57	68	436	135	571
TRINITY	25	2	27	75	265	340	100	267	367
TULARE	221	159	380	7	14	21	228	173	401
TUOLUMNE	66	83	149	8	9	17	74	92	166
VENTURA	40	3	43	0	110	110	40	113	153
YOLO	90	13	103	0	0	0	90	13	103
YUBA	69	3	72	9	9	18	78	12	90
STATE TOTAL	5933	1415	7348	1683	1645	3328	7616	3060	10676

Figure 1--Hardwood Cover as a Percent of County Land Area

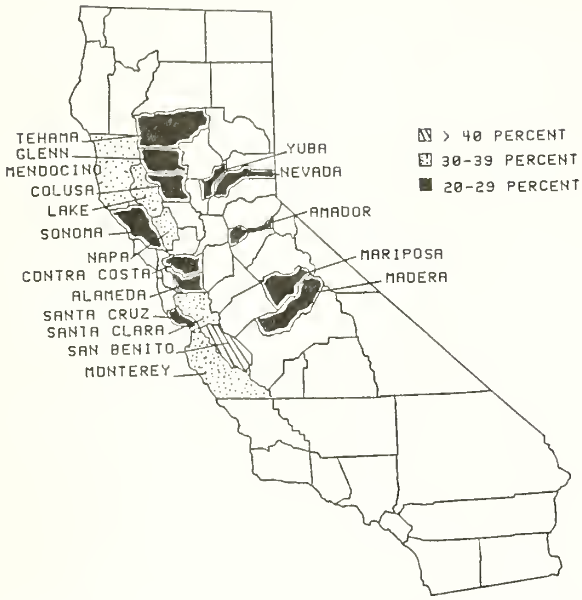


Figure 2--Statewide Hardwood Acreage (Comparison of Acres)

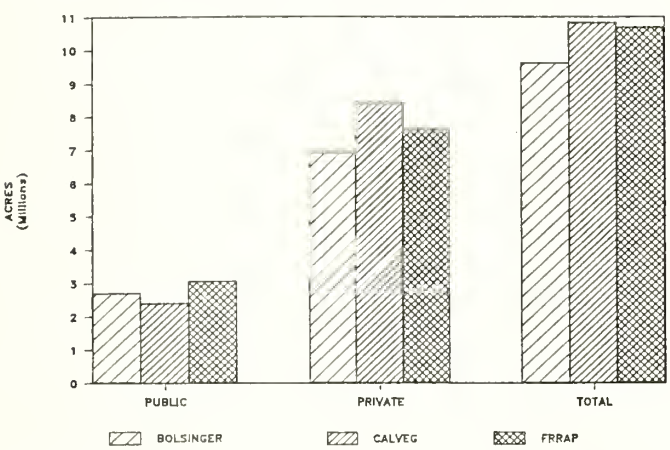
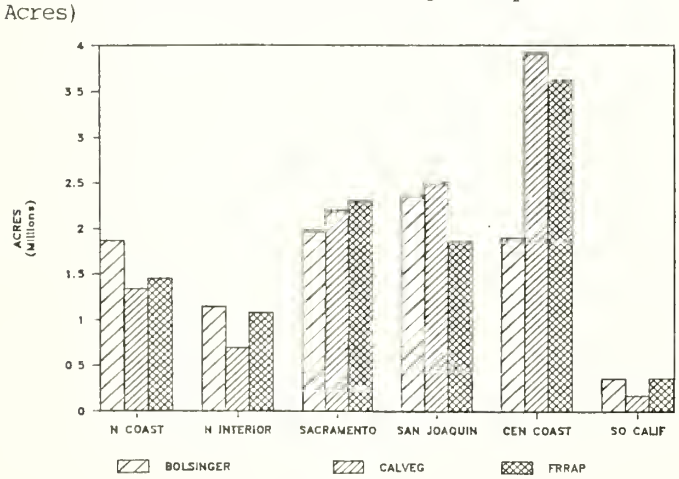


Figure 3--Regional Hardwood Acreage (Comparison of Acres)



References

Bolsinger, C. L., in prep. The hardwoods of California timberlands, woodlands, and savannahs Portland, OR: Pacific NW Res. Stn., Forest Service, USDA.

Barbour, M. G.; Major, J., eds. Terrestrial Vegetation of California. New York: Wiley; 1977.

Calif. Dept. of Fish and Game. Calif. wildlife habitat relationship program. Sacramento, CA.; 1987.

Calif. Dept. of Forestry. California's Forest Resources, Preliminary Assessment, 1979. Chapter 14.

Parker, Ike; Matyas, Wendy. CALVEG, a classification of California vegetation. Revised Edition. December 1979. Forest Service, U.S. Department of Agriculture; Bureau of Land Management, U.S. Department of Interior; California Dept. of Fish and Game.

Wieslander, A. E. Vegetation types of California. Berkeley, CA: Calif. Forest and Range Exp. Stn., Forest Service, USDA; 1945.

Wieslander, A. E.; Jensen, H. A. Forest areas, timber volumes, and vegetation types in Calif. Berkeley, CA: Calif. Forest and Range Exp. Stn., Forest Service, USDA; 1946.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Hardwood Density Distribution Mapping from Remotely Sensed Imagery[1]

John A. Brockhaus and Norman H. Pillsbury[2]

ABSTRACT: Density characteristics of hardwood stands found within a study site defined by the boundaries of the Atascadero 7.5' topographic sheet were mapped using United States Geological Survey (USGS) orthophoto quadrangle maps, National High Altitude Photography (NHAP) color infrared (CIR) photography, and Thematic Mapper Simulator (TMS) digital data. An independent verification data set consisting of 60 hardwood stands, 20 stands per density class, were selected for determining the accuracy of each of the three mapping techniques. The NHAP CIR photography provided the best results with 93% of the 60 verification stands being interpreted as belonging to the proper density class, the interpreted USGS orthophoto sheets had an overall accuracy of 75%, and the TMS digital data 65%. For detailed mapping of hardwood stand densities on a regional basis it is recommended that NHAP, or a similar type of imagery, be used. Initial assessments of individual sites may be conducted with USGS orthophoto maps and field data for calibration purposes.

A significant portion of California's forestland is made up of hardwood forests. Recent studies indicate that public and private demands put upon this renewable resource will continue to increase because of a shrinking land base, increasing population, and greater use of the resource for the production of wood fiber, lumber, wildlife management, and recreation. The forest manager must know where these hardwood resources occur and what their condition is in order to decide how best to balance the many demands on this resource. Remote sensing has the potential for playing a key role in this management by providing accurate, timely and cost effective evaluations of California's hardwood resource.

Aerial photography has been used in volume estimation since the late 1920's, with some of the earliest work being done by Canadians. Seely (1929) used oblique photographs to measure tree heights and relate these measurements to timber volume. Heights, tree counts, and crown density measurements made on aerial photographs were described by Andrews and Torrey (1933), Andrews (1936), and Nash (1948). In the United States it was not until the late 1940's that forest volume estimation from aerial photography become a widespread practice. The work of Rogers (1946, 1947, 1949) and Moessner (1948, 1949) contributed to the promotion of photo-interpretation and photo measurements in the nationwide forest survey.

There are two general approaches to the development and use of aerial photo volume tables, the individual tree approach and stand approach (Paine, 1981). Tree photo volume tables give volume per tree, while the stand photo volume tables give volume per unit area. The chief drawback to the tree volume approach is the difficulty of obtaining accurate crown counts. Pillsbury and Brockhaus (1979) found that visible crown diameter was poorly correlated with individual tree volume for California's central coast hardwoods. This poor correlation was due to the growth habit of the trees with several trees growing in close proximity to one another forming what appears to be one continuous crown on an aerial photo. Stand volume tables use a measure of stand crown closure in addition to average tree height for estimating stand volume. These tables are the most popular method of estimating timber volume primarily because crown closure can be substituted for crown diameters that are often quite inaccurate and difficult to obtain. Pope (1962) produced stand volume tables for

[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Douglas-fir in the Pacific Northwest using several combinations of average stand height, visible crown diameter and percent crown closure. Pillsbury and Brockhaus (1981) demonstrated that percent crown closure alone provided accurate estimates of volume for hardwood stands in California.

STUDY SITE DESCRIPTION

A study site located north of the city of San Luis Obispo, California, was selected for this research. Boundaries of the site are defined by the Atascadero 7.5' USGS topographic map. A wide range of hardwood stand density conditions exist within this site as well as an adequate transportation network providing ready access to the resource for field data collection.

The area is part of the Santa Lucia Mountain Range typified by low rolling hills and rugged mountains. Streams and rivers throughout the area are typically dry during summer months and freeflowing only during the winter wet season. Natural vegetation within the study site may be classified into three types: 1) grassland; 2) woodland; and 3) shrubs. Within the grasslands annual grasses predominate during the winter and spring, with herbaceous plants generally being more conspicuous during late summer and autumn. Woodlands are made up of three hardwood species with coast live oak (*Quercus agrifolia* Nee.) found on protected slopes, and blue oak (*Quercus douglasii* Hook. and Arn.) on exposed drier slopes, while white oak (*Quercus lobata* Nee.) is found primarily on valley bottoms. A substantial portion of the site is generally termed chaparral and is composed of several different species of shrubs.

METHODOLOGY

Research completed by Pillsbury (1978) succeeded in quantifying stand density characteristics for native hardwood species in California's central coast. Three stand density classes were identified and described by class average and a range of values for volume, weight, and basal area (Table 1). In addition, a simple and inexpensive method of determining the stand density class for a site with a wedge prism was developed. During the course of the field investigative phase of this study it was noted that not only were the three density classes distinct from one another in terms of volume, weight, and basal area but that each appeared to be associated with a different range of canopy crown closure.

Table 1.--Hardwood stand density class ranges and averages (Pillsbury, 1978).

A. Stand density class ranges.

Density Class	Gross volume per area cubic ft/ac	Green weight per area tons/ac	Basal area per area sq. ft/ac
Low	1-1430	1-55	1-70
Medium	1431-4300	56-135	71-155
High	4300+	136+	156+

B. Stand density class averages.

Density Class	Avg. Gross volume/area cubic ft/ac	Avg. Green wt./area tons/ac	Ave. basal area sq ft/ac
Low	974	32	37.3
Medium	2335	80	105.9
High	6862	206	220.7

A follow-on project (Pillsbury and Brockhaus, 1981) was conducted to determine the reliability of using aerial photography for mapping the spatial distribution of hardwood stand density throughout a four-county region in central California. The NASA-AMES Research Center, Moffett Field, California, provided complete CIR aerial photographic coverage at a scale of 1:130,000. Initial interpretation of the photography indicated that three crown closure classes could be identified: 1) 10-35 %; 2) 36-75%; and 3) >75% crown closure. Individual hardwood stands were delineated on the photography and assigned to one of the three crown closure classes, then outlined stands were transferred to a map base using a stereo zoom transfer scope.

A limited field investigation of the photo interpreted data showed that the actual stand density class of selected hardwood stands visited in the field corresponded to the stand density as interpreted from the aerial photography 85% of the time. These results were very encouraging and indicated that this type of aerial photography could reliably be used to map the distribution of hardwood stands and their associated density class on a regional basis. However, the photography used was flown specifically for this study and may not be available in the future for other sites throughout California. Other types of remotely sensed imagery do exist providing extensive coverage of the hardwood resource within California which are readily available to the general public and resource management agencies. It was decided that additional research needed to be conducted to determine which of the public domain imagery provides the most satisfactory results in terms of accuracy when mapping hardwood stand density characteristics. Since it was not feasible to study all of the various types of imagery which are available, three types of imagery available were selected which represented a range in both cost and type of imagery: 1) 7.5' USGS orthophoto map sheets; 2) CIR prints at a scale of 1:60,000 provided by the NHAP mission; and 3) digital TMS data.

Interpretation of USGS Orthophoto Imagery

An orthophoto is a photo reproduction that has been corrected for tilt, topographic displacement, and sometimes camera lens distortion. The reproduction process results in an orthophoto which is planimetrically correct, allowing the photo interpreter to make accurate measurements of distance, area, and direction directly on the orthophoto. Because an orthophoto is planimetrically correct it is considered to be a map. The USGS produces orthophoto maps which correspond to the 7.5' series of topographic quadrangle sheets, and an Atascadero orthophoto map was obtained from the USGS for use in this study.

A sheet of clear mylar was overlayed and secured to the orthophoto map. Interpretation of the imagery began at the northwest corner of the map and continued to the southeast corner. Interpretation of this imagery was a three phase process: 1) what appeared to be homogeneous hardwood stands in terms of crown closure were identified; 2) boundaries of these stands were then delineated on the mylar with an ultra fine point Pilot Pen; and 3) the density class of the stands were determined through an iterative process of elimination (i.e. is the crown closure greater than 10%, if greater than 10% is it less than 35%, etc.) and then annotated on the mylar within the boundaries of the stands. This process was continued until each portion of the orthophoto map had been interpreted.

Interpretation of NHAP CIR Aerial Photography

High altitude aerial photography has proven to be a valuable source of information for many federal and state agencies. In 1978, several agencies decided to coordinate their data acquisition activities because photographic coverage was lacking in some areas and duplicated in others, and many different photographic formats were used. Fifteen federal agencies have provided support for the NHAP program which began in 1980 and is being coordinated by the USGS. Under the NHAP program the USGS is systematically acquiring both black and white and CIR photographic coverage of the lower 48 states. Complete coverage of these states is expected to be done by the end of 1986. Requirements for a repeat cycle are being developed, but continuity of the program is not guaranteed.

NHAP 9" x 9" CIR photographic prints at a nominal scale of 1:60,000 were obtained from the EROS Data Center, Sioux Falls, South Dakota. Mylar sheets were secured to the photographs, and effective areas for each photograph were then delineated prior to interpretation. Interpretation of this imagery occurred in four steps: 1) hardwood stands with homogeneous crown closures were interpreted on NHAP stereo pairs with an Old Delft scanning stereoscope; 2) boundaries of these stands were delineated using the Pilot Pens described previously; 3) density class of the stands were determined and annotated on the mylar; and 4) photo interpreted detail were then transferred to a map base (USGS 7.5' orthophoto map) with a stereo zoom transfer scope.

Classification of TMS Digital Data

The Thematic Mapper (TM) is a satellite based scanner with seven bands chosen to enhance vegetation analysis, particularly agricultural applications. The first six bands (three visible, three reflective infrared) have a resolution of 30 m. The TMS is a NS001 multispectral scanner mounted on a NASA C-130B aircraft. This scanner contains the seven TM wavebands plus a band from 1.0 to 1.3 micrometers, and collects data at the same spatial resolution as the TM. In cooperation with the NASA-AMES Research Center TMS digital data were acquired providing complete coverage of the study site.

The first step in analyzing the TMS data was to extract the digital data representing the hardwood resource within the study site. It was felt that since three distinct cover types occur within the study site a preliminary classification of the data into a smaller number of data clusters might result in one of the clusters representing hardwood stands. Principal components analysis of the visible and reflective infrared TMS bands was conducted as a means of reducing this six band data set to a one or two band data set which would be more feasible for cluster analysis and at the same time not incur a significant loss of information content. It was found that the first principal component derived from the six TMS bands represented 91% of the variance contained within these bands. Interactive clustering of the first principal component produced three clusters which corresponded to the three cover types found in the study site. Areas clustered as hardwood stands were then used to extract pixel digital values from the six TMS bands forming a data set of TMS reflectance values for hardwood stands only.

Texture analysis of this data was then conducted to create a data set which indirectly gives a measure of stand crown closure by quantifying the contrast of pixels occurring within any given stand. For example, a low density stand would have a larger numerical texture value than a high density stand as a result of the difference in values between pixels representing grass and those representing hardwoods within the low density stand. Nine hardwood stands, three per density class, whose density class were known were selected as being representative of the three density categories. Textural data for these stands were extracted and used to develop three stand density texture signatures. These signatures were then applied to the hardwood texture data through a table look-up minimum distance classifier which assigned each hardwood pixel into one of the three density classes.

RESULTS AND DISCUSSION

In an effort to determine the accuracy of each mapping effort an independent verification data set was selected. Sixty hardwood stands whose stand densities were known from previous mapping efforts were chosen as being representative of the range of density conditions occurring throughout the study site. These 60 stands were identified within each of the three interpreted maps and the agreement between the actual and interpreted or classified stand densities were tabulated in the form of contingency tables.

Analysis of the contingency table (Table 2) for the orthophoto imagery shows that although the overall accuracy is 75%, 45 of the 60 stands were correctly interpreted; individual stand density category accuracies range from 65% for the medium density class to 85% for the high density category. The relatively high interpretation accuracies achieved for the high and low density classes, 85 and 80% respectively, were not unexpected. These two classes represent the upper and lower limits of crown closure to be interpreted resulting in fewer and easier decisions to be made by the photo interpreter.

As was anticipated the majority of interpretation errors were associated with the medium density category. Opportunities for confusion within this category are higher because it is an intermediate crown closure class requiring more decisions to be made by the interpreter. The low accuracy level, 65%, for this density category seems to support this, however, the majority of interpretation errors did not occur when medium density stands were assigned to the high or low density class but when medium density class stands were interpreted as shrubs.

Table 2--Contingency table for interpreted orthophoto map

		Predicted density class				
		1	2	3	Other	Total
Actual Density Class	1	17	3	-	-	20
	2	2	13	1	4	20
	3	-	2	16	2	20
	Total	19	18	17	6	60

Note:
1- High density hardwood stands.
2- Medium density hardwood stands.
3- Low density hardwood stands.
Other- Non hardwood cover types.

This would seem to be a serious error on the part of the interpreter until the reasons for it are identified. Two distinct types of understory vegetation are visible within medium density stands, grass and shrubs. The type of understory present has a significant impact on the texture of a stand as it is interpreted on the imagery. Grass understories contrast sharply with the hardwood overstory resulting in a rough texture which makes the determination of crown closure a much simpler process. Shrub understories may often attain a height of ten feet and appear very similar to the hardwood overstory in terms of gray tone. This results in a very smooth texture which may cause the interpreter to: 1) misinterpret the stand as shrub since this condition often occurs when hardwood stands are found within a larger area dominated by shrubs; or 2) if properly interpreted as a hardwood stand to overestimate crown closure because of the poor contrast between the overstory and understory vegetation. Thus, these errors do not represent "blunders" on the part of the interpreter, but normal interpretation errors due to the characteristics of the imagery being used and the vegetation types being discriminated.

Results of the verification of the NHAP imagery were very encouraging. An overall accuracy of 93% was attained, 56 of the 60 hardwood stands used for verification were properly interpreted (Table 3). Individual class accuracies ranged from 90% for the medium density category to 95% for the high and low density classes. Errors were never across more than one class; i.e., a low density stand was never interpreted as a high density stand, and a high density stand was never interpreted as a low density stand. Half of the interpretation errors occurred when medium density stands were interpreted as belonging to the high density class. In both of these cases each stand was located on a steeply sloped northern aspect with a significant amount of shadowing evident within the stand causing crown closure to be overestimated. It is important to note that the problems which arose in the interpretation of medium density stands with a brush understory were not encountered with the NHAP imagery. The reason for this is twofold: 1) on CIR film hardwood stands appear as various shades of magenta while brush is blue making discrimination between the two a straightforward process; and 2) the ability to see in the third dimension allowed the interpreter to more easily determine crown closure when the understory was near the level of the overstory. Although a number of hardwood stands were omitted from the interpretation of the orthophoto imagery due to confusion with shrubs, it is felt that the distinct color contrast between the two vegetation types on CIR film allowed the interpreter to identify

Table 3. Contingency table for interpreted NHAP CIR photography.

Actual Density Class	Predicted density class 1	2	3	Other	Total
1	19	1	-	-	20
2	2	18	-	-	20
3	-	1	19	-	20
Total	21	20	19	-	20

Note:
1- High density hardwood stands.
2- Medium density hardwood stands.
3- Low density hardwood stands.
Other- Non hardwood cover types.

Table 4--Contingency table for classified TMS digital data.

Actual Density Class	Predicted density class 1	2	3	Other	Total
1	15	2	-	3	20
2	2	14	1	2	20
3	-	2	10	8	20
Total	17	18	11	13	60

Note:
1- High density hardwood stands
2- Medium density hardwood stands
3- Low density hardwood stands
Other- Non hardwood cover types

every hardwood stand in the study site with the NHAP photography.

Results obtained from the analysis of the TMS digital data showed that there was significant difficulty in identifying low density hardwood stands. As can be seen from the TMS contingency table (Table 4) 50% of the low density hardwood stands were classified properly. Of the ten stands assigned to another category two were classified as being in the medium density hardwood class, the remaining eight stands were omitted from the hardwood categories altogether. These errors occurred in the initial pre-classification stage when the principal components data were clustered to develop vegetation type strata. Open grown hardwood stands with low crown closure values were included in the grassland strata due to the open nature of the stand. A majority of the digital values within these stands actually represent the grass understory and thus were put into that strata, whereas, with the aerial photography and orthophoto imagery the photo interpreter was able to "see the forest through the range" by interpreting the site instead of individual pixels as was the case with the TMS data. Low accuracy levels were also attained for the medium and high stand density classes as well, 70 and 75% respectively. Classification errors between the medium density category and the other two classes were expected. Two stands were classified as high density and one as low density, however, two additional stands were mis-classified as non-hardwood types due to their location on steeply sloped northern aspects which were severely shadowed. Similar classification errors occurred within the high density class. Three of the five errors were instances where the stands were on northern aspects with significant shadowing. Pre-processing of the data to compensate for severe shadowing may have alleviated this problem which could have resulted in the correct classification of these stands, thus increasing the overall accuracy of the classification.

CONCLUSIONS

Analysis of the verification data set for each of the three mapping techniques results in the following ranking of interpretation accuracy: 1) National High Altitude Photography color infrared imagery, 93%; 2) United States Geological Survey orthophoto maps, 75%; and 3) Thematic Mapper Simulator digital data, 65%. Clearly, interpretation of the NHAP CIR photography will provide the best results for a detailed mapping of hardwood stand density characteristics. Equipment required for the proper interpretation of this imagery include a mirror stereoscope and some type of optical transfer device such as a zoom transferscope, if a stereo zoom transferscope is available then interpretation and transfer of detail may be completed in one step. Although the interpretation of the orthophoto imagery only provided an overall accuracy of 75%, individual class accuracies for the high and low density categories were 80% and above. Based upon these values this imagery could be used for the initial assessment of hardwood stand density conditions for a specific area, however, for an intensive inventory the orthophoto's would need to be supplemented with other imagery and field data. Results obtained from the analysis of the digital TMS data were poor, but this is not to imply that better results cannot be achieved using these data, as the approach taken is just one of many alternatives available for analysis of these data. For example, stratification by texture instead of by clustering of principal components data may result in better discrimination of low density stands by defining a textural signature such as photo interpreter would do. It is doubtful that the TMS accuracy could be improved to a level which would exceed that which can be expected from the use of NHAP CIR photography. Analysis of the TMS data requires the most technically complex and expensive equipment of the three image types studied: 1) a Central Processing Unit, either mainframe, mini or micro; 2) a high resolution color display monitor; 3) image processing software; and 4) an output device such as a plotter or film recorder.

ACKNOWLEDGEMENTS

The authors would like to thank the Forestry Department, School of Forest Resources, North Carolina State University, for the use of their photogrammetry laboratory which was used to complete the photo-interpretive phase of this research. Analysis of the TMS digital data was conducted at the Computer Graphics Center (CGC), North Carolina State University, funding for this analysis was obtained through the CGC faculty development seed grant program. We would also like to acknowledge Mr. James Brass of the NASA-AMES Research Center who was instrumental in acquiring the TMS data used in this research.

BIBLIOGRAPHY

Andrews, G. S. 1936. Tree heights from air photographs by simple parallax measurements. Forestry Chron., vol. 12, no. 2, pp. 152-197.

Andrews, G. S.. and L. G. Torrey. 1933. The use of aerial photographs in forest surveying. Forestry Chron., vol. 9, no. 4, pp. 33-59.

Moessner, K. E. 1948. Photo classification of forest sites. Soc. Am. Foresters, 1948 Proc., pp. 278-291.

Moessner, K. E. 1949. A crown density scale for photo interpreters. J. Forestry, vol. 47, no.7, pp. 569.

Nash, A. J. 1948. Some volume tables for use in air survey. Forestry Chron., vol. 24, no. 1, pp. 4-14.

Paine, D. P. 1981. Aerial photography and image interpretation for resource management. John Wiley and Sons, New York, New York, 571 pp.

Pillsbury, N. H. 1978. Hardwood stand density characteristics for central coast counties in California. USFS and SCS.

Pillsbury, N. H., and J. A. Brockhaus. 1979. Tree photo volume and weight tables for California's central coast. Calif. Dept. of Forestry, USFS, and the SCS.

Pillsbury, N. H., and J. A. Brockhaus. 1981. Hardwood biomass inventory maps for California's central coast. Calif. Dept. of Forestry, USFS, and the SCS.

Pope, R. B. 1962. Constructing aerial photo volume tables for Douglas-fir in the Pacific Northwest. U. S. Forest Service, Pacific Northwest Forest and Range Expt. Sta. Research Note no. 214.

Rogers, E. J. 1946. Use of parallax wedge in measuring tree heights on vertical aerial photographs. U. S. Forest Service, Northeastern Forest Expt. Sta., Forest Survey Note no. 1.

Rogers, E. J. 1947. Estimating tree heights from shadows on vertical aerial photographs. U. S. Forest Service, Northeastern Forest Expt. Sta., Sta. Paper No. 12.

Rogers, E. J. 1949. Estimating tree heights from shadows on vertical aerial photographs. Jour. Forestry, vol. 47, no. 3, pp. 182-191.

Seely, H. E. 1929. Computing tree heights from shadows on aerial photographs. Forestry Chron., vol. 5, no. 4, pp. 24-27.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Thematic Mapper Analysis of Coast Live Oak in Santa Barbara County[1]

Frank W. Davis[2]

Abstract: Thematic Mapper Simulator (TMS) data from July 1984 and Thematic Mapper (TM) data from December 1984 are analyzed to map coast live oak woodland and forest near Lompoc, in northern Santa Barbara County. Using summer data, land cover, oak forest and oak woodland are mapped with 89 percent, 77 percent and 95 percent accuracy respectively. Using winter data, land cover, oak forest and oak woodland are mapped with 84 percent, 94 percent and 86 percent accuracy, but systematic commission errors make this map less useful than that based on summer data

Integrated management of California's hardwood resources requires accurate up-to-date information on the distribution and stocking of vegetation types which collectively cover over 3.1X10^6 hectares on private land alone (Passof and Bartolome 1985). Satellite data can be used to monitor hardwood cover over this large area (e.g., Newland et al. 1980), but research is still needed to guide the choice of sensor system(s), algorithms for data handling and image processing, vegetation classification, map accuracy tolerance, and digital ancillary data. Here I analyze the performance of Thematic Mapper (TM) data in mapping coast live oak (Quercus agrifolia Nee) forest and woodland. My objectives are to:

(1) examine the spectral separability of vegetation classes containing oaks, in summer and winter TM imagery

(2) test the use of ancillary environmental data to improve discrimination of vegetation classes

(3) evaluate the accuracy and bias of vegetation maps derived from summer and winter TM data.

BACKGROUND

Three satellite-borne radiometric sensors currently provide synoptic coverage of California, including the Landsat TM, the Landsat Multi-spectral Scanner (MSS), and the NOAA Advanced Very High Resolution Radiometer (AVHRR). The minimum cell (pixel) size of these satellites is 30X30 m, 80X80 m, and 1.1X1.1 km respectively. The Landsat systems provide repeat coverage every 18 days; AVHRR is on a 12 hour repeat cycle. AVHRR data are especially suited to mapping land cover or biomass over very large areas up to continental scale, but are too coarse to reliably map regional natural vegetation (Tucker et al. 1985).

The Landsat MSS has 4 channels measuring albedo in the blue, green, red and near-infrared wavelengths. The Landsat TM has 7 channels, including two mid infrared-red channels and a thermal channel not available on the MSS (Table 1). TM data are superior to MSS data in terms of radiometric quality and resolution, cartographic accuracy and spatial resolution (Walker et al. 1984, Anuta et al. 1984, Malila 1985). Cartographic accuracy is especially important if the data are to be incorporated into a geographically referenced computer database.

The improved spatial resolution of TM over MSS does not guarantee higher accuracy in mapping natural vegetation. With increasing resolution, a vegetation stand is decomposed into its constituent elements (e.g. trees, gaps, shadows), and the accuracy of stand classification is accordingly reduced (Sadowski and Sarno 1976, Toll 1985). This problem is significant for woodlands comprised of scattered large trees in a shrub or grassland matrix (Lacaze et al. 1983). In TM mapping of complex vegetation mosaics, however, loss in accuracy due to increased within-stand spectral variation may be more than offset by improved discrimination of stand margins, the information provided by the three additional bands, as well as by the greater dynamic range of TM vs. MSS data (256 vs. 128 level quantization) (Toll 1985, Teillet et al. 1981).

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[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Because of its higher spatial resolution and 3 additional bands, TM generates more than twelve times as much data per area as MSS, increasing storage and processing costs. However, a subset of 3 bands including a visible band, the near-infrared and a mid-infrared band provides almost as much discrimination of vegetation cover

Table 1. Thematic Mapper Spectral Characteristics (after Tucker (1978))

Band	Wavelength	Related Vegetation Features
TM 1	0.45-0.52 (blue)	Photosynthetic pigments
TM 2	0.52-0.60 (green)	Green biomass
TM 3	0.63-0.69 (red)	Chlorophyll
TM 4	0.76-0.90 (near infra-red)	Plant biomass
TM 5	1.55-1.75 (mid infra-red)	Leaf water content
TM 7	2.08-2.35 (mid infra-red)	Leaf water content
TM 6	10.4-12.5 (thermal infra-red)	Surface temperature

types as all seven bands (Williams and Nelson 1986, Benson and DeGloria 1985, Horler and Ahern 1986). Alternatively, because of the high correlation between bands, the first three or four principal components of the original bands, which typically contain 90-97 percent of the total variance in the data, may be used for scene classification (Horler and Ahern 1986).

TM data have been used successfully to monitor biomass or to map cover classes in a wide range of vegetation types including grassland, hardwood forest, coniferous forest and shrublands (Williams and Nelson 1986, Teillet et al. 1981, Horler and Ahern 1986, Franklin 1986, Davis et al. 1986). The ability to distinguish vegetation classes depends very much on the season in which the image is acquired, atmospheric conditions and the ruggedness of topography. Landsat data acquisition is fixed at 9:40 am local time when vegetation in shadow may be difficult to discriminate. Terrain effects can be partly overcome by image enhancement and band ratio methods (Yool et al. 1986), or by incorporating digital topographic data into the classification process (e.g. Strahler 1981, Guindon et al. 1982).

STUDY AREA

I have analyzed vegetation pattern in the Burton Mesa and Purisima Hills (latitude 34° 38' N, longitude 120° 27' W). The climate is Mediterranean with a strong maritime influence, with relatively cool summers and mild winters. Over 90 percent of the 34 cm average annual precipitation falls between November and April.

The Burton Mesa is underlain by marine sedimentary rocks covered with Orcutt sandstone, 0.5 to 40 m of weakly cemented Quaternary aeolian sands (Dibblee 1950). Level upland expanses from 100 to 120 m above sea level are dissected by streams that have formed wide valleys with short steep slopes. Most of the valley bottoms are developed or under cultivation. Uplands are covered by "sandhill chaparral," an oak woodland comprised of coast live oaks scattered among hard chaparral species such as Adenostoma fasciculatum, Arctostaphylos rudis, A. purisima, Ceanothus ramulosus var. fascicularis, and C. impressus. Upland areas have been subjected to livestock grazing, clearing and burning, and the oak woodland is now one element in a mosaic of vegetation types including grassland, coastal scrub, and hard chaparral (see Ferren et al. 1984 for a fuller description). Coast live oak forests occur near streams and on steep north facing slopes. Dry exposures are dominated by Salvia mellifera or other coastal scrub species.

The Purisima Hills border the Burton Mesa to the north and are a northwest-southeast trending anticline of marine sedimentary rocks including clays, mudstone, diatomaceous shale and sandstone (Dibblee 1950). Elevations range from 225 to 450 m, and the topography consists of rolling hills with short steep slopes and narrow valley bottoms. Predominant vegetation types include coastal sage scrub, chamise chaparral, Bishop pine (Pinus muricata) forest, grassland, and coast live oak savanna, woodland and forest. Cole (1980) and Wells (1962) have documented the association of vegetation in the region with geology, topography and fire.

METHODS

Imagery

Cloud-free Thematic Mapper Simulator data were acquired on July 13, 1984, at midday with a Daedelus Airborne Thematic Mapper flown on a U-2 aircraft at an altitude of 21,340 meters. Ground resolution of the original data was 28 m. The data were resampled to 30 m resolution and registered to U.S. Geological Survey 30-meter digital elevation data of the Lompoc Quadrangle (Universal Transverse Mercator projection) using bilinear interpolation. No atmospheric corrections were made.

Cloud-free TM data were collected on December 14, 1984 (Scene I.D. 5028818043), and were initially processed by the Thematic Mapper Image Processing System at the Goddard Space Flight Center as a "P" tape (NASA 1983). The data were registered to the digital elevation data by bilinear interpolation.

The first six bands of the TMS and TM data were reduced to three principal component bands using the Video Image Communication Analysis and Retrieval (VICAR) image processing system. Initial analyses showed that the thermal band was not useful for distinguishing natural vegetation classes, so this band was excluded from the analysis. For the TMS data, the first three principal components captured 76.2 percent, 12.9 percent and 6.5 percent of the variance (95.6 percent total) in the original scene. For the TM data, the first three components accounted for 83.7 percent, 10.0 percent and 5.2 percent of the variance (98.9 percent total).

Several topographic parameters derived from the digital elevation data, included slope, exposure, "southness" (sin(slope) X cos(exposure), where slope is in degrees and exposure is measured as degrees from south), drainage basin position, and solar illumination of the study area at the time of the December satellite overpass, using the QDIPS image processing system (Frew and Dozier 1982).

Spectral separability of Vegetation Classes

The study region was stratified into six subregions, and in each region, 15-30 vegetation stands were subjectively selected which were at least 60X60 meters in area and could be easily located in the images due to their proximity to obvious cultural or natural features such as roads, ridges, etc. Stands were classified into one of the vegetation classes listed in Table 2. A single pixel was sampled from the center of each stand, and its spectral and topographic values obtained from the corresponding images.

Class separability was measured using stepwise discriminate analysis for both the summer and winter scenes. The first three principal components of the spectral data as well as southness, illumination and drainage basin position were tested as discriminate variables.

Vegetation Mapping

Natural vegetation classes can be spectrally heterogeneous in satellite imagery due to within-class variations in species proportions or composition and various terrain conditions. For this reason it is difficult to use spectral pattern recognition to assign pixels to vegetation classes based on training sites (sometimes referred to as "supervised classification"). An alternative method developed and described by Strahler (1981) was used here.

First pixels were clustered into a pre-defined number of spectral classes (100 in this case) using the VICAR program USTATS (agglomerative centroid sorting, average link clustering). Each class was displayed on a video screen and identified as to vegetation type by analysts familiar with the study area. Spectral groups were combined to produce a preliminary vegetation map. The preliminary map was analyzed for systematic errors, and spectral classes relabeled and recombined as necessary to produce the final map.

An additional step was required to map vegetation from the winter TM scene. Because of the low sun angle in December, much of the area was in shadow. Vegetation discrimination was improved by first separating the image into sunlit and shadowed areas, and performing separate cluster analyses on each of the sub-images.

The final vegetation maps from summer and winter scenes contained a fair amount of "noise," that is high-frequency variation in vegetation stands at the spatial scale of the TM sensor. Some of this high frequency information was removed from the final vegetation maps by moving a 3X3 pixel window over each image and assigning the center pixel of the window to a vegetation class if that class occurred in at least five of the surrounding eight pixels.

Map accuracies were determined by comparing predicted to observed vegetation for a sample of 140-171 pixels, located and labeled as described in the previous section. Errors of commission (mapped as Class A when not Class A) and omission (not mapped as Class A when Class A), as well as overall map accuracy (sum of class accuracies each weighted by the proposition of the map in that class) were calculated from the resulting "confusion matrix" (Card 1982).

ANALYSIS AND RESULTS

Spectral Separability of Vegetation Classes

Loadings of TM bands 1 through 6 on the first three principal components of the summer scene are shown in Figure 1. Larger absolute magnitudes for the loadings indicate increased contribution of the original band to the score in the principal component channel.

Nearly identical results were obtained for the winter scene. Roughly equal loading of TM bands in the first principal component (PC1) indicates that this axis measures total albedo or "brightness" (Horler and Ahern 1986). The near-infrared band has a high positive loading in the second principal component, while the mid-infrared channels have negative loadings, suggesting that PC2 is positively related to leaf area or "greenness" (see Table 1). PC3 accounts for only 6.5 percent of scene variance, but a large negative loading for the blue band and positive loadings for all infrared bands suggests a positive relationship between this component and actively growing vegetation (the brightest features in the PC3 image are irrigated fields and a golf course).

Principal components 1 and 2 are the most important variables for discriminating natural vegetation classes in the summer TMS scene (Figure 2), although PC3 is also significant. Summer grassland is distinguished by high PC1 scores and low PC2 scores. The presence of oaks in the grassland substantially reduces values in PC1 and increases them in PC2, and some oak grassland pixels overlap with oak woodland or oak forest. Summer chaparral has low values in PC1 and PC2, and is distinct from all other classes except for some overlap with oak woodland. There is considerable overlap between summer oak woodland and oak forest, both of which have very low brightness and high greenness associated with high ground cover and leaf area.

The jackknifed classification of summer sites based on the discriminate functions is only 73.9 percent correct Figure 3, Table 3). The jackknifing procedure involves repeatedly removing individual training

Table 2 Description of Natural Vegetation Map Classes

Class	% Oak Cover	Dominant Species
Coast live oak forest	>60	Quercus agrifolia Toxicodendron diversilobum
Coast live oak woodland	20-60	Quercus agrifolia Adenostoma fasciculatum Arctostaphylos spp.
Coast Live oak grassland	10-20	Quercus agrifolia Bromus rigidus B. mollis Avena barbata
Chaparral	0-20	Adenostoma fasciculatum Ceanothus ramulosus C. impressus Arctostaphylos rudis A. purisima
Coastal Scrub	0-20	Salvia mellifera Baccharis pilularis Ericameria ericoides Artemisia californica
Grassland	0-10	Bromus spp. Vulpia spp. Avena barbata
Conifer Forest	0-30	Pinus muricata Quercus agrifolia Heteromeles arbutifolia
Riparian woodland	0-20	Salix spp. Platanus racemosa

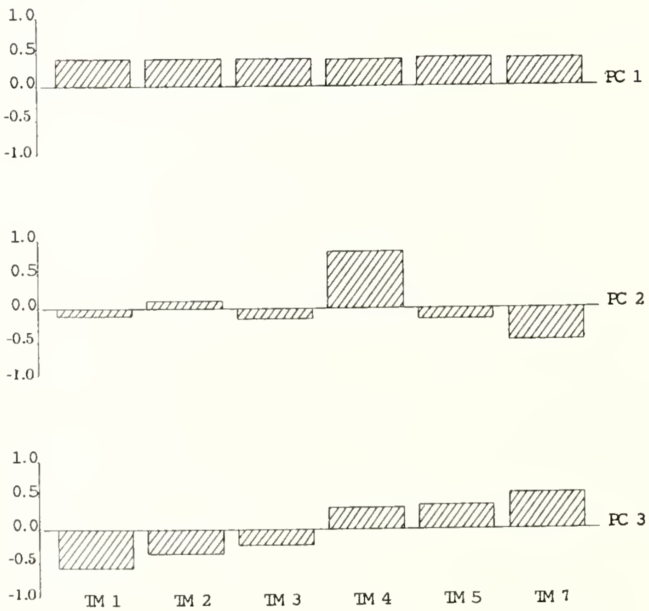

Figure 1. Loading on TM bands 1-7 on the first 3 principal components, TMS data for Lompoc, July 1984.

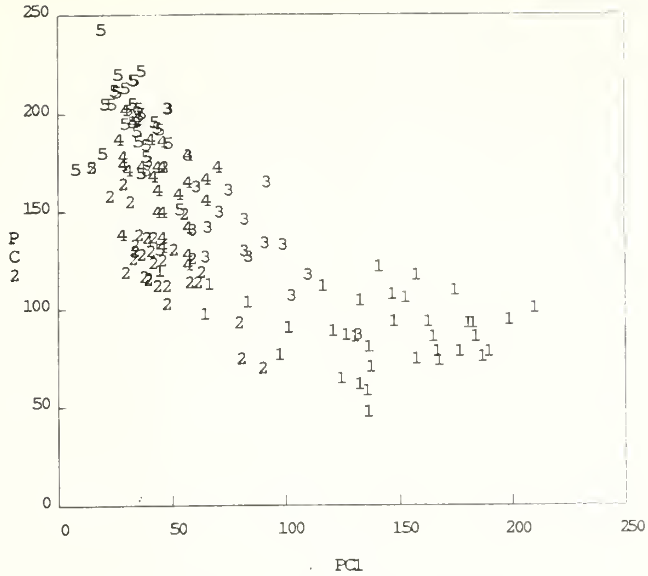

Figure 2. Scatter plot of training sites in principal components 1 and 2, July scene. 1-grassland, 2-chaparral, 3-oak grassland, 4-oak woodland, 5-oak forest.

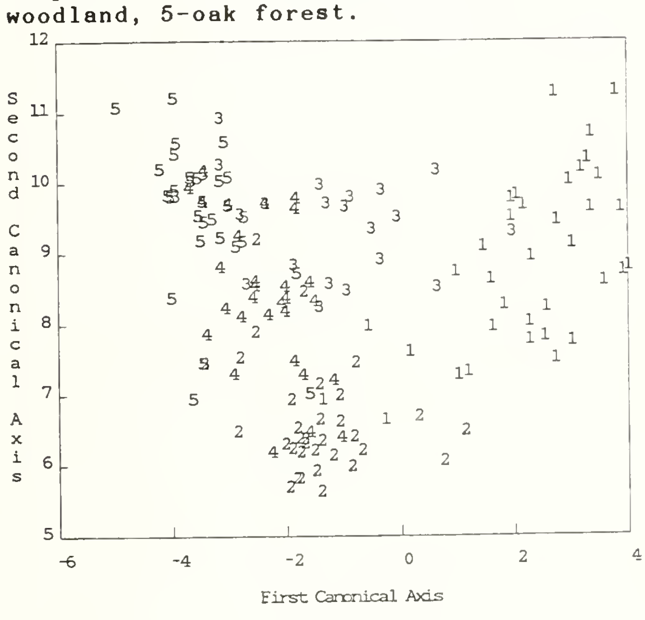

Figure 3. Discriminate analysis of training sites with variables July PC1, PC2, and PC3. 1-grassland, 2-chaparral, 3-oak grassland, 4-oak woodland, 5-oak forest.

observations, recomputing group means and cross products, and measuring the distance from the removed observation to the groups formed by the remaining cases. Based on jackknifed classification accuracies, oak woodland and oak grassland are most frequently misclassified. This is largely due to the spectral variability of these vegetation types at TM spatial resolution.

Vegetation classes are not as spectrally distinct in the winter scene, and PC1 and PC3 are the most important spectral variables (Table 4). Winter grassland is distinguished by high brightness and greenness, and by high values in PC3. The remaining classes share low values in all three principal components and are not easily discriminated. Much of the spectral variation within classes is related to variations in illumination. Thus oak forest is lowest in PC1, PC2 and PC3 in part because this class occurs characteristically on steep north-facing slopes and ravines which are in shadow at the time of satellite overpass (Davis et al. 1986). When terrain variables are included in a stepwise discriminant analysis, the illumination factor is the second variable to enter, and two discriminant axes based on PC1, illumination and PC3 significantly improve class separability (Figure 4). The illumination image also slightly (but significantly) improved discrimination of vegetation classes using the summer data.

The jackknifed estimate of classification accuracy for winter sites in 53.1 percent, and poorest results are again obtained for oak grassland and oak chaparral (Table 4). Variation in these types are partly due to TM sensor resolution, but are also due to variations in illumination, since both types occupy a wide range of topographic positions.

Vegetation Mapping

Poor spectral separability of some of the natural vegetation classes was partly overcome by specifying narrow statistical limits to the classes generated by cluster analysis and relying on analyst expertise to label spectral clusters based on additional information such as cluster location, topographic setting, patch shape and size. Using this approach it was possible to map land cover using the July TMS data with overall accuracy of 89 percent (Table 5). Oak woodland was misclassified as oak forest in 23 percent of the cases (these tended to be stands of dense oak woodland). Other natural vegetation classes were mapped with high accuracy and with little bias, that is with equal rates of omission and commission errors (Card 1983).

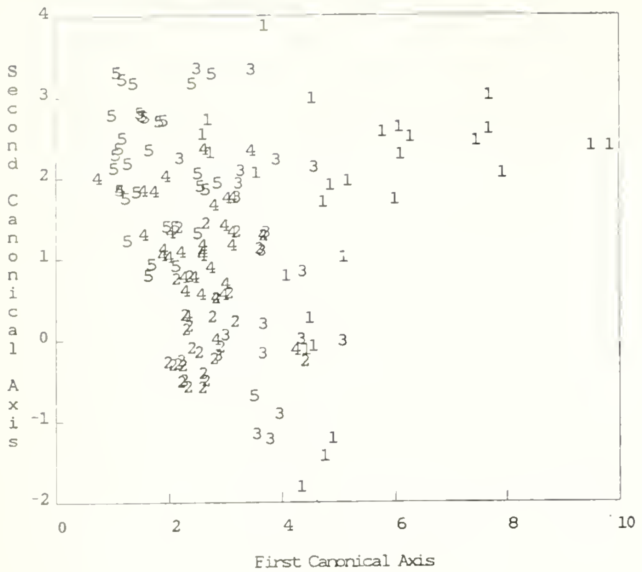

Figure 4. Discriminant analysis of training sites using December PC1, PC3 and illumination. 1-grassland, 2-chaparral, 3-oak grassland, 4-oak woodland, 5-oak forest.

Table 3. Classification functions and jackknifed classification accuracy for vegetation training sites, July scene.

Variable	Grassland	Chaparral	Oak grassland	Oak woodland	Oak forest
PC1	0.272	0.138	0.132	0.134	0.109
PC2	0.319	0.322	0.391	0.409	0.466
PC3	0.140	0.081	0.194	0.127	0.161
Classification Accuracy (%)	86.5	81.8	65.0	50.0	78.8

Table 4. Classification functions and jackknifed classification accuracy for vegetation training sites, December scene.

Variable	Grassland	Chaparral	Oak grassland	Oak woodland	Oak forest
PC1	0.156	-0.031	0.029	0.019	0.025
Illumination	0.101	0.060	0.085	0.076	0.092
PC3	0.017	0.113	0.084	0.058	0.024
Classification Accuracy (%)	53.6	66.7	25.0	44.1	66.7

Overall map accuracy using the December TM data was 84.3 percent, but systematic misclassification of natural vegetation classes reduced the utility of the map. (Table 6) Oak forest was mapped with a low rate of ommission error, but oak woodland was frequently

Table 5. Error matrix, TMS classification, summer scene (n=141).

IMAGE CLASS	GROUND CLASS OF	OW	Ch	Con	CS	G	R	Other	% Commission Error
% IMAGE	4.5	13.0	5.9	2.8	20.0	11.9	1.0	40.9	
Oak Forest	17			1					6
Oak Woodland	4	21	1						19
Chaparral		1	22		1				8
Conifer Forest	1			12					8
Coastal Scrub			1		12	2			20
Grassland			1		1	16		2	20
Riparian							9		0
Other								16	0
Total	22	22	25	13	14	18	9	18	
% Ommission error	23	5	12	8	14	11	0	11	
Weighted map accuracy		89 %							

misclassified as oak forest, chaparral misclassified as oak woodland, and grassland mistaken for coastal scrub. Several riparian areas clustered with oak woodland and orchards, and some cultivated fields were confused with grassland. Thus the winter map systematically overestimated oak cover and grassland while underestimating conifer, riparian and cultural cover classes.

Table 6. Error matrix for TM classification of Lompoc Region, winter scene (n = 172).

IMAGE CLASS	GROUND CLASS OF	OW	Ch	Con	CS	G	R	Other	% Commission Error
% IMAGE	6.9	19.4	5.7	1.0	19.4	17.6	0.1	29.9	
Oak Forest	29	5	2	2					24
Oak Woodland		38	5	1					14
Chaparral			25		1				4
Conifer Forest	2		1	9					25
Coastal Scrub		1	1		9	3		1	40
Grassland			1			14		2	18
Riparian							4		0
Other						1	1	14	13
Total	31	44	35	12	10	18	5	17	
% Ommission error	6	14	29	25	10	22	20	18	
Weighted Map Accuracy		84.3 %							

CONCLUSIONS

1. The first three principal components of Thematic Mapper bands 1 through 6 contain 95-99 percent of scene information for a complex region of coastal California. All three principal components from either summer or winter imagery contain information useful for mapping natural vegetation.
2. For summer imagery, increasing coast live oak cover is related to decreasing PC1 (brightness) scores and increasing PC2 (greenness) scores. Oak forest is spectrally distinct from most other vegetation classes; oak grassland and oak woodland show spectral overlap with

grassland, chaparral and forest due to spectral variability of stands at the spatial resolution of TM. Oak cover types can be mapped with relatively high accuracy using summer imagery and iterative cluster labeling, but this requires that the analyst be familiar with the area.

3. For winter imagery, increasing oak cover is related to decreasing values in the first three principal components. Shadows and generally poor illumination reduce the spectral separability of natural vegetation classes. Incorporation of an illumination image significantly improves class discrimination due to the systematic association of vegetation and topography. Oak cover types are mapped with fairly high accuracy, but there is a systematic tendency to over-estimate oak cover based on winter imagery.
4. Additional studies are recommended to analyze the relationship between scale-dependent spatial pattern in oak canopy cover and multispectral scanner resolution, the use of multi-date imagery to improve classification accuracy of oak cover classes, and the use of additional ancillary data such as seasonal insolation images or geology to improve discrimination of vegetation classes. Also, further studies are recommended to analyze the spectral properties of deciduous oaks and mixtures of evergreen and deciduous oaks.

ACKNOWLEDGEMENTS

I would like to thank J. Bass, J. Meyers, M. Spanner and R. Wrigley of NASA/Ames Research Center for providing the TMS data, Laura Haston and Ralph Dubayah for help in data analysis, and Charles Bolsinger and Norm Pillsbury for reviewing early drafts of the manuscript.

REFERENCES

Anuta, Paul E.; Bartolucci, Luis A.; Dean, M. Ellen; Lozano, D. Fabian; Malaret, Erick; McGillem, Clare D. Valdes, Jose A.; Valenzuela, Carlos R. **LANDSAT-4 MSS and Thematic Mapper data quality and information content analysis.** IEEE Transactions on Geoscience and Remote Sensing GE-22 (3): 222-235; 1984 May.

Benson, Andrew S.; DeGloria, Stephen D. **Interpretation of LANDSAT-4 Thematic Mapper and Multispectral Scanner data for forest surveys.** Photogrammetric Engineering and Remote Sensing 51(9):1281-1290; 1985 September.

Card, Don H. **Using known map category marginal frequencies to improve estimates of thematic map accuracy.** Photogrammetric Engineering and Remote Sensing 48(3): 432-439; 1982 March.

Cole, Kenneth; **Geologic control of vegetation in the Purisima Hills, California.** Madrono 27(2): 78-79; 1980 April.

Davis, Frank W.; Goetz, Scott; Franklin, Janet. **The use of digital satellite and elevation data in chaparral ecosystems research.** In: Proceedings of the Conference on chaparral watersheds; 1985 May 16-17; Santa Barbara, Calif.; Rep. 62. Davis, Calif: California Water Resources Center; 1986; 19-27.

Dibblee, Thomas W. **Geology of southwestern Santa Barbara County.** Bulletin 150. Sacramento, Calif: California Division of Mines; 1950. 95 p.

Ferren, Wayne R.; Forbes, Holly C.; Roberts, Dar A.; Smith, Dale M. **The botanical resources of the La Purisima Mission State Historic Park.** Herbarium Publication. 3. Santa Barbara, Calif.: Department of Biological Sciences, University of California; 1984. 159 p.

Franklin, Janet. **Thematic mapper analysis of coniferous forest structure and composition.** Int. J. Remote Sensing 7(10):1287-1301; 1986.

Frew, James; Dozier, Jeff. **The QDIPS image processing system.** Unpublished report; Santa Barbara, Calif.: Department of Geography, University of California. 1982, 17p.

Guindon, B.; D.G. Goodenough; P.M. Teillet. **The role of digital terrain models in remote sensing of forests.** Canadian J. Remote Sensing 8(1):4-15; 1982 July.

Horler, D.N.H.; Ahern, F.J. **Forestry information content of Thematic Mapper data.** Int. J. Remote Sensing 7(3):405-428; 1986.

Lacaze, Bernard; Debussche, Genevieve Jardel, Jacques. **Spatial variability of mediterranean woodlands as deduced from LANDSAT and ground measurements.** In: Proceedings of the 14th congress of the int. society of photogrammetry, vol. 2-TP-1; 1983 August 31-Sept. 2; San Francisco, Calif. New York, NY: IEEE Catalogue 83CH1837-4; 1983; 4.1-4.5.

Malila, William A. **Comparison of the information contents of Landsat TM and MSS data.** Photogrammetric Engineering and Remote Sensing 51(9):1449-1457; 1985 September.

National Aeronautics and Space Administration. Thematic Mapper computer tape (CCT-AT, CCT-PT) interface control document LSD-ICD-105. Rev. A. Greenbelt, Maryland: Goddard Space Flight Center; 1983. 184p.

Newland, Willard, Peterson, Dave, Norman, Susan. **Bulk processing techniques for very large areas: Landsat classification of Calif.** In: Proceedings of the 6th Annual Symposium for machine processing of remotely sensed data; 1980 June 3-6; West Lafayette, Indiana: Purdue University; 1980; 306-317.

Passof, Peter C.; Bartolome, James W. **An integrated hardwood range management program.** Rep. 6. Berkeley, Calif.; Wildland Resources Center, University of California; 1985. 18p.

Sadowski, Franklin G.; Sarno, Jane E. **Additional studies of forest classification accuracy as influenced by multispectral scanner spatial resolution.** Technical Memorandum NASA CR-ERIM 1227004-R. Ann Arbor, Mich.: Environmental Research Institute of Michigan; 1976. 60p.

Strahler, Alan H. **Stratification of natural vegetation for forest and rangeland inventory using Landsat digital imagery and collateral data.** Int. J. Remote Sensing 2(1):15-41; 1981.

Teillet, P.M.; Guindon, B.; Goodenough, D.G. **Forest classification using simulated Landsat-D Thematic Mapper data.** Canadian J. Remote Sensing 7(1):51-60; 1981 July.

Toll, D. **Effect of Landsat sensor parameters on land cover classification.** Remote Sensing of Environment 117(2):129-139; 1985.

Tucker, Compton J.; **A companion of satellite sensor bands for vegetation monitoring.** Photogram metric Engineering and Remote Sensing 44(11): 1369-1380; 1978 November.

Tucker, Compton J.; Townshend, John R.G.; Goff, T.E. **African land cover classification using satellite data.** Science 227 (4685):369-375; 1985 January.

Walker, R.E.; Zobrist, A.L.; Bryant, N.A.; Gohkman, B.; Friedman, S.Z.; Logan, Thomas L. **Analysis of Landsat-4 Thematic Mapper geometric properties.** IEEE Transactions on Geoscience and Remote Sensing GE 22(3):288-293; 1984 May.

Wells, Phillip V. **Vegetation in relation to geological substratum and fire in the San Luis Obispo quadrangle, California.** Ecological Monographs 32(1):79-103; 1962.

Williams, Daniel L.; Nelson, Ross F. **Use of remotely sensed data for assessing forest stand conditions in the eastern United States.** IEEE Transactions on Geoscience and Remote Sensing GE-24(1): 130-148. 1986 January.

Yool, Stephen R.; Star, Jeffrey L.; Estes, John E.; Botkin, Daniel B.; Eckhardt, David W.; Davis, Frank W. **Performance Analysis of image processing algorithms for classification of natural vegetation in the mountains of southern Calif.** Int. J. Remote Sensing 7(5):683-702; 1986.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Site Index and Yield Equations for Blue Oak and Coast Live Oak[1]

Michael J. DeLasaux and Norman H. Pillsbury[2]

Abstract: Preliminary site index, variable density yield, and stand volume yield prediction equations were developed for blue oak (*Quercus douglasii* Hook & Arn.) and coast live oak (*Quercus agrifolia* Née) from moderate to heavily stocked stands of each species located in Monterey and San Luis Obispo counties, California. Height and age data were obtained from sample tree stem analysis. The individual parameter prediction equation approach was used to develop the site index equations. The variable density and stand volume yield prediction equations were developed from stand information obtained at each of the sample plots. Individual yield equations of each type were developed for all trees, all trees 4 inches and larger, trees 8 inches and larger and trees 11 inches and larger for both species. This information will aid the owner of hardwood rangeland as management strategies are developed.

The hardwoods of the western United States are an important natural resource, although often not managed for sustained multiple-use benefits. Oaks comprise about 80 percent of California's total hardwood resource and grow on 9 to 10 million acres in California (Bolsinger, 1979). In Monterey and San Luis Obispo counties hardwoods, predominately oaks, occur on three quarters of a million acres (Pillsbury and Brockhaus, 1981). Their extensive acreage means there is tremendous volume available for producing fiber for fuel and wood products.

Oak from the woodlands of California's central coast historically have been used for charcoal and tannin, and the woodlands themselves have been used as rangeland or have been converted to cropland. Increasing urbanization, rangeland and agricultural practices, and recent demands for a renewable source of energy are pressuring the resource.

Fuelwood consumption has increased dramatically in the United States since the early 1970's. A number of studies have shown the importance of hardwoods as a renewable source of energy for space heating in homes in California (Bolsinger, 1986) and nationwide (Skog and Watterson, 1983). In Monterey, San Luis Obispo, and Santa Barbara counties it was estimated that 4,300 cords of oak were sold as fuelwood in 1979, and that between 1977 and 1980 the volume of fuelwood sold increased by 175% (Pillsbury and Williamson, 1980).

The increased demand for fuelwood presents a challenge to the resource manager. Sound management of California's oak resource requires a base of information about existing volume, present and potential growth, and potential yield.

Managing the oak woodlands for the production of wood fiber means that methods for determining the volume of individual trees and the productive capacity of the land in terms of growth and expected yields must be available. A number of hardwood volume equations have been developed in California, however site index prediction curves or equations for assessing the productive potential of a given site; or yield tables or equations for predicting present and future volume yield are available only for red alder (*Alnus rubra* Bong.) (Bishop and Johnson 1958, Porter and Wiant 1965), tanoak (*Lithocarpus densiflorus* (Hook. and Arn.) Rehd.) (Porter and Wiant 1965, Nguyen 1979), madrone (*Arbutus menziesii* Pursh.) (Porter and Wiant 1965), and California black oak (*Quercus kelloggii* Newb.) (Powers 1972).

The methods used to develop site index estimating systems have been steadily evolving over the years. Although tree and stand measurements needed for a site index analysis are standard, there is no "cookbook" approach to site index equation development. However, recent work with western conifers by several authors, Dahms (1975), Barrett (1978), Cochran (1979) and Dolph (1983) has been based upon similar procedures. Their methods are well documented and tested (Curtis et al 1974) and were selected for this study.

The purpose of this study was to sample coast live oak and blue oak in Monterey and San Luis Obispo counties to develop site index and yield prediction equations.

SILVICAL AND ECOLOGICAL CHARACTERISTICS OF BLUE OAK AND COAST LIVE OAK

Blue oak and coast live oak were selected for the study because of their divergent growth habits, silvical characteristics and their wide distribution. The contrasting characteristics of the two species are outlined in Table 1.

Blue oak distribution in Monterey and San Luis Obispo counties is mostly restricted to dry inland sites. Pure blue oak stands generally occur at elevations ranging from 100 to 300 feet mixing

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Table 1. Relative differences between blue oak and coast live oak.

Characteristic	Blue Oak	Coast Live Oak
Geographic range	inland	coastal
Precipitation	lower rainfall	higher rainfall
Soils	shallow; xeric	deeper; mesic moisture regime
Growth form	short, generally straight	variable height, seldom straight
Bark	thin, flaky	thick, corky
Leaf habit	deciduous	evergreen
Sprouting	variable, but often poor	prolific

Table 2. Comparison of stand characteristics based on 5 studies of blue oak and 4 studies of coast live oak.

Researcher	Number of stems no./ac.	Basal area sq.ft./ac.	Volume cu.ft./ac.
BLUE OAK			
White (1966)	207	87	N/A
McClaren (1983)	325	83	N/A
Pillsbury (1978)	387	91	1,915
De Lasaux (1984)	223	41	754
Pillsbury & De Lasaux (1985)	375	71	1,575
COAST LIVE OAK			
Pillsbury (1978)	164	148	3,558
De Lasaux (1980)	239	148	2,144
Pillsbury (1985)	339	159	4,106
Pillsbury & De Lasaux (1985)	283	155	4,449

with digger pine (*Pinus sabiniana* Dougl.) at elevations between 500 to 3,000 feet to form the blue oak-digger pine type (Neal 1980). Coast live oak is generally associated with coastal sites with elevation ranging from sea level to 3,000 feet (Finch and McCleery 1980).

The Mediterranean climate, characterized by hot dry summers and mild wet winters typifies the conditions of both species, however, coast live oak stands are more commonly found on sites which receive considerably more rainfall. Blue oak can occupy sites which receive as little as 10 inches of precipitation annually (Neal 1980).

Both species are commonly found on well-drained soils. Finch and McCleery (1980) found that coast live oak stand density seems to relate to soil texture. Coastal stands that are fairly dense and with closed canopies are primarily associated with a loamy soil texture. Inland, where coast live oak trees are larger and stands are more open, sandy soils prevail. At higher coastal elevations, coast live oak is associated with shaly clay-loam soils.

Coast live oak and blue oak each have the capacity to sprout. However coast live oak is generally more prolific, with the ability to crown sprout after severe damage by fire and to sproutbasally after cutting. Blue oak basal sprouting ability appears to vary with geographic location but often is poor or in some areas non-existent. Where sprouting does occur a bush-like or stunted tree form may result.

Stand conditions for several studies of blue oak and coast live oak are summarized in Table 2. Coast live oak stands are largely between 40 and 110 years of age although stands have been measured as young as 28 years and as old as 131 years; typically they average 60-80 years in age. Site index values varied from a low of 32 feet to a high of 84 feet in 50 years. Blue oak stands range from 80 to 140 years old and are typically 90 to 100 years old. Site index ranges from a low of 13 feet to a high of 30 feet in 50 years.

METHODS

Sampling

Twenty-five, one-fifth acre circular plots were located in moderate to heavily stocked stands in Monterey and San Luis Obispo counties for each species. Moderately to heavily stocked stands are defined as having a crown cover of 50% or greater. The criteria used for plot and tree selection were:

Plot Selection Criteria:

a) The stand should be pure or nearly pure (90%, based on number of stems).

b) The stand should be even-age. The actual ages of individual trees may vary plus or minus 15 years of the average stand age. For the best results, stand age determination may require felling or boring several trees (at least two).

c) There should be no signs of cutting.

d) The sample plot should be located within the stand such that there is a surrounding buffer strip that is at least as wide as the dominant trees are tall.

Sample Tree Selection Criteria:

a) Sample trees (2 to 4) are the tallest in the plot.

b) No signs of past injury.

c) No signs of suppression are evident from breast-height disk or increment core.

d) The tree should have developed as part of the present stand (not a residual).

Two to 4 trees chosen for stem analysis were felled and sectioned. Disks were taken at approximately 1 foot, breast-height (4.5 feet), 10 feet, and successive intervals of 5 feet. Disks were taken from the main stem; the stem that was tallest and most upright. Information obtained from each stem analysis tree included total height which was measured as a straight line distance from the tree base to the tip of the main stem after the tree was cut, total length which was measured along the sinuosities of the main stem, and age and height at each section point.

Stand data obtained or developed from each plot for yield equation development included species composition, diameter at breast height for all plot trees, average stand diameter, number of trees per acre, basal area per acre, volume per acre, breast-height stand age, and the tallest tree (tallest stand element). Average stand age was calculated from average breast-height age of the cut trees.

Tree ages at successive heights were determined by counting annual growth rings on each disk. Each species presented unique difficulties with respect to ring counting. We found that obtaining a smooth surface and wetting the disk with water provided the best results. Blue oak had well-defined growth rings, however, due to slow radial growth, a smooth surface cut with a sharp knife and a dissecting scope was often used. Coast live oak disks were sanded and then soaked to enhance ring definition.

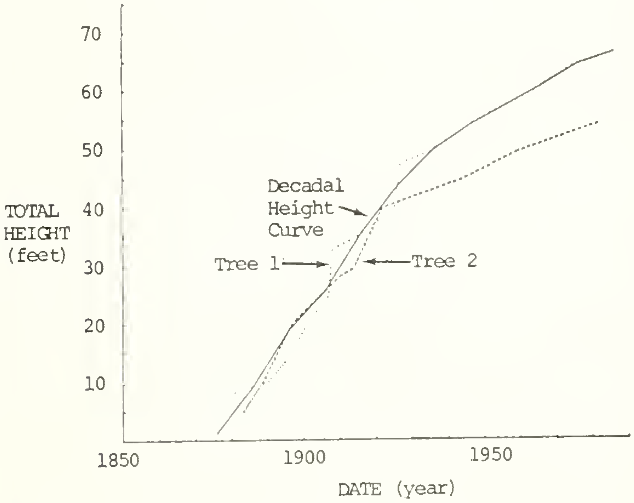

Figure 1. Graph of adjusted height versus age at breast-height with the decadal height versus age curve for a coast live oak sample plot. The decadal height curve is plotted with height and age points that represent the tallest tree for each 10 year period.

SITE INDEX PREDICTION EQUATION DEVELOPMENT

Height Versus Age Plot. Tree height and age data obtained from stem analysis were plotted for each field plot. The height versus age curves were examined for early height growth suppression or uneven age structure.

Following procedures developed by Carmean (1972), section point tree heights were adjusted to obtain a more accurate estimate of actual height at a given age. Adjusted tree heights for sample trees were plotted for each stand and the tallest tree at each decade was determined (Figure 1).

Main Stem Length Versus Total Height. Because the deliquescent growth habit of both coast live oak and blue oak presents an anomaly where total height, as measured in a straight line distance from the ground to the tip, will differ from the main stem length, as measured along the sinuosities of the main stem from the ground to the tip, the possibility of using an equation to adjust total height to total length was explored. An equation was developed to estimate stem length based on total height.

$$\text{Main Stem Length (feet)} = 1.342 + 1.019(\text{Total Height (feet)}) \quad [1]$$

$r^2 = 0.988$, S.E.= 1.35 feet

Because total stem length is a better measure of stem growth and therefore site quality, the authors considered using this equation to adjust total height to obtain an estimate of total length which would subsequently be used for estimating site index. However, after careful consideration the adjustment procedure was not incorporated into the site index estimation system for several reasons: 1) the adjustment to stem length was generally small, about 2 per cent, and 2) increased complexity of using an adjustment procedure.

Site Index Equations. The procedure used to obtain the site index equations first involves the development of equations to model the intercept (b_0) and slope (b_1) parameters as well as height (HT) in the basic site index model (Eqn. 2).

$$SI - 4.5 = b_0 + b_1 (HT - 4.5) \quad [2]$$

where, SI = site index (total height in feet of tallest tree at breast-height base age 50 years),
HT = tallest tree height in feet at successive 10 year intervals, b_0 and b_1 = regression coefficients, and
- 4.5 = to correct for breast-height measurements.

Table 3. Coast live oak site index regression summaries.

Breast-height age (years)	Site Index (feet)	Coefficients		Total Height (feet)	r^2	Standard Error (feet)	n
		b_0	b_1				
20	SI-4.5	= 6.01773	+ 1.52794	HT-4.5	0.60	5.9688	25
30	"	= 2.62329	+ 1.26173	"	0.76	4.5971	25
40	"	=-1.59484	+ 1.19586	"	0.91	2.8547	25
50	"	= 0.00000	+ 1.00000	"	1.00	0.0000	25
60	"	= 1.99701	+ 0.84037	"	0.97	1.6110	23
70	"	= 4.25593	+ 0.70853	"	0.95	2.2798	21
80	"	= 3.83575	+ 0.65597	"	0.94	2.3938	18
90	"	= 3.14491	+ 0.63866	"	0.97	1.5756	9
100	"	= 2.21358	+ 0.60715	"	0.96	1.7469	9

Identical methods were used for both coast live oak and blue oak. Only coast live oak examples are shown in this paper, however the site index equations and graphs are shown for both species. For a detailed discussion of the methods the reader is referred to Pillsbury and De Lasaux (1985). Both blue oak and coast live oak were evaluated for site index at breast-height base age 50. The procedure involves three major steps which are outlined and discussed below.

Step 1. An equation to estimate the slope coefficient (b_1) in Eqn. 2 is developed. Height at breast-height age 50 (site index) is regressed against the height data for successive decades

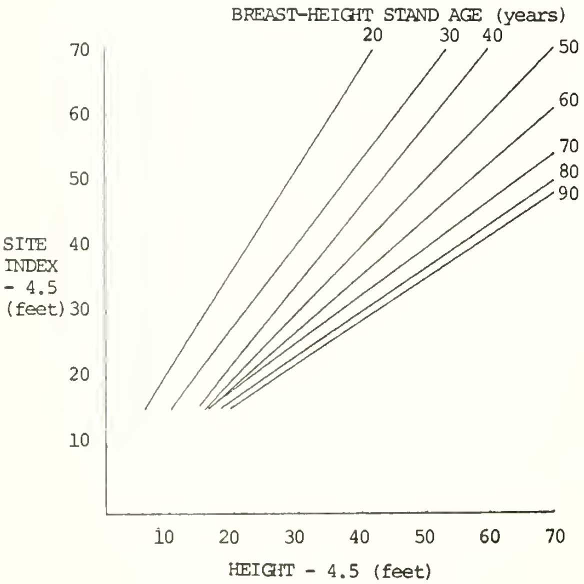

Figure 2. Regression lines from individual regressions of site index (height at age 50) versus height at breast-height stand ages 10, 20, 30,...,90 years for coast live oak.

(decadal ages, e.g. 20, 30, 40, ..., AGE_n). The resulting slope coefficients (b_{20}, b_{30}, b_{40}, ..., b_n) are then modeled by regressing them against the decadal ages to obtain the slope prediction (b_1) equation.

Linear regression models using site index as the dependent variable were fit to the decadal height data (independent variable) for each successive decade (20, 30, 40, ..., AGE_n) using the site index equation (Eqn. 2). Table 3 is a summary of the regression equations. The regression line for each equation, illustrated in Figure 2, shows the relationship between height of the tallest stand element and the height attained at the base age (site index), at 10 year intervals. The slope (b_1) for each breast-high age regression line represents the mean height for different levels of site index (conditions) sampled. The slope of each regression line characteristically decreases with increasing age because the height attained by the tallest stand element on a good site is greater relative to that of a poor site as stand age increases.

Using non-linear regression, the decadal estimates of slope (b_{20}, b_{30}, b_{40},...b_n) were smoothed and conditioned to pass through 1 at the base age. Conditioning the smoothed curve is necessary so that site index (height at breast-height age 50) equals the mean height at age 50 obtained from the plot data. The conditioned slope (b_1) prediction equation (Eqn. 3) for coast live oak is listed below and the fit is illustrated in Figure 3.

$$b_1 = 1.607197 - 1.117641(1- e^{-0.037426AGE})^{3.650238} \quad [3]$$

$r^2 = 0.9952$, SE = 0.0461

Step 2. An equation to estimate the intercept coefficient (b_0) in Eqn. 2 is then developed. Equation 2 is rearranged to estimate the intercept coefficient (b_0) based on site index (SI), slope (b_1) and Height (HT). An average height prediction (HT) equation to model HT in Eqn. 2, was developed by regressing average decadal height for all plots against decadal age.

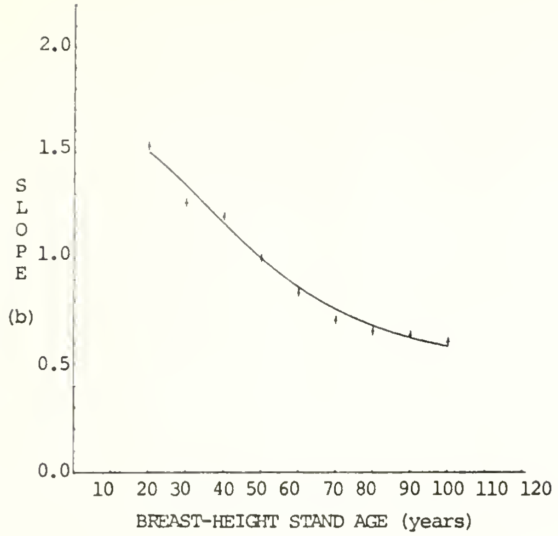

Figure 3. Slope (b_1) prediction curve for coast live oak, based on equation 3.

The intercept prediction equation is obtained by substituting an average height (HT) prediction model, the slope (b_1, from Step 1) prediction model and average site index into Eqn. 2 and rearranging. Average decadal heights for the 25 plots are determined and a regression model is developed. The average decadal heights model was conditioned to pass through mean site index (mean height at base age) of 37.07 feet for coast live oak. The model was also constrained so that height at breast-height age 0 would equal 4.5 feet. Figure 4 shows the fit of the average height prediction model for coast live oak.

$$HT-4.5 \text{ feet} = 141.500295\ (1- e^{-0.002969AGE})^{0.676188} \quad [4]$$

$r^2 = 0.9938$, SE = 0.5869 feet

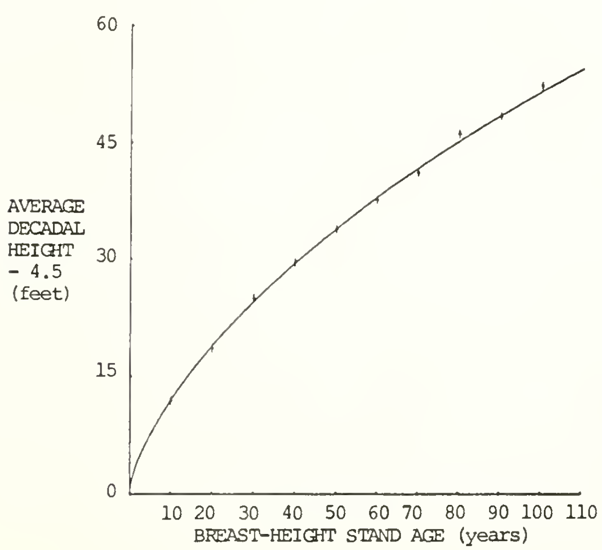

Figure 4. Average decadal height (HT) prediction curve for coast live oak, based on equation 4.

The slope prediction (b_1) equations and the average height prediction (HT) equations developed in steps 1 and 2 and average site index for the study sites was substituted into Eqn. 2 to estimate the intercept coefficient (b_0). The equations used to predict the intercept (b_0) in Equation (2) are given below.

$$b_0 = 37.07 - (1.607197 - 1.117641(1- e^{-0.037426AGE})^{3.650238})\ (141.500295\ (1- e^{-0.002969AGE})^{0.676188}) \quad [5]$$

Step 3. The site index prediction equation is then obtained by substituting the intercept (b_0), slope (b_1) and prediction models into Eqn. 2.

Substituting the prediction models, b_1 (Eqn. 3), and b_0 (Eqn. 5) into Equation (2), the basic model SI - 4.5 feet = $b_0 + b_1$ (HT - 4.5 feet), gives the final equation used to estimate site index as a function of age and height in Eqns. 6 and 7. The site-index prediction curves are shown in Figure 5.

Blue Oak Site Index Prediction Equation

$$SI-4.5 = 21.03 - \left(1.249698 - 0.005423AGE + \frac{0.757848}{AGE - 14.671621}\right)\ (101.351892\ (1- e^{-0.002109AGE})^{0.683229}) + \left(1.249698 - 0.005423AGE + \frac{0.757848}{AGE - 14.671621}\right)\ (HT - 4.5) \quad [6]$$

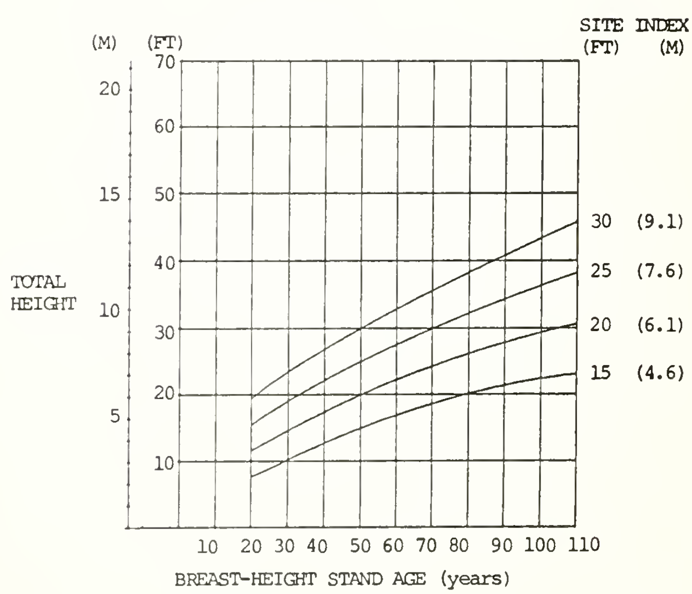

Figure 5 Site index curves for blue oak, based on equation 6.

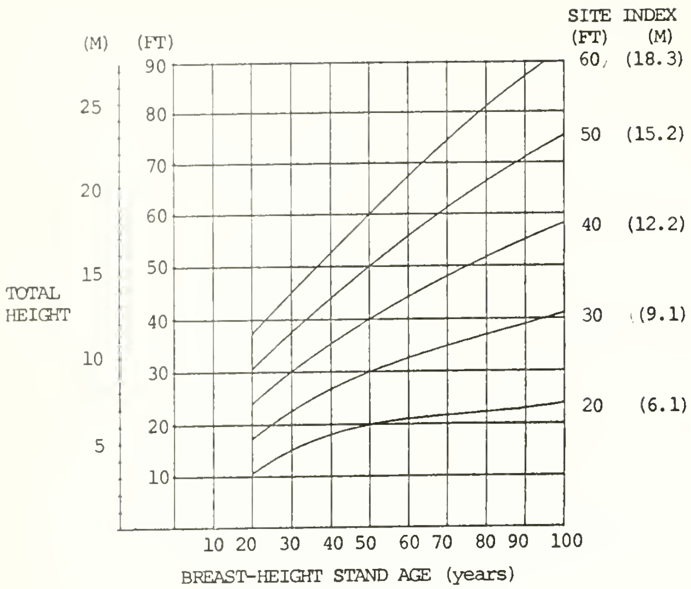

Figure 6 Site index curves for coast live oak, based on equation 7.

Coast Live Oak Site Index Prediction Equation

$$SI-4.5 = 37.07-(1.607197-1.117641(1-e^{-0.037426AGE})^{3.650238})$$
$$(141.500295\ (1-e^{0.002969AGE})^{0.676188}) +$$
$$(1.607197 - 1.117641(1-e^{-0.037426AGE})^{3.650238})$$
$$(HT-4.5) \qquad [7]$$

TEST OF SITE-INDEX EQUATIONS

The accuracy of the blue oak and coast live oak site-index equations can be initially judged by examining the coefficient of determination (r^2) and the standard error of the estimate for each of the individual site index regressions (Table 2).

It is possible to test the accuracy of the site index equations using linear regression analysis with the actual height and age data from stem analysis for each plot. The independent variable is estimated site index, estimated by substituting the decadal heights from the stem analysis data as the height and age variables into the site-index equations. The actual site index, height at age 50 years, is the dependent variable.

The SE and the r^2 estimates for each age in Table 4 are only approximate because the b_0 and b_1 values for each age are themselves estimated values of b_0 and b_1.

The estimates of site index become more accurate as breast-height stand age approaches index age (50 years). Site index estimation was not as accurate at earlier ages as older ages, particularly for coast live oak stands.

Table 4. Statistics for goodness-of-fit of site index curves generated by the site index prediction equations.

Breast-height age (years)	Blue oak			Coast live oak		
	Standard Error of Estimate (feet)	r^2	n	Standard Error of Estimate (feet)	r^2	n
20	4.69	0.75	25	6.26	0.60	25
30	2.10	0.91	25	5.14	0.76	25
40	1.00	0.97	25	2.99	0.91	25
50	0.00	1.00	25	0.00	1.00	25
60	0.85	0.99	25	1.69	0.97	23
70	1.44	0.97	25	2.54	0.95	21
80	1.87	0.92	24	2.50	0.94	18
90	2.42	0.85	24	2.32	0.97	9
100	3.06	0.80	15	2.16	0.96	9
110	3.35	0.75	10	--	--	--

SITE INDEX ESTIMATION

Estimates of site index for a blue oak or coast live oak stand can be obtained by following the steps given below.

1. Determine the average breast-height stand age from a sample of at least two of the tallest trees in a one-fifth acre plot located within the stand.

2. Measure the total height of the tallest tree. Sample tree selection should be made following stand and sample tree considerations mentioned earlier.

3. There are three options available for estimating site index:
   a) Use site index graph (Figure 5 for blue oak or Figure 6 for coast live oak).

   b) If a computer is available the appropriate site index prediction equation may be used (Equations 6 or 7). An example of the full site index prediction equation is shown below for a stand with a breast-height stand age of 43 and height of 25 feet.

   c) For field use a table can be developed to give the b_0 and b_1 coefficients for the various ages.

EXAMPLE: Given a coast live oak stand that is 43 years old at breast-height and the tallest tree in the plot is 25 feet tall the site index can be estimated as follows using Equation 7.

$$SI-4.5\ ft = 37.07-(1.607197-1.117641(1-e^{-0.037426(43)})^{3.650238})$$
$$(141.500295(1-e^{-0.002969(43)})^{0.676188})+$$
$$(1.607197-1.117641(1-e^{-0.037426(43)})^{3.650238})$$
$$(25-4.5\ feet)$$

SI-4.5 ft = 22.8.

Table 5. Variable density yield equations for blue oak and coast live oak.

Volume (cu.ft./ac)	regression coefficients					Statistics		
	b_0	b_1	b_2	b_3	b_4	N	R^2 (%)	SE (%)
BLUE OAK								
log V_t	2.47743	-9.46312	0.00259	0.00665	0.04146	25	84.9	2.5
log V_4	2.53629	-19.87246	0.00365	0.00605	0.04475	25	85.1	2.7
log V_8	1.88438	-23.05717	0.00199	0.01776	0.04975	25	81.8	7.0
log V_{11}	1.52423	21.23267	0.00220	0.02797	0.02081	21	94.7	3.9
COAST LIVE OAK								
log V_t	2.80981	-2.24168	0.00250	0.00318	0.02346	25	94.4	1.1
log V_4	2.77577	-1.25340	0.00173	0.00311	0.02721	25	95.0	0.9
log V_8	2.59655	-1.79513	0.00083	0.00362	0.03571	25	95.0	1.4
log V_{11}	2.48601	0.83152	0.00185	0.00437	0.02948	24	94.6	1.5

STAND YIELD INFORMATION

In addition to developing site quality information this study was also designed to test several models for predicting current yield. Estimates of stand volume are normally made by inputting measurable characteristics of the forest such as age, site index, and stand density information into a yield prediction equation. These estimates can be used to help make decisions about rotation age (optimum age to harvest), levels of planting density, and timings of management activities such as thinnings (Clutter et al 1983).

Total plot volumes were derived using local volume equations for both coast live oak and blue oak. The equations were developed from data used to develop standard volume equations from a study by Pillsbury and Kirkley (1984). Two types of yield equations were developed for predicting current yield: Variable density yield equations and stand volume equations. The two types of equations as developed can be used for predicting total cubic foot volume per acre or cubic foot volume per acre for trees 4, 8, and 11 inches diameter and larger. The various diameter limits are intended to give the woodland manager flexibility in predicting yield for different cutting strategies based on diameter. The 11 inch and larger class was selected to represent approximate sawlog size as defined by Pillsbury and Kirkley (1984). The equations for diameter limits of 4 and 8 inches and larger were developed to provide further flexibility between total volume yield and volume yield of trees greater than 11 inches.

Variable Density Yield Prediction Equations

A Schumacher type (1939) yield model was used. This model is a semi-logarithmic equation (only the dependent variable is a logarithm transformation).

$$\log V = b_0 + b_1(1/AGE) + b_2 SI_{50} + b_3 BA + b_4 D \quad [8]$$

where V = cubic foot outside bark volume for all trees on a per acre basis,
AGE = breast height stand age (years),
SI_{50} = site index in feet, 50 year base,
BA = basal area (square feet per acre) for all trees in square feet,
D = quadratic mean breast height diameter (inches) for all trees, and
b_0, b_1, b_2, b_3, b_4 = regression coefficients.

The variable density yield equation coefficients for both blue oak and coast live oak are given in Table 5.

EXAMPLE: A stand of blue oak is sampled using a 1/5 acre plot for trees 8 inches dbh or larger. The following data are collected:

a) Tallest stand element (tallest tree in plot) is 50.6 feet tall.

b) Three dominant trees are found to average 94 years in age at breast-height.

c) Site index (from Figure 6) is 38 feet.

d) The basal area for all trees 8 inches and greater is 35.41 square feet per acre.

e) The quadratic mean diameter for all trees 8 inches dbh and greater is 14.72 inches.

$$\text{Log } V_8 = 2.59655 - 1.79513(1/94) + 0.00083(38) + 0.00362(35.41) + 0.03571(14.72)$$

Log V_8 = 3.26, V_8 = 1,832 cubic feet per acre

Stand Volume Equations

A simple method for estimating yield uses basal area and height. Prediction equations of this

Table 6. Stand volume equations for blue oak and coast live oak.

Volume (cu.ft./ac)	Regression coefficients			Statistics		
	b_1	b_2	b_3	N	R^2 (%)	SE (%)
BLUE OAK:						
V_t	-609.54232	15.56392	28.97422	25	78.3	17.7
V_4	-540.05916	17.40456	24.63352	25	79.0	18.3
V_8	-22.55589	32.18872	-2.40465	25	89.3	21.1
V_{11}	-168.17116	37.39653	2.55831	21	91.5	22.3
COAST LIVE OAK:						
V_t	-1136.76355	27.98208	23.16980	25	81.2	14.2
V_4	-1158.04514	28.88979	21.69496	25	83.6	13.4
V_8	-678.55350	32.02865	9.46762	25	94.2	9.4
V_{11}	-243.42712	33.44860	2.71874	24	95.3	8.8

type are referred to as stand volume equations due to their similarity to individual tree volume equations. They have the advantage of simplicity but in this study they do not predict current volume as well as the variable density yield equations. The form of the stand volume equation used is:

$$V = b_0 + b_1 BA + b_2 TSE \quad [9]$$

where V = per acre, total cubic-foot outside bark volume for all trees

BA = basal area per acre for all trees in square feet

TSE = tallest stand element (tallest tree in the stand) in feet

b_0, b_1, b_2 = regression coefficients.

The stand volume equation coefficients for both blue oak and coast live oak are given in Table 6.

Prediction of present yield using a stand volume equation is illustrated below for blue oak:

EXAMPLE: A 1/5 acre plot is established in a stand of blue oak and sampled for trees 8 inches dbh and larger. The following information is obtained:

a) Tallest tree in plot = 50.6 feet.

b) The basal area for trees 8 inches and larger is 35.4 square feet per acre (calculated by converting tree diameters to basal area and summing for all trees (Example. Basal area for 1 tree = [DBH(inch)]2 x 0.005454, 222 (0.005454) = 2.64 square feet per acre).

$$V_8 = -678.55350 + 32.02865\ (35.4) + 9.46762\ (50.6)$$

$$V_8 = 934.32 \text{ cubic feet per acre}$$

SUMMARY AND DISCUSSION

Site index and current yield prediction equations were developed for blue oak and coast live oak in moderate to well-stocked stands in Monterey and San Luis Obispo counties. This information will help woodland managers to more effectively assess and manage blue oak and coast live oak woodlands.

The site index prediction system for each species can be used to determine the potential productivity of the site. Landowners may use this information to calculate the productivity level of their land and make appropriate management decisions. Estimates of site index can be obtained when a measure of average breast-height stand age and total height of the tallest stand element is measured.

Breast-height stand age can be difficult to determine for both species. For coast live oak, accurate age determination may require cutting several dominant trees to determine average stand age. Destructive sampling to determine age may not be desirable because dominant trees are often the crop trees. Cutting blue oak is not needed to determine age because an accurate estimate of age can be determined using an increment borer and dissecting scope.

The variable density yield equations and stand volume yield equations can be used to estimate current stand yield. Breast-height stand age is an independent variable in the variable density yield prediction equations, and as discussed earlier may be difficult to determine without cutting a few trees.

LITERATURE CITED

Barrett, James W. Height growth and site index curves for managed, even-aged stands of ponderosa pine in the pacific northwest. Res. Paper PNW-232. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service U.S. Department of Agriculture. 1978. 14 p.

Bishop, Daniel M.; Johnson, Floyd A. Site index curves for red alder. Res. Note PNW-162. Portland OR; Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture. 1958 7 p.

Bolsinger, Charles L. Oaks in California's commercial forests--volume, stand structure, and defect characteristics. In: Proceedings of the Symposium on Ecology, Management, and Utilization of California Oaks; 1979 June 26-28; Claremont, CA; Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1979; 101-106.

Bolsinger, Charles L. (In press). The hardwoods of California timberlands, woodlands, and savannahs. U.S.D.A. For. Serv.. Pacific Northwest Forest and Range Experiment Station.

Carmean, Willard H. 1972. Site index curves for upland oaks of the central states. Forest Science 18(2):109-120.

Clutter, Jerome E.; Fortson, James C.; Pienaar, Leon V.; Brister, Graham H.; Bailey, Robert L. Timber management: a quantitative approach. John Wiley and Sons, Inc.; 1983. 333 p.

Cochran, P.H. Site index and height growth curves for managed, even-aged stands of white fir or grand fir east of the Cascades in Oregon and Washington. Research Paper PNW-252. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1979. 13 p.

Curtis, Robert O.; DeMars, Donald J.; Herman, Francis R. Which dependent variable in site index-height-age regressions? For. Sci. 20(1):74-87; 1974 January.

Dahms, Walter G. Gross yield of central Oregon lodgepole pine. In: Management of Lodgepole Pine Ecosystems Symposium Proceedings; Pullman, WA; Washington State University Cooperative Extension Service; 1975. 208-232

De Lasaux, Michael J. Deer Valley Ranch woodland inventory report, San Miguel, California. (unpublished) 1984. 56 p.

De Lasaux, Michael J.; Jacobs, Benjamin; Krehbiel, Laura. Inventory of the coast live oak resource for the Dry Creek Ranch, Buellton, California. Senior Project. California Polytechnic State University; 1980. 73 p.

Dolph, K. Leroy Site index curves for young-growth incense-cedar of the Westside Sierra Nevada; Research Note PSW-363, Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1983. 8 p.

Finch, Sherman J.; McCleery, Dick. California coast live oak. IN: Forest Cover Types of the United States and Canada. Washington, D.C., Society of American Foresters; 1980. pp. 127-128.

Johnson, Floyd A., and Norman P. Worthington. 1963. Procedure for developing a site index estimating system from stem analysis data. Research Paper PNW-7. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, USDA. 10 p.

McClaren, Mitchel P. Quercus douglasii stand structure on grazed and ungrazed sites in Tulare county, California. Report to the Sequoia Natural History Association.

Neal, Donald L. Blue oak-digger pine. IN: Forest Cover Types of the United States and Canada; Washington D.C.; Society of American Foresters; 1980. pp. 126-7.

Nguyen, Can Thien. A preliminary simultaneous growth and yield model for tanoak. Master's thesis. Humboldt State University. 1979. 71 p.

Pillsbury, Norman H. Hardwood stand density characteristics for central coast counties in California. Central Coast Resource Conservation and Development. 1978. 32 p.

Pillsbury, Norman H.; Brockhaus, John A. Hardwood biomass inventory maps for California's central coast. Salinas, CA: Forest Service, U.S. Department of Agriculture; Central Coast Resources Conservation and Development, Soil Conservation Service, U.S. Department of Agriculture, California Polytechnic State University, California Department of Forestry; 1981; 10 p.

Pillsbury, Norman H.; Williamson, Daniel P. The landowners guide for fuelwood marketing opportunities in the Central Coast. Forest Service, U.S. Department of Agriculture. 1980; 13 p.

Pillsbury, Norman H.; Kirkley, Michael L. Equations for total, wood, and saw-log volume for thirteen California hardwoods. Research Note PNW-414. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1984. 52 p.

Pillsbury, Norman H.; De Lasaux, Michael J. Site index, height and yield prediction equations for blue oak and Coast live oak in Monterey and San Luis Obispo counties, California. Forest Service, U.S. Department of Agriculture (unpublished). 1985. 125 p.

Powers, Robert F. Site index curves for unmanaged stands of California black oak. Research Note PSW-262. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1972. 5 p.

Porter, D.R.; Wiant, Jr. H.V. Site index equations for tanoak, pacific madrone, and red Alder in the Redwood Region of Humboldt County, California. J. For. 63(9):286-28; 1965, September.

Skog, Kenneth E.; Watterson, Irene A. Residential fuelwood use in the United States: 1980-81. Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; 1983.

Schumacher, F.X.; A new growth curve and its application to timber-yield studies. J. For.37:819-820.

White, Keith L. Structure and composition of foothills woodland in central coast California. Ecology 47:229-237.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Population Structure of the Valley Oak in the Santa Monica Mountains National Recreation Area[1]

Timothy W. Thomas[2]

Abstract: This study was initiated as a result of recent National Park Service acqusition of valley oak habitat and the need to understand the status of this species in the Santa Monica Mountains. A population structure using size classes established from data gathered in 1985 reveals a pattern similar to that found elsewhere in its distribution. Just over 50 percent of the sample (n=882) were seedlings and saplings and over 30 percent of those were fire resprouts.

Valley oak (Quercus lobata Nee.) savannas reach their southern boundaries in the Santa Monica Mountains National Recreation Area in southwestern Los Angeles County. Although the valley oak has a large distribution which extends to the Mount Shasta region, its persistence in the landscape is uncertain. Current knowledge concerning the status of the valley oak is largely addressed to populations well within the species range (White 1966, Griffin 1976). Little is known regarding the condition of the valley oak at the limits of its distribution.

As part of a baseline data gathering project, studies of the valley oak savanna have been initiated by the National Park Service, California Department of Parks and Recreation, and the California State University (Los Angeles and Northridge). The intent of this research is to provide data for the long term management, planning and protection of the public natural areas in the Santa Monica Mountains National Recreation Area.

SETTING

The Santa Monica Mountains were formed as an accreted terrain, rotated clockwise 90 degrees, and have been compressed into a complex westward plunging anticline. An emergent coastline defines the southern edge of the mountains where wave cut terraces are estimated to have been rising out of the ocean at a rate of 30 cm per 1,000 years for the last 100,000 years. The valley on the north side of the mountains, averaging 300 m elevation, is the southern most syncline in the Transverse Province which forms the southern limit of Quercus lobata's range. There seems to be only one record for the occurrence of Quercus lobata on the coastal side of the Santa Monica Mountains known from a collection made by Abrams in 1910 (Griffin and Critchfield, 1972).

CLIMATE

In general the valley oak occurs in the protective lee (rain shadow) of the Santa Monica Mountains on expansive clay soils. Its distribution extends to less than five miles east of Pierce College in the San Fernando Valley along the north slopes of the Santa Monica Mountains. The climatic data for the period of record (1950 to 1982) at Pierce College indicates the mean temperature minima and maxima is 8.4C (41.7F) and 26.5C (79.8F) respectively and average precipitation is 406mm (16 in.) (Raven, P. et al. 1986).

STUDY AREA

Past and present land use management has altered most of the oak savanna ecosystems (Griffin 1976). The four data collection sites selected for analysis provided a gradation of land use patterns that range from most to least disturbed. Three of these are managed by the National Park Service (NPS) and one by the California Department of Parks and Recreation (CDPR).

Rancho Sierra Vista/Satwiwa (NPS), situated at the western edge of the Santa Monica Mountains is the only station sampled that receives a coastal influence. Moist coastal air flows from the ocean to this site via Sycamore canyon. Boney Ridge, the highest point in the mountains (948 meters above msl), creates a barrier to coastal breezes, causing air masses from the ocean to

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flow directly over the site. Sea salt aerosol damage (Ogden 1982) is apparent on many of the valley oaks at this site. Land use practices at the site includes a working horse ranch, grazing and dry land farming under a special use permit.

Cheseboro Canyon (NPS) was grazed by cattle at the time of the survey, however grazing pressures were reduced in 1985. Several long term monitoring programs have been established to record ecosystem response to the release of grazing pressures.

At Paramount Ranch (NPS) major impacts include those associated with movie production and large public events. Grazing use ended in the mid 1970's. A seven acre valley oak restoration area was established in 1980 by the National Park Service to protect a portion of the habitat that has been used for parking associated with major public events.

Malibu Creek State Park is situated on the north slopes of the Santa Monica Mountains on the south side of the transverse valley. The eastern and northern portion of this park unit contains ideal valley oak savanna habitat. Rolling shale hills are dissected by riparian habitats primarily flowing south. Only a small portion of the potential and actual valley oak habitat was surveyed. This site appears to be the least disturbed location containing the largest protected valley oak habitat in the Santa Monica Mountains. Grazing pressures were released in the early 1970's.

HISTORIC VEGETATION

All four stations were delineated on the Vegetation Types of California Maps produced by Wieslander (1938, 1939). Rancho Sierra Vista was classified as cultivated lands which were bordered by grassland. Valley oak habitat was not identified in the vicinity. Currently the trees at this site are widely scattered and isolated on ridges and hills above the zones of past and present cultivation.

Cheseboro Canyon is depicted on these early vegetation maps as having valley oaks only on a small rise at the lower end of the canyon surrounded by cultivation. Coast live oaks, sycamores and willows were designated as the woodland components of the narrower canyon area. Currently this classification still stands.

Paramount Ranch is the only study site which is represented on the Wieslander maps as being completely valley oak habitat. Today the broad valley where Paramount Ranch is located has largely been converted to urban land use.

Malibu Creek State Park was mapped with riparian corridors dominated by *Quercus agrifolia* Nee. surrounded by cultivated land. One hillside on the west was designated as valley oak habitat. The cultivated land has been converted to annual grassland and the valley oaks can be found throughout the riparian area and on the hillside mapped by Wieslander.

METHODOLOGY

A one hundred percent inventory was conducted on the entire portion of the three National Park sites and part of the State Park site. Data was gathered during the spring and summer of 1985 for 882 individual valley oaks. The intent of the project was to utilize tree size as the basis for population analysis. Standard diameter measurements were taken for specimens larger than 1.5 centimeters in diameter at breast height (dbh). Individuals with a diameter less than 1.5 cm were measured only for height and are termed seedlings in this study although small saplings were included in this category. Resprouts are defined as individuals less than 1.5 cm dbh with charred central branches (trunks). At each site, data for aspect, slope steepness and topographic position were recorded. Aspect and topographic position were analyzed as variables in the site preference of *Quercus lobata*. Aspect was arranged on a scale from northeast to southwest using the assumption that those end points represent the relative extremes of an environmental gradient from mesic to xeric, respectively (Whittaker 1976). An assumption was made that aspect would have little effect on site selection for the riparian and alluvial flats habitats, therefore information gathered on lower, middle and upper slopes (hillsides) was expected to give some sort of indication for site preference. A five point scale was developed to record topographic position (1-riparian or watercourse; 2-alluvial flats or valley floor; 3-lower slopes of hills; 4-mid slope; 5-upper slope or top of ridge or hill).

The associated vegetation within the immediate vicinity of an individual was recorded. Relative vigor of the valley oak was recorded on a one to three scale (1-healthy; 2-some epicormal sprouting and large dead branches; 3-damaged trunk, abundance of dead branches, thin canopy). Other notes recorded include presence of fire scars, abundance of galls, use of tree by acorn woodpecker as a granary, and presence of ground squirrel dens under the canopy.

All sites have a riparian component, Malibu Creek State Park and Paramount Ranch with year round surface water or hydroriparian and Rancho Sierra Vista and Cheseboro Canyon with intermittent water or mesoriparian (Johnson, R. et al. 1984). Each of the sites has a broad alluvial flat with a meandering riparian corridor and rolling hills. Riparian trees were defined as those

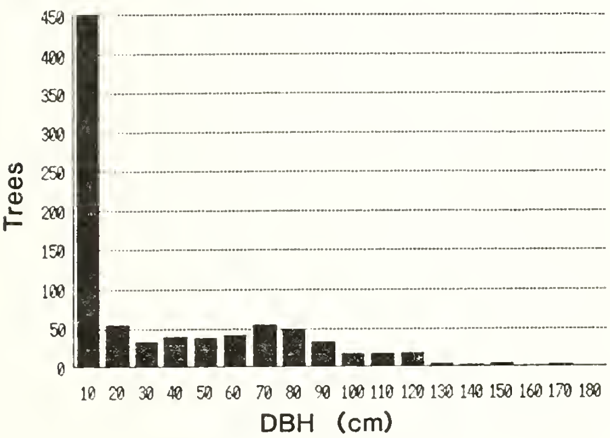

Figure 1. Size class distribution for total sample (n=882). Each size class is less than or equal to the number.

individuals whose canopy covered at least a portion of a stream course.

DISCUSSION

A total of 882 Quercus lobata individuals were inventoried of which 49 percent were trees, 32 percent were seedlings and 19 percent were fire resprouts (fig. 1). Trees occurred on all four sites, resprouts were found at Paramount Ranch and Malibu Creek State Park and seedlings were found only at Malibu Creek State Park. Each site has had a different land use history and recruitment of younger size classes initially appears to have a relationship to the time since last major disturbance and fire history. Virtually all seedlings found during the survey were in Malibu Creek State Park which has had major physical impacts removed for the longest period of time (15 years). A subjective rating was developed to reflect the condition of the trees inventoried. Based upon a three tiered scale 43 percent of the trees inventoried were in good condition, 40 percent were average and 17 percent were in poor condition. Fire scars were present on 15 percent of the trees inventoried . Malibu Creek, Paramount and Cheseboro experienced major fires in 1978 and 1982. Over 18 percent of the trees had ground squirrel dens under their canopies. Just less than 10 percent were being used by acorn woodpeckers as granary trees.

Associated understory vegetation

Annual grasslands were associated with 50 percent of the valley oaks surveyed. These grasslands are dominated by European species such as, Avena barbata Brot., A. fatua L., Bromus diandrus Roth., B. mollis L., B. rubens L., Hordium murinum L. and Festuca myorus L. Over 20 percent of the trees had a mustard (Brassica geniculata (Desf.) J. Ball., B. niger (L.) Koch.) understory. Chaparral species (Rhamnus californica Esch., Ribes malvaceum Sm., Rhus laurina Nutt. in T.&G., Ceanothus spinosus Nutt., Arctostaphylos glandulosa Eastw. and Adenostoma fasciculatum H.&A.) were present with 14 percent of the trees. Heavy shrub cover accumulation under some of the valley oaks is probably the result of fire exclusion. The same land management has also allowed coastal sage scrub species (Artemisia californica Less., Eriogonum fasciculatum Benth., and Salvia leucophylla Greene.) to occur in 8 percent of the samples. Native grasses (Stipa pulchra Hitchc., Bromus carinatus H.& A. and Elymus glaucus Buckl.) were discovered under 2.8 percent of the trees. Silybum marianum (L.) Gaertn. occurred in 2.2 percent of the observations. Opuntia littoralis (Engelm.) Ckll. was found as an understory component at Rancho Sierra Vista.

Tree Data

The data were organized into 10 centimeter dbh (excluding individuals less than 1.5 cm. dbh) size classes, and site preference classes using aspect and topographic position data. Only seven percent of the 433 trees inventoried were located at the Rancho Sierra Vista site. Virtually no size class pattern was detected there. The other three sites have different size class distributions from one another that apparently reflects land use histories. Separation of the data for riparian

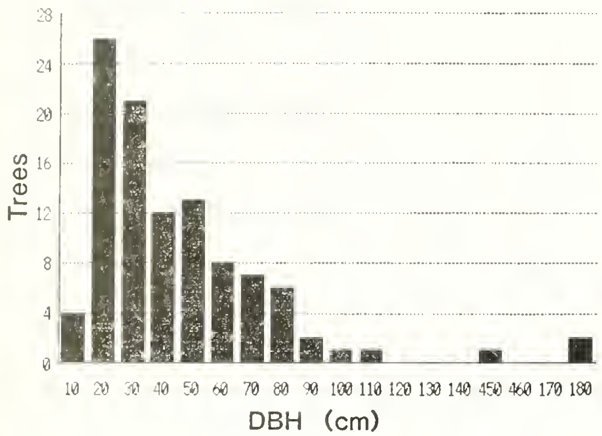

Figure 2. Size class distribution for riparian trees (n=104). Each size class is less than or equal to the number.

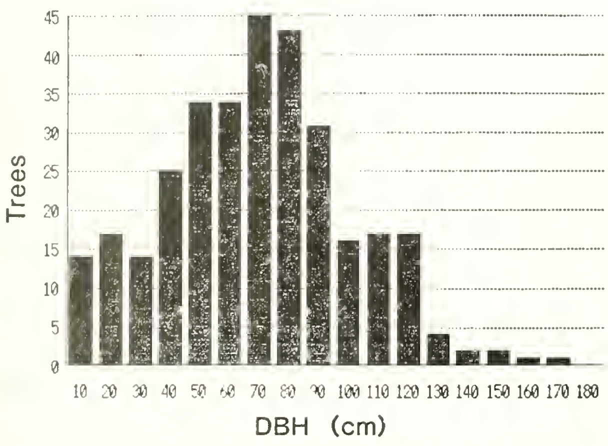

Figure 3. Size class distribution for combined hillside and alluvial trees. Each size class is less than or equal to the number.

trees reveals a different size class structure (fig. 2) than when the total data are viewed. The size class distribution for the riparian trees, representing 25 percent of the trees inventoried, approximates what could be expected for a normal recruitment curve or a J-shaped curve from the 20 cm dbh class on up. The largest individual surveyed in this study occurred in this habitat at 172 cm. (68 in.) dbh.

The frequency distribution patterns for trees occurring on hillsides and alluvial flats have bell shaped curves with peaks at the 70 and 80 cm. diameter classes (fig. 3). The alluvial flats trees and the hillside trees represent 35 percent and 40 percent of the inventoried trees respectively.

The data for Cheseboro Canyon indicates that virtually nc recruitment has occurred there recently. Recent impacts by cattle grazing are probably responsible for the absence of the smaller size classes at this site.

The largest numbers of individuals occurred on the northwestern aspect for hillside sites. On the valley floor or alluvial flat habitat the southwestern aspect appears as an important aspect.

<u>Seedling data</u>

Of the 281 seedlings inventoried 75 percent occurred on hillsides (fig. 4). The tops of the hills, included in the hillside category, had the smallest occurrence of seedlings (one percent). Likewise the riparian sites had a poor representation of seedlings with seven percent and the alluvial flats had 18 percent of the inventoried seedlings.

A size class distribution was arranged by height in 25 cm. increments

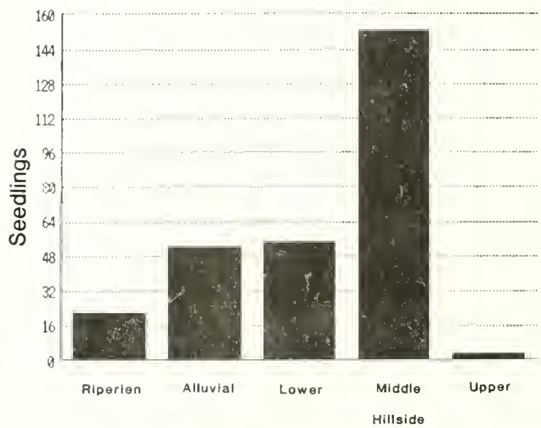

Figure 4. Topographic preference of seedlings.

(fig. 5). The smallest size class (25 cm) had fewer individuals than the 50 cm. size class, otherwise a J-shaped curve seems apparent. There are so few recruitments that could graduate from the sapling to the tree category that a normal contribution to the overall population stability seems to be lacking. The aspect distribution indicates a site preference on eastern aspects with 52 percent of the seedlings. There were no seedlings found in mustard stands.

Resprout data

It has been theorized that fire could enhance root growth and provide seedling establishment opportunities at the dry southern end of the valley oak distribution (Swirsky 1986). Field investigations conducted indicated that 12 percent of the seedlings and saplings in the study plots were fire resprouts. Total resprouts at sites selected for this research represent 36 percent of the individuals with less than 2.5 cm. dbh and 19 percent of the total inventory. The features of site preference indicated in the seedling data are also apparent in the resprout data. Hillsides, especially midslope, represent the favored topographic position with 75 percent of all the resprouts. The eastern aspect is also the most favored site containing 54 percent of the resprouts.

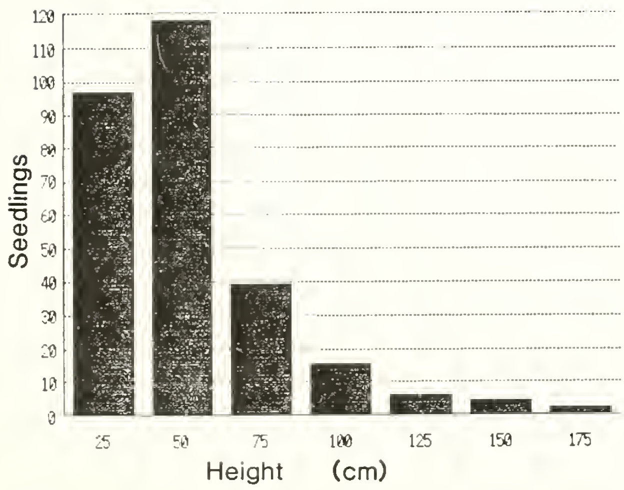

Figure 5. Size class distribution for seedling height.

CONCLUSIONS

The population structure for *Quercus lobata* at the southern limit of its distribution in the Santa Monica Mountains has a size class structure that shows declining recruitment in the small size classes. The 70 and 80 cm size classes form the peak of the bell shaped population curve generated from the data set for this study. A normal population curve for a long lived species such as *Quercus lobata* should appear as an inverted 'J' shaped curve with a high number in the small size class. If age studies were carried out for the peak size classes from this study, a time period could be assigned to the beginning of changing land use patterns or other factors which may have caused regeneration problems. Only recently have all sites in this study been managed for their ecosystem values. They represent a very small portion of the existing valley oak habitat in the Santa Monica Mountains.

A large percent of the trees inventoried occurred on northwestern aspects in all topographic habitats. Alluvial flats had the largest proportion of trees occurring on southwestern aspects and all habitats had some trees occurring on southwest aspects.

In the riparian habitat the highest percent of the trees occurred in the smaller size classes, except for seedlings and saplings. Cheseboro canyon had virtually no small size class trees.

Although not abundant, seedlings and saplings are appearing, especially on sites that have had domestic grazing removed for several years. The highest percentage of seedlings inventoried occurred on hillsides with the east facing slopes containing the largest number of seedlings. The same phenomena occurred with the fire resprouts. If there is some sort of competitive advantage for seedling establishment as a result of being burned another factor in valley oak management needs to be addressed. Fire frequency and exotic fuels effects on the valley oak are in need of answers. Population dynamics involving the mortality and recruitment rates for the maintenance of a stable population need to be understood for the successful long term management of the valley oak.

Acknowledgments: I thank several students for their assistance with data collection, Karen Danielson, Joanne Gonzales, Kim Horne and especially Karin Yamashita for needing field work and essentially causing this project; and to Paul Rose for his patience and constructive criticism.

REFERENCES

Griffin, James R. Regeneration in Quercus lobata savannas, Santa Lucia Mountains, California. Amer. Mid. Nat. 95:422-435; 1976.

Griffin, James R.; Critchfield, William; The distribution of forest trees in California. Res. Paper PSW-82. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1972, 113p.

Johnson, R. Roy; Carothers, Steve W.; Simpson, James M. A riparian classification system. In: Warner, R. E., and Hendrix, K. M. eds. California Riparian Systems - Ecology, Conservation and Productive Management. U. C. Press. 1984: 375-382.

Ogden, Gary L. Sea salt aerosol damage to Quercus agrifolia and Quercus lobata in the Santa Ynez Valley, California. In: Plumb, T. ed. Proceedings of the symposium on the ecology, management, and utilization of California oaks; 1979 June 26- 28; Claremont, California. Gen. Tech. Rep. PSW-44. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1979; 230-237.

Raven, Peter H.; Thompson, Henry J.; and Prigge, Barry A. Flora of the Santa Monica Mountains, California. 2d ed. University of California, Los Angeles. Southern California Botanists Special Publication No. 2; 1986; 181 p.

Swirsky, Karen. Valley oak savanna: an ecological approach to habitat restoration. Los Angeles, CA. California State University, Los Angeles; 1986. 73 p. Thesis.

White, Keith L. Structure and composition of foothill woodland in central coastal California. Ecology 47:229-237; 1966.

Whittaker, Robert H. Communities and ecosystems. New York: Macmillan; 1970. 385 p.

Wieslander, Albert E. Vegetation types of California, Calabasas quadrangle, 161 D. Forest Service, U.S. Department of Agriculture; 1938; map.

Wieslander, Albert E. Vegetation types of California, Triunfo Pass quadrangle, 161 C. Forest Service, U.S. Department of Agriculture; 1939; map.

Range

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Hardwood Range Management[1]

John W. Menke[2]

Following the 1979 Symposium on Ecology, Management and Utilization of California Oak Woodlands and Savannahs, controversy erupted over the effect of blue oak (Quercus douglasii) tree canopy on understory forage production for livestock. At a northern California Sierra Nevada foothills site tree removal increased forage production, while at a southern Sierra foothill site forage production under oaks was higher than in adjacent grassland. During the discussion period of this symposium the two investigators, B. L. Kay and V. L. Holland, and other knowlegeable researchers helped resolve this apparent discrepancy. The open status of the savannah at the southern site on the San Joaquin Experimental Range coupled with light-textured granitic soils likely make the site a relatively xeric one. Oak canopy cover probably benefits forage production by reducing transpiration of understory forage plants thereby extending the growing season. In a very different woodland situation on a slightly north-facing slope at the northern site on the Sierra foothill range field station, heavier-textured soil, higher rainfall, and additional sunlight due to oak removal clearly enhanced forage production. Thus oak removal effects on livestock forage production depend on local edaphic and climatic conditons as well as oak density.

A second outcome of particular interest from this symposium is the additional finding of B. L. Kay from his long-term study at the Sierra foothill range field station. His results show that forage production enhancement due to oak removal, above that of open grassland, lasts for only approximately 15 years. Managers must realize that oak woodland conversion to open grassland creates rangeland with productivity of open grassland, and that the enhancement of production over that of open grassland is not sustainable for more than about 15 years. The length of the enhancement period obviously must depend on the age of the oak stand and the accrued standing crop of nutrients in the understory soils.

Given that rangelands produce multiple products, it is often difficult to determine the net value of oak removal projects. Thinning of dense oak woodlands on sites with well-developed soil profiles and relatively high rainfall can be an effective means of creating more grassland for livestock forage production. However, under poorer, open deciduous oak savannah conditions, the practice of type conversion is not justified because wildlife habitat losses probably outweigh forage enhancement values.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1987, San Luis Obispo, California.

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

The Effect of Blue Oak Removal on Herbaceous Production on a Foothill Site in the Northern Sierra Nevada[1]

Henricus C. Jansen[2]

Abstract: The effect on herbaceous production of blue oak canopies of 25, 50, and 75 percent, and the effect of complete removal of such canopies were determined over a 7-year period for a single site in the foothills of the northern Sierra Nevada. Tree covered plots produced 12 percent less than open grassland plots, while cleared plots produced 46 percent more than tree covered plots. Percentage differences in production were about the same for the middle and end of the growing season, but were considerably less at the beginning of the growing season. Large, climatically induced, annual variation in production mask the long term trend of the effect of tree removal on annual production. Tree canopy, whether present or removed, has no discernable correlation with production due to tree size, stocking and other plot effects.

Blue oak (Quercus douglasii Hook. and Arn.) is a dominant white oak of the foothill woodland vegetation type of California (Griffin 1977). This vegetation type extends from southern California to northern California occupying foothills and valley borders between 120 and 900 m elevation (Munz and Keck 1959). For the most part, blue oak is restricted to the foothill woodland community and forms extensive savannas (Griffin and Critchfield 1972; Griffin 1977).

The importance of the blue oak has been stressed by numerous authors, notably at the 1979 Symposium on the Ecology, Management and Utilization of California Oaks (Plumb 1980) and the concensus was that this resource suffered from poor stand regeneration, lack of management, and lack of proper utilization. The widespread and apparently accelerating practice of oak killing and removal was of particular concern and a source of controversy. Kay and Leonard (1980) reported on the effect of blue oak removal on herbaceous forage production in the northern Sierra Nevada foothills. Over a 13-year period they found that forage yields averaged 67 percent more on cleared areas than on tree covered areas, and 17 percent less on tree covered areas than on adjacent open grassland areas. These results are similar to but much less than those reported by Johnson et al. (1959), who obtained a 5-fold increase in forage yield from cleared areas as compared to tree covered areas for a location approximately 40 km to the south. Murphy and Crampton (1964) studied the effect of blue oak removal in the northern Coast Ranges and reported a 120 percent increase in forage yield from cleared areas as compared to adjacent open grassland. The early findings by Johnson et al. and by Murphy and Crampton provided support for state-wide recommendations for the removal of blue oak from rangeland as a means of increasing forage production, livestock grazing, and ranch income (Bell 1963; Murphy and Berry 1973; Holland 1976).

In contrast to these findings and recommendations, Holland (1973; 1976; and 1980) reported that forage production was 40 to 100 percent greater under blue oaks than in open grassland and recommended that blue oak clearing be stopped (Steinhart 1978). Holland's findings were based on studies in the south-central Sierra Nevada foothills and southern Coast Ranges and are supported by observations made by Duncan and Reppert (1960), Duncan (1967), and Duncan and Clawson (1980). Possible explanations for these contradictory findings are given by Duncan and Clawson (1980) and Holland and Morton (1980) and include: (1) regional climatic differences; (2) different levels of blue oak canopy; and (3) edaphic differences.

This study was initiated in the fall of 1979 to determine the relationship between the level of blue oak canopy and herbaceous production throughout the season of rapid plant growth (approximately March 1 to May 31) for two contrasting situations: (1) tree canopy left intact; and (2) tree canopy removed. A second purpose of the study was to determine the long term trend in herbaceous production following tree removal.

To provide for replication of the study and account for regional variation in climatic and edaphic conditions, 3 study sites were proposed. However, lack of available resources and funding prevented the inclusion of 2 sites in the study. Results obtained from the one remaining study site should therefore be considered as descriptive and no inferences should be drawn beyond the narrow confines and limitations of this study.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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STUDY SITE

The study site is located in northern California at the University of California Sierra Foothill Range Field Station, on the east side of the Sacramento Valley. Elevation of the site is 425 m, slopes are gentle (less than 10 percent), and aspect is southerly. The average annual rainfall for the last 20 year period is 732 mm. The soils at the site are shallow to moderately deep clay loams in the Auburn-Las Posas-Sobrante complex. They contain gravel, stones and occasional outcrops of bedrock. Blue oak dominates the site, while digger pine (*Pinus sabiniana*) and interior live oak (*Quercus wislizenii*) are minor constituents. The blue oaks are unevenly distributed and their canopies have created a vegetative mosaic ranging from small open grassland areas, through savanna, to dense woodland. Shrubs are represented by occasional plants of buck brush (*Ceanothus cuneatus*). The herbaceous vegetation is continuous and is dominated by soft chess (*Bromus mollis*), annual ryegrass (*Lolium multiflorum*), broadleaf filaree (*Erodium botrys*), and rose clover (*Trifolium hirtum*). Open areas are considerably richer in species than densely wooded areas. Principal species are listed below in order of importance:

Open Grassland	Dense Woodland
Bromus mollis	*Cynosurus echinatus*
Erodium botrys	*Lolium multiflorum*
Trifolium hirtum	*Bromus mollis*
Taeniatherum asperum	*Geranium molle*
Vulpia megalura	*Trifolium hirtum*
Lolium multiflorum	*Bromus madritensis*
Hordeum hystrix	*Stipa pulcha*
Aira caryophyllea	*Avena barbata*
Hypochoeris glabra	*Bromus diandrus*
Trifolium dubium	
Tunica prolifera	
Avena barbata	
Brodiaea laxa	

The site is grazed each year by cattle in both the green and dry seasons.

METHODS

In the fall of 1979, eight 0.1 ha plots were established on the 20 ha site. The site was selected from aerial photos and chosen because it provided a full range in oak canopy levels in close proximity, under conditions of similar aspect, slope, and soil characteristics. One pair of plots was located in open grassland and 3 pairs were located in blue oak woodland such that these 3 pairs of plots had approximately 25, 50 and 75 percent tree canopy (table 1). Canopy cover was initially determined on the aerial photos, and was remeasured on the ground by running 3 transects in each plot location and noting the frequency of overhead tree canopy. Stocking and tree diameter were also recorded at this time (table 1). In early February 1980 tree canopies were completely removed from one randomly selected plot of each of the 3 pairs. Great care was taken to minimize soil surface disturbance during tree removal. In late February, 12 small 0.9 m^2 (9.6 ft^2) wire mesh cages of the type described by Robertson (1954) were placed in each of the 8 plots. A stratified random procedure with proportional allocation was used for cage placement, with existing or former tree canopy and non-canopy areas serving as the 2 strata. In late December or early January of each subsequent growing season, all cages were moved to different locations within their respective plots, using the same placement procedure. Cage relocation is necessary to avoid the effects of litter accumulation, clipping, and absence of grazing which influence species composition and production (Bartolome, Stroud and Heady 1980; Heady 1956; Heady 1977).

Table 1--Description of the 6 plots located in blue oak woodland.

Removal Treatment	Canopy Cover (pct)	Stocking (Stems/ha)	Tree dbh[1] (cm) Avg	Range
Clearcut	28	60	32.5	26.0-50.0
None	27	90	25.0	10.0-39.5
Clearcut	50	50	50.5	25.5-73.5
None	54	130	30.0	10.5-57.5
Clearcut	74	160	35.5	11.5-69.5
None	75	170	34.4	8.5-47.5

[1]dbh: diameter at breast height

While the determination of total annual production was of primary interest, treatment effects might vary during the growing season. In addition, early in the growing season the standing forage crop is small and in high demand by livestock while at the end of the growing season this situation reverses itself. Cumulative growth data were therefore collected and all plots were sampled 3 times each year: at the beginning (late February-early March); middle (early-late April); and end (mid May-early June) of the spring growing season. With the exception of the first year of the study (1980), the clipping dates were determined by stage of plant development. The early season clipping occurred when the blue oaks were first beginning to leaf out and buck brush was approaching full bloom. Mid season clipping occurred when *Geranium molle* and *Erodium botrys* had reached the full bloom stage. End of season clipping occurred when the range was drying up, except for depressions. At this time, *Lolium multiflorum* was mature and *Taeniatherum asperum* was in the milk to dough stage. Clipping occurred inside the cages on 0.09 m^2 (.96 ft^2) microplots. Clipped plots did not overlap to avoid measurement of regrowth and clipping effect, and were clipped to ground level. The harvested material was air dried at 70°C for 24 to 48 hours, cleaned to remove foreign and herbaceous material produced in previous years, and weighed.

Table 2--Herbaceous standing crop at the beginning (A), middle (B), and end (C) of the growing season as affected by removal and canopy levels of blue oak.

A

Experimental treatment	Early Season Standing Crop							
	1980	1981	1982	1983	1984	1986	Mean[1]	S.E.
	kg/ha							
No tree removal								
0 pct canopy (control)	[2]482	294	644	960	638	489	605	109
25 pct canopy	630	181	487	863	553	447	506	109
50 pct canopy	700	282	645	1097	720	469	643	136
75 pct canopy	478	249	587	903	688	457	577	110
Complete tree removal								
0 pct canopy (control)	564	292	628	882	735	607	629	97
25 pct canopy	707	454	755	924	627	556	663	82
50 pct canopy	742	484	631	999	823	738	735	87
75 pct canopy	567	535	836	1038	799	847	811	81

B

Experimental treatment	Mid Season Standing Crop							
	1980	1981	1982	1983	1984	1986	Mean[1]	S.E.
	kg/ha							
No tree removal								
0 pct canopy (control)	2305 a	1603 a	1793	2300	1949 a	2337 ab	1996 a	143
25 pct canopy	2105 a	858 b	1501	1999	1526 b	1831 bc	1543 b	195
50 pct canopy	1747 a	1153 ab	1370	2507	2109 a	2633 a	1954 a	298
75 pct canopy	772 b	1039 ab	1478	2000	2076 a	1686 c	1656 ab	188
Complete tree removal								
0 pct canopy (control)	1062 y	1182 y	1450 y	2163 y	1742 z	2037 y	1715 z	182
25 pct canopy	2027 x	2165 x	1824 xy	2867 x	1987 yz	2905 x	2350 y	226
50 pct canopy	1683 xy	2183 x	1584 y	2841 x	2234 xy	3403 x	2449 xy	311
75 pct canopy	1154 y	2777 x	2281 x	3192 x	2484 x	3142 x	2775 x	179

C

Experimental treatment	End of Season Standing Crop							
	1980	1981	1982	1983	1984	1986	Mean[1]	S.E.
	kg/ha							
No tree removal								
0 pct canopy (control)	2026 a	3315 a	3425 a	4484 a	2767 a	2807	3360 a	310
25 pct canopy	2332 a	1982 b	2490 bc	4204 b	2332 b	2574	2716 b	385
50 pct canopy	1856 a	1990 b	2600 b	4803 a	2968 a	3012	3075 ab	469
75 pct canopy	1224 b	2235 b	2050 c	5013 a	2718 a	2443	2892 b	542
Complete tree removal								
0 pct canopy (control)	2384 x	2326 y	3226	4518 z	2982 z	2480 z	3106 z	389
25 pct canopy	1778 xy	3504 x	3511	6210 xy	3589 y	3405 y	4044 y	542
50 pct canopy	2087 xy	3856 x	3361	6101 y	4228 x	4531 x	4415 x	464
75 pct canopy	1634 y	3224 x	3193	6795 x	4054 x	3661 y	4185 xy	671

[1]Data for 1980 excluded.

[2]Average of 12 observations. Mean separation in a column by DMRT at 5 pct level. Where no letter is shown, no significant difference exists.

nual or seasonal rainfall. High rainfall in 1983 with a favorable distribution (50 percent during the February through May growing season) gave this year the highest production for all experimental conditions.

The results of the Duncan Multiple Range Test on plot means are shown in table 2. Comparisons were made within each year, season, and tree removal condition for all 4 canopy levels. Comparisons for early season standing crop gave identical results for all years and tree removal conditions. Canopy levels were not significantly different at the 5 percent level. Mid-season comparisons for non-cleared canopy showed that standing crop on plots with 25 and 75 percent canopy was significantly less ($p<0.05$) than that on open grassland plots in 2 out of 6 years. In contrast, standing crop on cleared plots exceeded that on open grassland plots in 4 to 5 out of 5 years (1980 exclud-

The mean production data, averaged over all years of the study, were analyzed by split-split-plot procedure with tree removal and tree canopy serving as split-plot and split-split-plot factors. The annual production data were similarly analyzed, using a split-plot procedure. Mean separation of simple plot means was by Duncan Multiple Range Test. Since plots are not replicated, canopy effect and plot effect on herbaceous production are confounded and cannot be separated.

RESULTS AND DISCUSSION

Changes in Herbaceous Production

Blue oak removal did not cause significant changes in production during the 1980 growing season. This was probably due to the fact that removal took place during the first half of February while germination and establishment of the mostly annual, herbaceous vegetation takes place in the preceeding fall. Murphy and Crampton (1964) and Kay and Leonard (1980) also reported a lack of effect for the first growing season following tree removal.

The standing crop for the 3 stages of plant development (early, mid, and end-of-season) for all years of observation is shown in table 2. The split-split-plot analysis of the mean annual data (excluding 1980) led to the following findings. Tree removal had no significant effect on early season standing crop, but had a highly significant effect ($p<0.001$) on mid-season and end-of-season standing crops. Cleared plots yielded 28, 47, and 46 percent more than tree covered plots at early, mid, and end-of-season time of observation, while tree covered plots yielded 7, 8, and 12 percent less than open grassland plots at these times.

The effect of tree canopy (ranging from 0 to 75 percent) on standing crop was highly significant for both non-cleared and cleared conditions ($p<0.01$ and $p<0.001$). However, this effect varied by season and was not significant at the beginning of the growing season. Tree canopy effect on standing crop was greater for cleared than non-cleared conditions. Results of an analysis of variance with orthogonal contrasts are shown in table 3. Differences in the end-of-season standing crop of open grassland and non-cleared plots, and of open grassland and cleared plots were highly significant ($p<0.001$). However, end-of-season differences among the 3 non-cleared plots and among the 3 cleared plots were not significant. Differences in the mid-season standing crop of open grassland and non-cleared plots, and of open grassland and cleared plots were, respectively, not significant and highly significant ($p<0.001$). Mid-season differences among the non-cleared plots and among the cleared plots were, respectively, not significant and significant ($p<0.05$). Because of the small observed differences among the 3 non-cleared, the 3 cleared, and the 2 open grassland plots, plot results were grouped for each season and year of observation (fig. 1).

Table 3--Partial data for split-split-plot analysis of variance[1] showing tree canopy effect within tree removal treatment within season of observation averaged over 5 years of the study (1980 excluded).

Source of Variation	df	Sum of[2] Squares	Mean Square	F	Sign[3] Level
C/R/S[4]	18	995.992	55.333	7.17	***
C/R1/S1	3	4.986	1.662	1.00	ns
C/R1/S2	3	74.314	24.770	3.21	*
[5]Contrast 1	1	29.120	29.120	3.77	ns
Contrast 2	2	45.194	22.597	2.93	ns
C/R1/S3	3	113.282	37.761	4.89	**
Contrast 1	1	81.200	81.200	10.52	***
Contrast 2	2	32.082	16.041	2.08	ns
C/R2/S1	3	9.804	3.268	1.00	ns
C/R2/S2	3	295.486	98.495	12.76	***
Contrast 1	1	245.916	245.916	31.86	***
Contrast 2	2	49.570	24.785	3.21	*
C/R2/S3	3	495.933	165.311	21.42	***
Contrast 1	1	460.760	460.760	59.70	***
Contrast 2	2	35.173	17.586	2.28	ns
Error (c)	72	555.689	7.718		

[1]Main plot and split-plot analysis excluded; coefficient of variation for sub-sub plot analysis = 13.5 percent.

[2]Multiply sum of squares and mean squares values by 10^4 to obtain actual values.

[3]Ns = not significant at 5 pct level; * = significant at 5 pct level; ** = significant at 1 pct level; *** = significant at 0.1 pct level.

[4]C/R/S = Tree canopy (C) effect within tree removal (R) treatment within season (S); R1 = no tree removal; R2 = tree removal; S1 = early season; S2 = mid season; S3 = end of season.

[5]Contrast 1 = 0 pct tree canopy versus the average of 25, 50 and 75 pct tree canopy; contrast 2 = 25 pct versus 50 pct versus 75 pct tree canopy.

Lack of replication made the split-plot analysis by years rather limited as insufficient degrees of freedom were available for testing tree removal effect. For each year, the significance of canopy effect (4 levels) averaged over the 3 seasons of observation was tested for conditions with and without tree removal. Canopy effect without tree removal was significant only in 1980 ($p<0.05$), while with tree removal (e.g. residual effect) it was significant in 1981, 1983, 1984, and 1986 (no data available for 1985). Significance levels were at 5, 5, 1, and 1 percent, respectively.

Both 1981 and 1985 were dry years with annual rainfall of 488 and 492 mm, while 1982 and 1983 were wet years with annual rainfall of 1129 and 1046 mm (table 4). No correlation could be established between tree canopy effect and either an-ed). End-of-season standing crop on non-cleared plots was significantly less ($p<0.05$) than that on open grassland in 4 out of 6 years for the 25 percent tree canopy plot, and in 2 out of 6 years for the 50 and 75 percent tree canopy plots. End-of-season standing crop on cleared plots exceeded that on open grassland in 4 out of 5 years for the 3 tree canopy levels (1980 excluded).

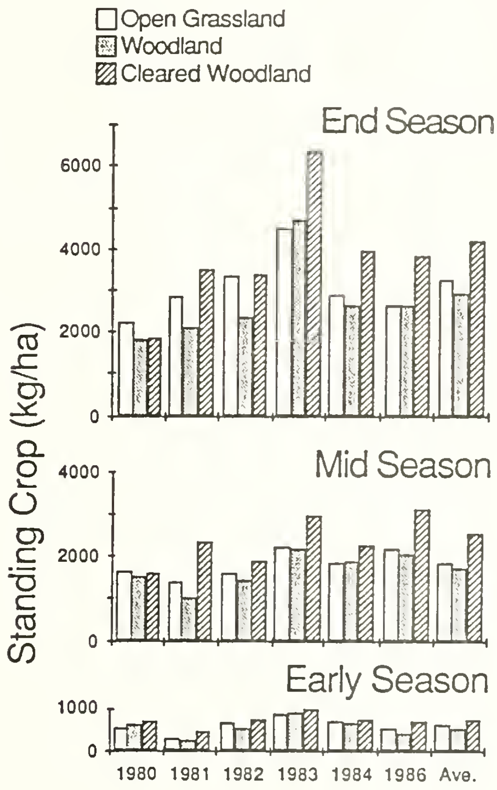

Figure 1--Herbaceous standing crop at 3 stages in the growing season for the years in the study. Columns for average standing crop exclude the data for 1980. Columns for open grassland based on 24 observations, columns for woodland and cleared woodland based on 36 observations.

Figures 2 and 3 illustrate the yearly response of herbaceous standing crop to tree removal and tree canopy conditons. As herbaceous growth progresses through the seasons, differences between cleared and non-cleared conditions increase (fig. 2). Differences in standing crop between cleared and non-cleared conditions (including the trivial case of 0 percent tree canopy) are shown in figure 3. The difference between the 2 plots with 0 percent tree canopy (e.g. open grassland) gives an indication of the variance between plots treated alike. The difference in end-of-season standing crop between the average of the 3 cleared, the 3 non-cleared, and the 2 open grassland plots, and the annual and seasonal (February through May) rainfall are shown in table 4. In 1980 there was no appreciable difference between cleared and non-cleared plots, indicating that tree removal did not cause an increase in standing crop. In 1981, a dry year, the difference in standing crop between cleared and non-cleared plots was 1459 kg/ha. The following two years were wet years, while 1984 and 1986 had normal amounts of rainfall. No correlation between either annual or seasonal rainfall and the difference in standing crop due to tree removal is apparent. We cannot confirm Kay and Leonard's (1980) observation that the relative difference in standing crop between cleared and non-cleared conditions is greatest during dry years. 1981 had low annual and low seasonal rainfall, but a large difference in standing crop, while 1983 had high annual and high seasonal rainfall and an even larger difference in standing crop. No explanation can be given for the relatively small difference in standing crop in 1982, a year with both high annual and seasonal rainfall. Since 1983 the difference in standing crop has declined regardless of annual and seasonal rainfall. However, the data are insufficient for making a definitive statement about this trend.

Table 4--Difference in end of season standing crop among 3 cleared, 3 non-cleared and 2 open grassland plots, together with annual and seasonal rainfall.

Rainfall year	Rainfall		Difference in standing crop		
	Year	Season	N-cleared vs open grassland	Cleared vs open grassland	Cleared vs non-cleared
	mm	mm	kg/ha	kg/ha	kg/ha
1979-80	694	260	-401	-372	29
1980-81	488	189	-751	708	1459
1981-82	1129	443	-946	29	975
1982-83	1046	519	172	1868	1696
1983-84	719	171	-201	1083	1284
1984-85	492	180	---[1]	---	---
1985-86	867	474	32	1222	1190

[1]No data available for this year.

The criterion used in plot selection and layout was tree canopy level, such that the 3 pairs of wooded plots had approximately 25, 50, and 75 percent tree canopy. Uniformity in tree density (stocking) and tree diameter were therefore sacrificed. On an absolute as well as weighted basis (100 percent tree canopy), the cleared plot with 50 percent tree canopy had the lowest stocking (50 trees/ha) and the highest average diameter (50.5 cm) (table 1). In 4 out of 6 years this plot had the most end-of-season standing crop. It also had the highest average end-of-season standing crop. In contrast, the non-cleared plot with 27 percent tree canopy had the highest weighted stocking level (360 trees/ha) and the lowest average tree diameter (25 cm). In 3 out of 6 years this plot had the lowest end-of-season standing crop. It also had the lowest average end-of-season standing crop. Weighted stocking and average tree diameter of the cleared plots with 27 and 74 percent tree

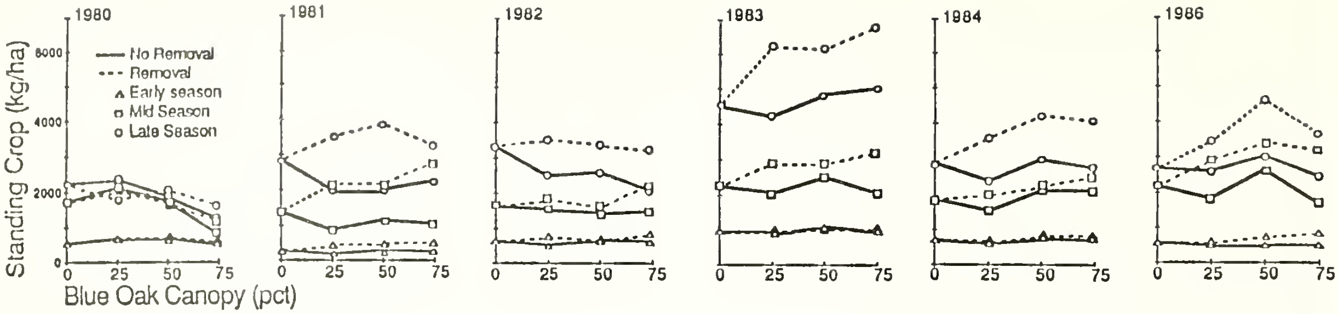

Figure 2--Herbaceous standing crop as a function of blue oak canopy and removal at 3 stages of growth for the years in the study.

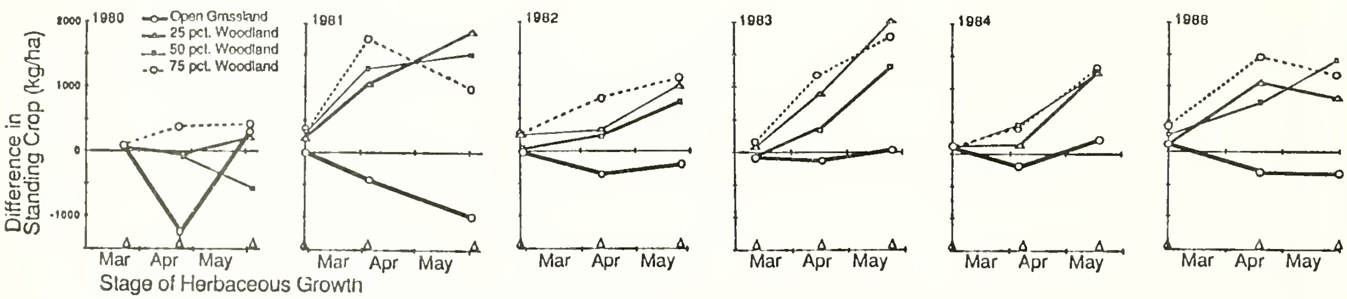

Figure 3--Difference in standing crop between cleared and non-cleared plots as a function of stage of growth for 4 canopy levels for the years in the study.

canopy were very similar, with the 74 percent canopy plot having slightly lower stocking and larger trees. This latter plot produced slightly more end-of-season standing crop following tree removal. The 2 remaining plots had 54 and 75 percent tree canopy and were not cleared. Plots were again very similar in their weighted stocking and average tree diameter, with the 75 percent canopy plot having slightly lower stocking and larger trees (average diameter 34.5 cm). However, the plot with 54 percent tree canopy had 2 trees which were 15 and 21 percent larger than the largest tree in the 75 percent tree canopy plot. End-of-season standing crop of these 2 plots was very similar, with the 54 percent tree canopy plot producing slightly more.

The foregoing results (as well as field observations at the site) indicate but do not prove that high weighed stocking levels and small tree size are associated with low levels of herbaceous production, and that low weighted stocking levels and large tree size are associated with high levels of herbaceous production. Also, the absolute increase (but not necessarily the percentage increase) in herbaceous production following the removal of small trees is considerably less than the absolute increase in production resulting from the removal of large trees.

In this study, plot effects including those due to tree size and tree stocking, are confounded with tree canopy effects, which would help explain the lack of correlation between blue oak canopy cover and standing crop (fig. 2). This, and other studies on the effect of blue oak removal in the foothills of the northern Sierra Nevada (Johnson et al. 1959; Kay and Leonard 1980) dealt with canopy cover levels within the range of 25 to 75 percent. Of these 3 studies, this study had the largest increase in production, the largest average tree diameter, and the lowest stocking level (table 5). The contrasting results obtained by Holland (1973; 1980) for the foothills of the central Sierra Nevada cannot be compared with the above results because Holland worked with large, isolated trees at extremely low stocking levels. Such trees often serve as shade and resting places for livestock and the soil surrounding such trees is enriched by animal excretions. At the other end of the spectrum is the study by Murphy and Crampton (1964) with an extremely high stocking rate (562 stems/ha), small average tree diameter (21.6 cm), and the largest reported increase in herbaceous production (2915 kg/ha). The tree canopy cover for this study is not known, but was presumably higher than that of any other study.

Changes in Botanical Composition

Open grassland and savanna (25 percent tree canopy) support a great variety of native and introduced annual grasses and forbs. Many of these species are non-productive or not desirable as feed for livestock, including such species as *Taeniatherum asperum*, *Hordeum hystrix*, *Vulpia megalura*, *Aira caryophyllea*, *Hypochoeris glabra*, *Tunica prolifera*, and *Navarretia* sp. Dense blue oak woodland (75 percent tree canopy) and the areas underneath tree canopy in moderately dense woodland (50 percent tree canopy) support a more restricted flora of shade tolerant species (page 2 of this paper).

Table 5--Increase in herbaceous production as related to average tree diameter and stocking level for different studies on oak removal.

Location (Author)	Production increase		Avg tree diam	Stocking level
	kg/ha	pct	cm	stems/ha
Placer County (Johnson et al. 1959)	1267	400	19.0	288
Hopland Field Stn. (Murphy and Crampton 1964)	2915	650	20.3	562
Sierra Field Stn. (Kay and Leonard 1980)	1053	66	27.9	375
San Joaquin Exp Range (Holland 1973, 1980)	decrease		30.5	10
This study	1320	46	34.7	50-170

Following tree removal, species intolerant of full sunlight e.g. Cynosurus echinatus, Geranium molle, Bromus madritensis, Sanicula sp. and Ranunculus sp. quickly disappeared, and were replaced by species of the open grassland. Where removed trees had been large (diameter greater than 30 cm) the replacement species were dominated by productive grasses, especially Lolium multiflorum, Bromus mollis, and Avena barbata, however, where removed trees had been small, the replacement species were more representative of the general open grassland mix, and increases in Lolium multiflorum, Bromus mollis, and Avena barbata were much less pronounced and did not persist as well.

Six years after tree removal, the approximate extent of the former tree canopies is still visible through the presence of a greener color in the vegetation and a different species composition. These canopy projections in the herbaceous vegetation are most pronounced for the larger trees but are generally diminishing in size and clarity as time progresses.

CONCLUSIONS

Blue oak removal did not cause significant changes in herbaceous production and species composition in the first growing season following late winter tree removal. During subsequent years the difference in mid-season and end-of-season standing crop between cleared plots and similar, but non-cleared plots, was highly significant. However, this difference was not significant at the beginning of the season of rapid plant growth. Increases in standing crop were 161, 807, and 1320 kg/ha for early, mid, and end-of-season. Non-cleared plots on which tree canopy had been left undisturbed, produced significantly less than adjacent open grassland plots. These differences were significant only for the middle and end of the growing season and amounted to 42, 138, and 339 kg/ha for early, mid, and end-of-season. While cleared plots consistantly outproduced open grassland plots, this was not the case for plots on which the tree canopy had been left intact. In some years, non-cleared plots out-produced open grassland plots; however, no cause related to either annual or seasonal rainfall could be found to explain this.

The presence of blue oaks slightly depressed herbaceous production, while their removal greatly enhanced it. For the range of tree canopy levels examined, no correlation with herbaceous production was apparent for either condition of tree canopy removal (e.g. removed, non-removed). This lack of correlation is thought to be due to other factors, such as tree diameter and stocking, with which tree canopy is confounded. On the site examined in this study, large tree sizes (more than 30 cm in diameter) and low stocking levels are associated with areas of above average herbaceous production following tree removal, and (but to a lesser extent) without tree removal. On the other hand, small trees with high stocking levels are associated with areas of below average herbaceous production, and with small increases in production after tree removal.

The herbaceous vegetation under moderate to dense (50 to 75 percent) blue oak canopy levels is dominated by shade tolerant species. These were quickly replaced by sun loving or sun tolerant species following tree removal. The most productive and most palatable species have tended to dominate areas marking the approximate extent of former tree canopies and have mostly persisted in areas which were occupied by the larger trees.

Since the tree removal in 1980 no clear evidence of a decline in the increased production levels caused by tree removal has become apparent. The slight decline which occurred in 1984 and 1986 is considered to be insufficient evidence of any long term trend.

The management implication of these findings may be of interest and concern to the different users of the blue oak woodland. The larger oaks are of obvious greater value for all users. Their removal to increase forage production would also produce large amounts of fuelwood and would have a major impact on the foothill woodland ecosystem. While the major benefits are likely to be short-term, loss of wildlife habitat, livestock shade, aesthetics, and possible soil erosion are more likely to be longterm.

Acknowledgements: I thank John W. Menke, University of California, Davis for his assistance and support in making this study possible, and numerous past students for their help with the extensive field work.

REFERENCES

Bartolome, James W.; Stroud, Michael C. and Heady, Harold F. Influence of natural mulch on forage production on differing California annual range sites. J. Range Manage. 33(1):4-8; 1980 Jan.

Bell, M. Grass not oaks makes 'em fat. Orland, Ca. Farm Advisor's Office, Univ. Calif. Coop. Extension Service; Misc. Publ.; 1963; unpaged.

Duncan, Don A. Blue oak canopy effect on herbage yield on central California foothill rangeland. In: Abstract of papers presented at the 20th annual meeting of the Am. Soc. Range Manage. 1967 Feb. 14-17; Seatle, WA. 1967; 61-62.

Duncan, D. A. and Reppert, J. N. A record drought in the foothills. Misc. Paper 46. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, USDA; 1960; 6 p.

Duncan, D. A. and Clawson, W. J. Livestock utilization of California's oak woodlands. In: Proceedings of the symposium on the ecology, management and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Report PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, USDA; 1980; 306-313.

Griffin, James. Oak Woodland. In: Barbour, Michael and Major, Jack, eds. Terrestrial vegetation of California. New York: John Wiley & Sons; 1977; 383-415.

Griffin, James and Critchfield, William. The distribution of forest trees in California. Res. Paper PSW-82. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, USDA; 1972; 114 p.

Heady, Harold F. Changes in California annual plant community induced by manipulation of natural mulch. Ecology 37 (4):798-812; 1956 Oct.

Heady, Harold F. Effect of cages on yield and composition in the California annual type. J. Range Manage. 10(4):175-177; 1957 July.

Heady, Harold F. Valley Grassland. In: Barbour, Michael and Major, Jack, eds. Terrestrial vegetation of California. New York: John Wiley & Sons; 1977; 491-514.

Holland, V. L. A study of vegetation and soils under blue oak compared to adjacent open grassland. Berkeley, CA: Univ. of California; 1973; 369 p. Dissertation.

Holland, V. L. In defence of blue oaks. Fremontia 4(1):3-8; 1976 April.

Holland, V. L. Effect of blue oak on rangeland forage production in central California. In: Proceedings of the symposium on the ecology, management and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Report PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, USDA; 1980; 314-318.

Holland, V. L. and Morton, Jimmy. Effect of blue oak on nutritional quality of rangeland forage in central California. In: Proceedings of the symposium on the ecology, management and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Report PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, USDA, 1980; 319-322.

Johnson, Walter; Mitchell, Cyrus; Evans, Raymond and Berry, L. J. Yield quality of annual range forage following 2,4-D application on blue oak trees. J. Range Manage. 12(1):18-20; 1959 Jan.

Kay, Burgess L. and Leonard, O. A. Effect of blue oak removal on herbaceous forage production in the north Sierra foothills. In: Proceedings of the symposium on the ecology, management and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Report PSW-44. Berkeley, CA; Pacific Southwest Forest and Range Exp. Stn., Forest Service, USDA; 1980; 323-328.

Munz, Philip and Keck, David. A California flora. Berkeley and Los Angeles, CA: Univ. of California; 1959. 1681 p.

Murphy, Alfred H. and Crampton, Beecher. Quality and yield of forage as affected by chemical removal of blue oak (Quercus douglasii). J. Range Manage. 17(3):142-144; 1964 May.

Murphy, Alfred H. and Berry, L. J. Range pasture benefits through tree removal. California Agriculture 27(1):8-10; 1973 Jan.

Plumb, T. R. (Tech. Coord.) Preface. In: Proceedings of the symposium on the ecology, management and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Report PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, USDA; 1980. 368 p.

Robertson, Jos. A low cost portable cage for range and pasture plots. J. Range Manage. 7(1):42; 1954 Jan.

Steinhart, Peter. As the old oaks fall. Audubon Magazine 80(5):30-40; 1978 Sept.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Long-Term Effects of Blue Oak Removal on Forage Production, Forage Quality, Soil, and Oak Regeneration[1]

Burgess L. Kay[2]

Abstract: Herbaceous forage response to the killing or removal of blue oak trees was measured for 21 years (1965-1985) in the north-Sierra foothills of California. Increased herbage was noted in all but three of the first 15 years (years one, nine, and fourteen), but not after the fifteenth year. Forage increases during this 15-year period averaged 66 percent if the roots were killed and 45 percent if only the tops were killed. Naturally occurring grasslands within the area averaged 26% higher forage production than the tree covered areas. Percent increases due to tree removal were the greatest in the driest years. Also increased following tree killing or removal were the percentage of desirable forage grasses, total ground cover, uptake/acre of nitrogen, phosphorus, sulfur, and the bulk density of the soil. Half of the trees which were removed without treating the stump sprouted to become bushy trees averaging thirteen feet tall in the sixteenth year. Possible reasons for the changes and the predictability of increasing forage on other sites are discussed.

Studies in northern California have demonstrated that herbaceous forage production can be increased at least fourfold by removing the overstory of blue oak trees (Quercus douglassii H. & A.) (Johnson et al., 1959; Murphy and Crampton, 1964; Murphy 1980). The improved forage yields have been shown to exceed those of adjacent grasslands (Murphy and Crampton, 1964). The increases are explained as resulting from the improved availability of light, moisture, heat, and soil nutrients. Also suggested as increasing yields was the stimulatory effect of low concentrations of 2,4-D exuded from the tops of dying trees killed by the cut-surface methods (Leonard et al., 1965). Changes in species composition following tree removal were listed as improving forage quality (Murphy and Crampton, 1964). Not reported in the above studies was the length of time these increases could be expected to last which is the purpose of the study reported here.

PROCEDURE

The site chosen (Figure 1) is a gentle north slope at the UC Sierra Foothill Range Field Station, at an elevation of 1,750 ft on the east side of the Sacramento Valley. Annual rainfall during the 22-year study averaged 28 inches and varied from 10 to 49 (Table 1). Soil is mapped as an Auburn, Las Posas, Sobrante complex. All are red soils derived from greenstone with a clay-loam surface. Depth varies from shallow to moderate with some soils underlain by clay. All have stones independent of the greenstone parent material.

Figure 1--Experimental area before trees were treated. Photographed May 15, 1964, at the peak of the herbaceous growing season.

The 4-acre study area was fenced to exclude deer, sheep, and cows. All trees were mapped and measured for stem diameter and canopy size. Calibration measurements of forage produced beneath the tree canopy were made in May of

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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1964, seven months before the tree-removal treatments were applied, to determine a logical sample size and experimental design. Forage yield was measured beneath 92 trees at the end of this growing season. Six hundred and eighty one-foot-square samples were clipped to ground level and oven-dried. Samples were taken from transects on both the north and south sides of each tree at 1.5 ft from the stem and every 3 ft to the edge of the canopy. Two to seven samples (mean of three) were taken on each transect, with two to four accounting for 88% of the transects. After the calibration period the study area was divided into four replications of about one acre each, and the three treatments and two controls (A-E listed below) were applied to blocks within each replication. Each treatment or control consisted of at least 10 trees to be included as transects in the yield sampling plus all other trees within the one-fourth acre, so as to reduce the edge effect of the observations. In addition to the live trees (untreated areas left as a control) (A) and naturally occurring openings or grasslands (B) which were generally less than 1000 ft^2 and may or may not be influenced by the trees, there were three treatments applied in December 1964: sprouting stumps (C) trees sawed about 6 inches aboveground and removed; trees sawed and removed and the stump painted with 2,4-D amine to prevent sprouting (D); and cut surface treatment (E) in which 2,4-D amine was placed in continuous horizontal cuts which penetrated the cambium layer (Leonard 1956). The trees in (E) fell after rotting in three to five years and were removed from the site.

Green-forage samples were taken near the end of each growing season for all years. The earliest harvest was on April 22, 1970, and the latest on June 2, 1975. Sampling after the calibration year was from a permanent transect on the north side of each of 10 trees or stumps in each treatment of each replication. Square ft samples were taken 1.5 ft from the stem and every 3 ft thereafter to the edge of the canopy. The number of ft^2 samples averaged 33/treatment, for a total of 533, plus 50 samples (10 or more/replication) used to sample the grasslands (B). The samples were oven-dried before weighing.

To determine whether significant phosphorus was released by the decomposition of roots and litter, soil phosphate phosphorus was sampled in the top six inches of treated and untreated areas both 13 and 16 months after the treatments were applied. The bulk density of the soil was sampled 14 years after treatment.

Forage composition and ground cover were measured near the end of the growing season using the step-point method and the values combined to obtain ground cover by species (Evans and Love, 1957). Forty points were taken in each treatment of each replication on transects within the treatment. Measurements began in the calibration year (1964) and continued through 1974.

Residues of 2,4-D were recovered from the roots in the zone 1-2 ft from the stem 172 days after treatment by digging a stump from treatments A, C, D, and E. 2,4-D amounts were determined by the cotton bioassay method (Leonard et al., 1962) and compared with the amount of 2,4-D in rainfall previously collected beneath cut-surface-treated trees (Leonard et al., 1965).

Recognizing that the herbaceous cover of annual plants would die each season, and the accumulation of residue represents an unnatural condition, efforts were made to remove the current seasons growth after it had matured and the seed shattered. In the summer of 1966 the study area was pastured by cows, and in 1970 through 1973 by sheep. Animals were in the area for only a 30-day period in the early summer. Utilization of this dry forage was unreliable and so was discontinued. In the years 1974 and later the general area of the transect was mowed and the forage removed in September, ensuring that an adequate seed source remained.

Data were analyzed by analysis of variance each year for forage yield, species and chemical composition, uptake of N, P, and S, and soil bulk density. Mean data for all years 1966-1978 were compared by a split-plot analysis with years as the main plots.

RESULTS

Calibration

Mapping the area showed there were 150 trees/acre averaging 11.1 inches in diameter measured 24 inches aboveground. The diameters varied from 4 to 36 inches, with only one tree/acre exceeding 22 inches. There were no trees smaller than four inches. Canopy radius averaged 9.2 ft on the south side of the trees, and 7.4 ft on the north, with the radius on the south side being equal to or greater than that on the north for 78% of the trees.

Forage samplings showed no difference in yield between the north and south sides or between samples closest to the stem and farthest from the stem. Therefore all future transects were located only on the north side of the trees. Average yield was 1,420 lb/acre under trees and 1770 lbs in the natural openings (Table 1).

Forage Yield

Tree-removal treatments were applied early in the growing season (December 1964) and did not result in significant changes in forage yield in the following spring (Table 1).

Table 1--Effect of tree treatments on forage yields. Precipitation data are shown at bottom of table.

Treatment	Year 64	65	66	67	68	69	70	71	72	73	74
	Tens of pounds/acre										
A Live trees	142	146	96	138	96	176	113	218	140	203	191
B Grassland	177	176	158	229	173	236	144	254	128	209	204
C Sprouting stumps		133	185	222	154	248	178	314	225	214	263
D Stumps + 2,4-D		156	195	232	186	290	203	352	255	247	296
E Cut-surface		156	214	224	205	335	195	324	226	240	299
LSD .05	NS	NS	29	58	37	55	47	72	49	NS	52
.01	--	--	41	--	52	77	65	102	69	--	73
Precipitation (in.)	21	26	21	38	22	42	31	29	18	40	41

Treatment	Year 75	76	77	78	79	80	81	82	83	84	85	X
	Ten of pounds/acre											
A Live trees	130	115	39	190	100	220	139	160	195	177	105	147
B Grassland	168	139	60	184	161	210	137	190	275	168	88	176
C Sprouting stumps	213	165	77	229	134	218	130	--	--	--	84	
D Stumps + 2,4-D	259	206	91	246	155	256	155	--	--	--	87	
E Cut-surface	247	202	104	264	169	291	165	--	--	--	96	
LSD .05	64	37	32	NS	24	NS	NS	NS	67	NS	NS	
.01	90	52	46	--	33	--	--	--	--	--	--	
Precipitation (in.)	24	13	10	34	24	27	19	49	44	28	19	28

Yields were significantly increased in the first full growing season following treatment (1966), from 960 lb under the live trees (A) to 2,170 lb under the cut-surface-treated trees (F). This 126% increase in forage exceeded the grassland yield (B) and was slightly higher than the stump treatments (C or D), which appeared to be depressed by sawdust accumulated from tree removal. This depression lasted for only one year.

Yield increases were significant in 12 of the first 15 years following treatment, averaging 67% for the cut surface treatment (F), 65% for stumps plus 2,4-D (D), and 45% for the sprouting stump (C). The grasslands (B) averaged 26% more than under the live trees (A). Relative yields were A < B < C < D or E (significant at the 0.01 level). Mean yields of D and E are not different.

Although the difference in yield between years was highly significant, there was no significant interaction between years and treatments.

Botanical Composition

Total ground cover (all species) for the 10-year period was greater on all cleared treatments (B-E) than the live trees (A), with the newly cleared areas (C-E) greater than the natural openings (B), which, in turn, averaged greater than the live-tree area (A) (Table 2).

Table 2. Mean percent ground cover by species groups and total cover for period 1965-1974.

Treatment	Grass	Legume	Other	Total
	Percent			
A Live trees	22	4	9	35
B Grassland	27	4	12	43
C Sprouting stumps	31	6	15	52
D Stumps + 2,4-D	32	5	15	52
E Cut-surface	32	16	15	53
LSD 0.05	5	NS	4	6
0.01	7	NS	5	8

Because of the sawdust the ground cover was lower around trees removed by sawing (C and D) than on the grassland (B) (1965) and the cut-surface (E) 1965 and 1966). In the cut-surface treatment (E) the trees were removed as they fell in later years, so there was never a reduction in ground cover.

Grass cover (1965-1974) was greater on all clearing treatments (B-E) (average 32% cover) than on the live tree area (A) (22%). Most of the increase was in soft chess (*Bromus mollis* L.), with a small increase in ripgut brome (*B. diandrus* Roth.).

Legumes (mostly *Trifolium* sp.), a small component of the ground cover, were not changed significantly by tree removal (C-E). Other forbs were increased slightly. There was an increase in tarweed (*Madia gracilis* Keck.) and a reduction in geranium (*Geranium molle* L.).

The difference between years in ground cover (total grass, legume, and forbs) was highly significant (0.01 level), as was the interaction between years and treatments.

Chemical Composition

Percent in the forage of nitrogen, phosphorus (total and phosphate), and sulfur was greatest beneath live trees (A) (Table 3). Although all treatments were still green at the time of harvest, there was generally a maturity difference between open (B-E) and shade-grown plants (A) which would account for the difference.

Total uptake/acre of all elements measured was significantly increased by all tree removal treatments (C-E), but did not differ between live trees (A) and natural openings (B).

There was a highly significant difference between years in percent of all measured elements as well as a significant interaction between years and treatments for the percent nitrogen and sulfur.

Soil Phosphorus

Available phosphorus, extracted from the top six inches of soil by 0.5 molar bicarbonate solution at pH 8.5 and expressed as ppm phosphorus in the soil, ranged from 12.6 to 18.0 in January 1966 (13 months after tree removal) and 5.9 to 9.4 in April 1966. There was no significant difference between treatments (A-E) at either date.

Bulk Density of Soil

Measured 14 years after treatment, soil collected from beneath live trees (A) was significantly lower (0.05 level) in density (1.074) than soil from natural openings (B) (1.183) or on cut-surface-treated areas (E) (1.179). Measurements were made near field capacity, and there was no difference in water-holding capacity. The difference was noticeable in walking on the area, with the tree-covered area being relatively spongy.

Table 3. Percent nitrogen (N), phosphorus (P), and sulfur (S) in forage, and total uptake of these elements/acre 1966-1978[1].

Treatment	N	Total P	PO_4 P	Sulfate S
	Percent in forage			
A Live trees	1.54	.273	.186	.132
B Grassland	1.34	.235	.148	.122
C Sprouting stumps	1.37	.247	.160	.117
D Stumps + 2,4-D	1.33	.222	.145	.116
E Cut-surface	1.34	.221	.138	.120
LSD 0.05	.04	.016	.016	.007
0.01	.06	--	.022	.009
	Average uptake (lb/acre/year)			
A Live trees	21.3	3.9	2.4	1.91
B Grassland	24.9	4.0	2.5	2.28
C Sprouting stumps	27.5	5.4	3.3	2.50
D Stumps + 2,4-D	29.5	5.3	3.1	2.65
E Cut-surface	30.4	5.2	2.9	3.00
LSD 0.05	4.8	0.7	0.7	0.45
0.01	6.4	0.9	0.9	0.60

[1] Except PO_4P, which is for 1967-1977 only.

Tree Regeneration

The chemical treatments (D and E) were completely effective in killing the trees. Half of the 40 untreated stumps (C) responded by sprouting, with 20 of the trees having multiple sprouts when measured in the 17th growing season. These bushy trees varied in average total sprout height from 9 to 17 feet, averaging 13 feet. The other 20 stumps did not sprout.

No blue oak seedlings were observed to establish in the 23 years since the area was fenced.

DISCUSSION AND CONCLUSIONS

The forage increases indicate forage production beneath the former tree canopy only and should not be interpreted as increased livestock carrying capacity without noting the amount of tree cover.

Forage increases were substantial in years 2 through 17 (though not statistically significant in two of these years). The data are conservative because of the effect of manure accumulations under the few remaining live trees in treatment A, which minimized the potential for increases from any of the comparative treatments or the natural grasslands. This is unavoidable if animals are to be used for forage removal. Animals can be expected to loaf in these protected areas, especially in hot weather, and added fertility is unavoidable. Future studies might consider the use of waste collection bags on the grazing animals to avoid this unwanted source of variability. Similarly the potential for maximal differences between the existing grasslands and tree covered areas is minimal because of their small size, maximum edge effect, and potential shading from adjacent treatments.

The conservative nature of the measurements does not adequately explain, however, the lesser increases compared to the previous reports (Johnston, et al., 1959; Murphy and Crampton, 1964). The trees in this study were larger than those in the above studies (11.1 in., compared with 7.5 and 8.0 in.). The number per acre was intermediate--150, compared with 115 and 225. Herbaceous ground cover under the trees was identical in this and the study by Johnson et al. (1959). Rainfall was intermediate, 27 inches, compared with 20-25 and 37 inches. The elevation was much higher (1,750 ft vs. 500 and 900 ft). The growing season was probably longer in this study because of the higher elevation and north slope. The growing seasons would start at the same time but maturity may be 15-20 days later.

In determining the potential of a tree-covered area for increased forage production from tree removal it may be best to compare yields under the live trees with open areas. This and other studies in northern California indicate that the increased yield can be expected to equal or exceed yields in the grassland areas. Murphy and Crampton (1964) indicate about a threefold difference between a tree and grassland area before the treatment that gave 400-650% increases when the trees were killed. By comparison, the study reported here shows only a 20% difference between grasslands and tree-covered areas, and a 67% increase from removing trees.

Not all areas will indicate increased yields. Savanna types, with only a few trees per acre, may actually show higher rather than lower forage production beneath the trees. So few trees are subject to considerable manure accumulation which may increase forage production. Also such few trees would have little if any effect on light availability to the forage. This suggests that a few trees could be left for shade and appearances without sacrificing forage potential. Areas with low soil fertility have also been shown to have higher forage production beneath the trees, apparently benefitting from the fertility contributed by fallen leaves (Holland 1973).

The use of canopy cover has been suggested as a means of predicting the potential for increasing forage production by removing blue oak trees. The data in this study do not agree with Passof et al. (1985) who suggest that forage under scattered deciduous oaks (up to 40-60% canopy cover) will be the same or greater than that outside the canopy. The method of determining canopy cover may need definition if cover is to be used as a tool. The use of aerial photographs may seem to be well suited. Figure 2 is an aerial photograph of this study site before tree removal, and contains the natural openings described above and at least two live oak thickets. Under these conditions estimates of canopy cover are too variable to be of value, and do not support the 40-60% limitations of Passof et al.

Shade (light intensity) cannot be completely ruled out as a factor in reduced forage production beneath trees. However, the shade of the dead trees in the early years after cut-surface treatment (E) did not reduce yields below those from removing the tree and treating the stump (C). Leonard et al. (1965) suggest that the leaves of blue oak do not develop until after most of the herbaceous growth has occurred, thus eliminating shade as a factor.

Competition with the living tree, perhaps for moisture and nutrients, may be a factor, as evidenced by the difference in yield between treated stumps (D) (roots killed) and allowing stumps to sprout (C) (Table 1). Also, production was greater beneath standing dead trees (E in early years) than standing live trees (A).

The increase in yield in excess of grass-

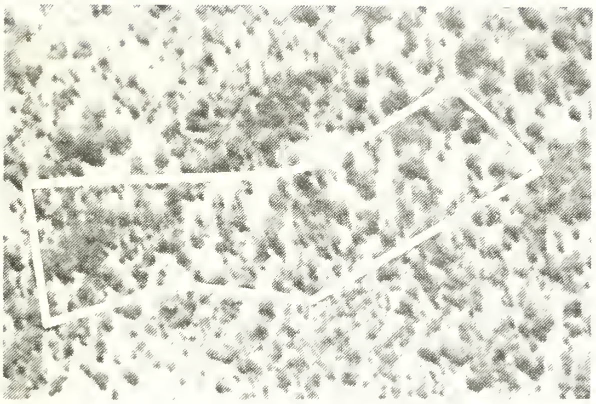

Figure 2--Aerial photo of study area before treatment. Note natural openings scattered through area and live oak thicket on the left.

land areas (B) following tree treatment (C-E) may be due in part to nutrients released by decomposing roots and litter. Forage increases were greater where roots were killed (D or E) than where roots were not killed (C). This seems the most likely explanation for the lack of increased forage beyond the 17th year and the shorter duration of increases adjacent to the sprouting stumps where there was less root decay.

Total uptake of nutrients (nitrogen, phosphorus, and sulfur) was greatest in all tree-removal treatments (C-E), possibly indicating greater availability. Soil phosphate measurements apparently were not precise enought to detect increases. However, these samples were only from the top six inches and may have failed to measure the contribution of the tree roots, which are abundant at 8-20 inches (Leonard et al., 1965). The lowest levels of soil phosphorus measured are suggestive of a possible deficiency.

The standing live trees contributed to reduced soil bulk density, and their removal resulted in increased density even with minimal livestock use. Animals were present only a few times, and then only in the dry summer months, so their influence on bulk density should have been minimal.

A stimulatory effect of low concentrations of 2,4-D seems unlikely. Leonard et al. (1965) measured 2,4-D in rainfall under cut-surface-treated trees and found small amounts in the first year after treatment, but none after one year. Roots measured in this study 1-2 ft from the stump contained 0.040 ppm and 0.011 ppm from the cut-surface (E) and 2,4-D-treated stump treatments (D), respectively, measured 172 days after treatment. The 2,4-D may have increased the rate of decomposition and resulting availability of plant nutrients.

The changes in botanical composition following tree removal generally improved forage quality. Of greatest importance was the increase in soft chess. The compositional changes might have been quite different if the area had been grazed in winter and spring, as is the common practice. An increase in legumes and other forbs could be expected if grazed.

The lesser variation between years in forage production on grassland or tree-removal treatments than on tree-covered areas is of great value to a livestock operator. The relative yield difference between live trees (A) and all tree-removal treatments (C-E) was greatest in the driest year, 1977, when rainfall was 64% below average. This indicates the importance of competition between trees and herbaceous forage for available moisture.

Variation in yields between years was nearly twice as great under live trees (A) as on the cut-surface treatment (E). Variation was from a minimum of 390 lb/acre, in 1977, to a maximum of 2,170 lb, in 1971, for the live-tree area (A), and 1,040 and 3,230 for the cut-surface treatment (E) in those same years. This is a 5.6-fold variation under the live trees (A), compared with a 3.1-fold variation on the cut-surface treatment (E) and 4.2 on the grassland area (B). The reduced variation may be of as much value as the increase in total forage production that results from tree removal.

Regeneration of the oak woodland was entirely from sprouting of the untreated stumps. These sprouted stumps returned the area to a woodland appearance. Because woodcutters do not usually treat stumps, such regeneration can be expected if trees are cut in early winter. Forage production may decline accordingly as sprouts increase in size, although this was not evident in the 21 years measured. There is not evidence that reproduction from acorns is a promising source of regeneration, even though the study area was protected from grazing for the last 12 years and has well distributed and numerous potential seed trees.

REFERENCES

Evans, R. A., and R. M. Love. The step-point method of sampling--a practical tool in range research. Jour. Range Manage. 10:208-212. 1957 September.

Holland, V. L. A study of vegetation and soils under blue oak compared to adjacent open grassland. Ph.D. dissertation, Dept. of

Botany, UC Berkeley. 1973.
Johnson, Walter, C. M. McKell, R. A. Evans, and L. J. Berry. Yield and quality of annual range forage following 2,4-D application on blue oak trees. Jour. Range Manage. 12:18-20. 1959 January.
Leonard, O. A. Effect on blue oak (Quercus douglasii) of 2,4-D and 2,4,5-T concentrates applied to cuts in trunks. Jour. Range Manage. 9:15-19. 1959 January.
Leonard, O. A., R. J. Weaver, and B. L. Kay. Bioassay method for determining 2,4-D in plant tissues. Weeds 10:20-22. 1962 January.
Leonard, O. A., C. E. Carlson, and D. E. Bayer. Studies on the cut-surface method. II. Control of blue oak and madrone. Weeds 13(4):352-356. 1956 April.
Murphy, A. H., and B. Crampton. Quality and yield of forage as affected by chemical removal of blue oak (Quercus douglasii). Jour. Range Manage. 17:142-144. 1964 May.
Murphy, A. H. Oak trees and livestock-management options. In: Proceedings of the symposium on the ecology, management and utilization of California Oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Forest Service, U.S. Department of Agriculture; 1980: 329-332.
Passof, Peter C., W. James Clawson, and E. Lee Fitzhugh. Guidelines for managing California hardwood rangelands. UC Coop. Extension mimeo 91 p. 1985.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Blue Oak Age Structure in Relation to Livestock Grazing History in Tulare County, California[1]

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Abstract: Blue oak age structures were compared among three different livestock grazing histories. Tree recruitment has been nearly absent in the study areas since the 1920's, while recruitment appears to have been fairly constant between 1850-1920. Stand age structure is younger on private livestock ranches grazed since the late 1800's compared with two areas in Sequoia National Park that were ungrazed and grazed only lightly since 1890. Livestock grazing may have enhanced past recruitment but recent unsuccessful recruitment with or without livestock suggests that blue oak establishment is more complicated than the presence or absence of livestock.

Past size structure research suggested that abundant blue oak (Quercus douglasii H. & A.) recruitment occurred between 1880-1920, followed by a period of poor recruitment that persists today (White 1966a, Vankat and Major 1978, Muick and Bartolome 1986). Several authors have proposed that livestock browsing, acorn consumption and trampling limit blue oak recruitment (Sudworth 1908, Bauer 1930, Twisselman 1956, 1967, Franco 1976, Anderson and Pasquinelli 1984). Brooks (1967) and Vankat and Major (1978) suggested that livestock grazing favored successful recruitment of blue oak through selective grazing that reduced herbaceous competition and the resulting reduction of fuels lowered fire frequencies.

To evaluate these disparate hypothesis concerning the role of livestock grazing in blue oak recruitment, age structures were determined using increment cores on sites with three different livestock grazing histories.

METHODS

In the spring of 1981 a total of fifteen 0.05 ha plots were sampled on five sites (figure 1) with similar physical site characteristics (McClaran 1986). Livestock grazing history was different among the sites: the Buckeye site (4 plots) in Sequoia National Park has been ungrazed by livestock since the establishment of the Park in 1890, the Shepard Saddle site (4 plots) in the Park has been lightly grazed since 1890 by horses and mules that are used in the backcountry during the summer, and the Shannon, Stout and Elliot ranches (3, 2 and 2 plots) have been commercially grazed by cattle since the late 1800's (McClaran 1986). Sites within these three grazing histories will be referred to as UNGRAZED, LIGHT and COMMERCIAL sites in the following text. Plots were randomly located in areas with small trees to emphasize the most recent tree establishment.

All trees were aged by extracting an increment core from a height of 60 cm. The one established plant shorter than 60 cm was cut at ground level. Seedlings (plants <15cm tall) were grouped into a single age class. The increment cores were dried, sanded with 200 grit paper and wet with water in preparation to count the annual rings under a 10-30X binocular dissecting scope. Ages for cores that missed the center, or for trees with rotten centers were estimated when <10 years were missing. Those samples with >10 missing were excluded from the sample, except for trees with 150 rings which were grouped in a single >150 year age class. Cores with missing or rotten centers accounted for less than 10 percent of the total sample.

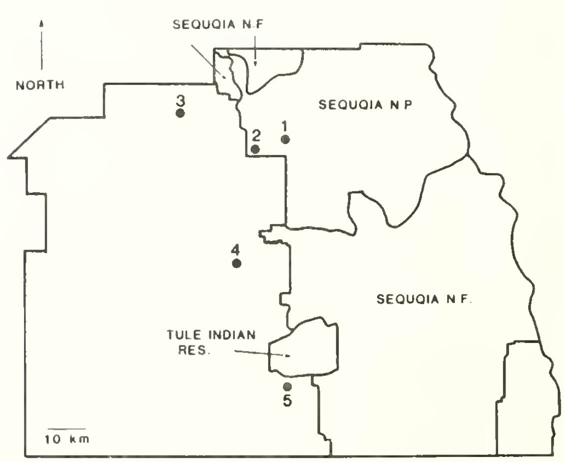

Figure 1--Plot locations in Tulare County. Numbers indicate the following sites: (1) Buckeye, (2) Shepard Saddle, (3) Elliot Ranch, (4) Stout Ranch and (5) Shannon Ranch.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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The age structures were compared among the three grazing histories, UNGRAZED, LIGHT and COMMERCIAL with a Smirnov test (Lehmann 1975). Seedlings were not included in the age structure analysis because they represent only potential recruitment, and much mortality is expected in this group before successful recruitment. Instead, a separate seedling density comparison was made among the three grazing histories with a Wilcoxon Rank Sum test (Lehmann 1975).

RESULTS

The age structure for all Tulare County sites shows a pattern of numerous seedlings, a general absence of trees <40 years old, a continuous representation of trees 60-130 years old, and a scarcity of trees older than 140 years (figure 2). Smirnov test results show that age structure was negatively related to grazing; the UNGRAZED stands were older ($p<0.05$) than the LIGHT and COMMERCIAL stands, and the LIGHT stands were older ($p<0.05$) than the COMMERCIAL stands. Seedling density was greatest in the LIGHT stands, and there was no difference between the ABSENT and COMMERCIAL stands:

Grazing History	#Plots	Seedlings/Plot[1]
ABSENT	4	3.5[a]
LIGHT	4	15.2[b]
COMMERCIAL	7	0.6[a]

[1] Superscripts denote different values ($p<0.05$) in each column.

DISCUSSION

Blue oak recruitment occurred more recently in areas grazed by livestock (COMMERCIAL), but the lack of recruitment on all sites since the 1920's shows that livestock grazing is not the only factor controlling blue oak recruitment. The presence of younger stands on sites with a history of commercial livestock grazing since the late 1800's (COMMERCIAL) compared with an area that has been free of livestock since 1890 (UNGRAZED) and one receiving very light use since 1890 (LIGHT) tends to support Brooks' (1967) and Vankat and Major's (1978) hypothesis that livestock grazing could enhance tree establishment by removing herbaceous competition and reducing fire frequencies. Direct evidence of any fire reduction resulting in increased recruitment was not available because the maintenance of fire records for the study areas began after the decline of recruitment in the 1920's. However the lack of recruitment since approximately 1920 on all sites suggests that livestock grazing may not be the only or the most critical cause of the absence of current, or the occurrence of past successful recruitment. For

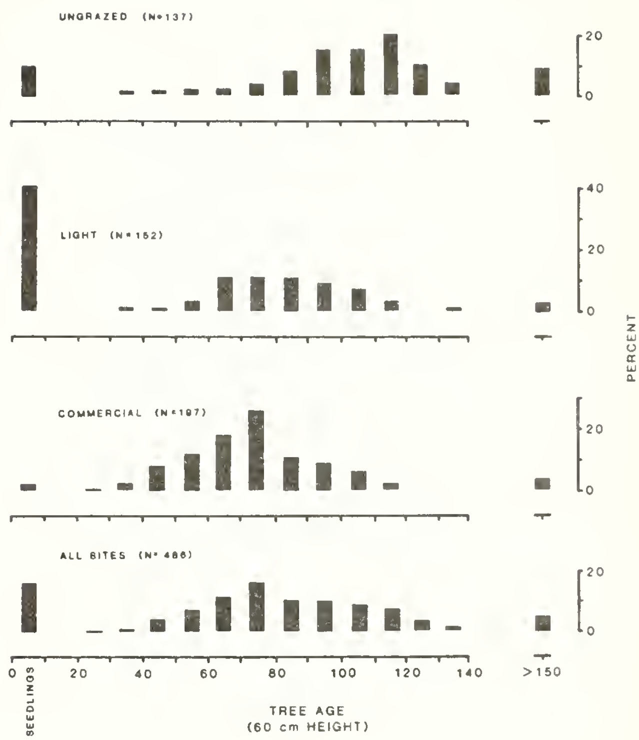

Figure 2--Blue oak age structure under different grazing histories in Tulare County.

example, the UNGRAZED area is part of the home range of a deer herd that has reached high population levels in the past, and may be at similar levels currently, Dixon and Herman (1945) cited a problem of overbrowsing as justification for removing 40 deer from the area in 1944 after earlier removals of fewer animals gave only temporary relief. During my field work, more deer were seen in the UNGRAZED area than in any other, suggesting that overbrowsing may again be present.

The age structure reported here does not fit the proposed pattern of abundant recruitment between 1860-1890 and poor recruitment from the turn of the century to the present (White 1966a, Vankat and Major 1978). Some recruitment has occurred on all sites between 1850-1920, and very little recruitment has occurred on any site since the 1920's (figure 2). Although the scarcity of trees >150 years old and the abundance of trees <80 years may be an artifact of the sampling design that directed plot location in areas with small trees. The poor correlation between blue oak size and age (McClaran 1986) may also be responsible for the poor fit of these findings with age structures proposed from size structures.

Greater seedling density under light and seasonal grazing (LIGHT) represents only potential recruitment, therefore an interpretation that recruitment is more likely in the LIGHT sites is premature. The slow recruitment of seedlings into tree populations under high deer numbers and an absence of livestock has been documented in Monterey County. In 1969, Griffin's (1971) census of 154 seedlings marked by White (1966a) in 1963 found only 58 plants, all of which were <10cm tall. Only three plants, which were <34 cm tall were found in a 1981 census of nineteen seedlings marked by White (1966b) in 1963 (James R. Griffin pers. comm.).

The inability to assign major responsibility for poor or abundant blue oak recruitment to livestock grazing, combined with the great length of time required for the transition from seedling to tree, suggests that no single event can assure recruitment and that any number of factors can limit recruitment. This interpretation fits Odum's (1971) "combined concept of limiting factors" which identifies a limiting factor as the cause of mortality while survival depends on a favorable combination of factors. Several authors have stated that successful blue oak establishment requires a combination of events including abundant acorn production and escape from consumers, sufficient rainfall and protection from dessication for initial seedling establishment, limited competition for light and water from neighboring plants, protection from browsing livestock, deer and rodents, and burrowing gophers, and they stress that any of these can limit the transition from seedling to sapling (Griffin 1971, Longhurst et al. 1979, Anderson and Pasquinelli 1984).

CONCLUSIONS

Blue oak age structure is not perfectly related to livestock grazing history. The age structure on sites that have had livestock grazing since the late 1800's was younger than on sites lightly grazed and ungrazed during the same period, but little recruitment has occurred since the 1920's on all sites. Seedling density was greater on lightly grazed sites, but the transition to tree sizes is too slow and unlikely to include these plants in the age structure analysis. These results suggest that successful blue oak establishment is more complicated than the presence or absence of livestock.

Acknowledgments: Partial financial support was provided by the Sequoia Natural History Association. Logistical support was provided by Dave Parsons, Steve DeBenedetti and Tom Stohlgren of the National Park Service, and Bob Miller of Cooperative Extension. Generous access was provided by the cooperating ranchers; Jack Shannon, F.T. Elliot and Steve Stout.

REFERENCES

Anderson, Melanie V.; Pasquinelli, Renee L. Ecology and management of the northern oak woodland community, Sonoma County, California. Cotati, CA: Sonoma State University; 1984. 128 p. Thesis.

Bauer, H.L. Vegetation of the Tehachapi Mountains, California. Ecology 11(2):263-280; 1930.

Brooks, William H. Some quatitative aspects of the grass-oak woodland in Sequoia National Park, California. Report to the Superintendent Sequoia-Kings Canyon National Parks, Three Rivers, CA. 1967. 24 p.

Dixon, Joseph S.; Herman, Carlton M. Studies on the condition of California mule deer at Sequoia National Park. Cal. Fish and Game 31(1):3-11; 1945.

Franco, Geria M.M. Grazing effects on oak distribution in Jasper Ridge and adjacent areas. Palo Alto, CA: Stanford University; 1976. 33 p. Thesis.

Griffin, James R. Oak regeneration in the upper Carmel Valley, California. Ecology 52(5):862-868; 1971.

Griffin, James R. Director, Hastings Natural History Reservation, Carmel Valley, CA. Letter to the author. 1981.

Lehmann, E. Non-parametric statistics: Statistical methods based on ranks. San Francisco: Holden-Day Inc.; 1975. 475 p.

Longhurst, William H.; Connolly, Guy E.; Browning, Bruce M; Garton, Edward O. Food interrelationships of deer and sheep in parts of Mendocino and Lake Counties, California. Hilgardia 47(6):191-247; 1979.

McClaran, Mitchel P. Age structure of Quercus douglasii in relation to livestock grazing and fire. Berkeley, CA; University of California; 1986. 119 p. Dissertation.

Muick, Pamela C.; Bartolome, James W. Statewide oak regeneration survey. Report to Forest and Range Resources Assessment Program, California Department of Forestry, Sacramento, CA; 1986. 100 p.

Odum, Eugene P. Fundamentals of ecology. 3rd. ed. Philadelphia: W.B. Saunders Co.; 574 p.

Sudworth, George B. Trees of the Pacific slope. Forest Service, U.S. Department of Agriculture; 1908. 441 p.

Twisselman, Ernest C. A flora of Kern County, California. Wasmann J. Biol. 25(1):1-395; 1967.

Twisselman, Ernest C. A flora of the Temblor Range and neighboring part of the San Joaquin Valley. Wasmann J. Biol. 14(2):161-300; 1956.

Vankat, John L.; Major, Jack. Vegetation changes in Sequoia National Park, California. J. Biogeog. 54(4):377-402; 1978.

White, Keith L. Structure and composition of foothill woodland in central coastal California. Ecology 47(2):589-594; 1966a.

White, Keith L. Old-field succession on Hastings Natural Reservation, California. Ecology 47(5):865-868; 1966b.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Beef Production on Converted Foothill Oak Woodland Range in the Western Sierra Nevada[1]

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Abstract: Criteria for vegetation type conversion (VTC) of foothill oak woodland were developed at the University of California's Sierra Foothill Range Field Station (Browns Valley, Yuba County) in conjunction with Station development to increase carrying capacity. The seven type-conversion criteria were subsequently applied to further land clearing activities associated with range improvement goals. On one completely cleared area seasonal grazing (late November to Late May) was done using stocker steers and heifers in a three-year multiple-element fertilizer experiment. Beef liveweight gains were best for moderate to high levels of phosphorus (P) and sulfur (S) applied together, or where nitrogen (N) was applied with P and S. Three-year total gains showed a profit over control up to \$138 ha^{-1}, but use of N alone or a low level of P and S resulted in economic losses. In range production systems such as the one examined range fertilization and carefully planned VTC are defensible range improvement practices if increased livestock production is a primary goal. However, attention must be given to utilization management, and year-to-year weather variations may significantly alter production responses to range fertilization.

The landowner's main objective in making range improvements is to increase productivity on a given unit of land (Herbel 1981). Numerous treatments, developments and structures can be employed in creating range improvements (Vallentine 1971). Generally, it is important that these actions be justified in terms of cost-effectiveness. However, economic justification can be complex and subject to an array of dynamic variables, including level of production-related resource inputs, management skill and year-to-year market and weather variations (Workman 1986). The prominent components of intensive range improvement activities most frequently used in California can be divided into four categories: 1. Vegetation manipulation, 2. Livestock/grazing management, 3. Seeding, and 4. Fertilization.

The use of control burning in vegetation-type conversion has been prominent in California for nearly four decades (Arnold et al., 1951). Only a few long-term studies of the effects of this procedure have been done, one of the more notable at the UC Hopland Field Station (e.g., Heady and Pitt, 1979). Historically, emphasis generally has been given to achieving as complete a degree of conversion (removal of woody vegetation) as possible (Arnold et al., 1951), and very little attention has been paid to the concept of treating the landscape as a mosaic and deriving criteria to employ in partial conversion (Albin-Smith and Raguse, 1984). Much attention has been paid to fertilization (e.g., Martin and Berry, 1970; Center and Jones, 1983; Wolters and Eberlein, 1986), often in connection with the concurrent use of annual legume introduction done as an integral part of the vegetation-manipulation process (Murphy et al., 1973). Comparatively little research literature exists in the area of livestock/grazing management on the annual type ranges typically resulting from converted oak woodland. A significant portion of this literature is based on studies done at the USFS San Joaquin Experimental Range (Bentley and Talbot, 1951; Hormay 1944), the UC Hopland Field Station (Heady and Pitt, 1979), and more recently, the UC Sierra Foothill Range Field Station (Raguse et al., 1986, manuscripts submitted to the Agronomy Journal.

The limited scope of many experiments, and the immense variability resulting from location, management and weather variables has made synthesis of a holistic view of range vegetation manipulation as a determinant of improved livestock production nearly impossible. In addition to woody overstory canopy cover and climatic constraints (especially the amount and seasonal timing of rainfall), a third factor limiting herbaceous forage production is soil fertility (Jones 1974). The range fertilization experiments reported here will aid in establishment of beef production norms for converted oak woodland in the Northern Sierra Nevada foothills. The UC Sierra Field Station's experiences in an on-going vegetation type-conversion program will aid in development of a more universally acceptable approach to the use of vegetation manipulation as a means of improving livestock production without unduly compromising aesthetic and natural resources conservation needs.

MATERIALS AND METHODS

Characteristics of the Site

The two studies were conducted at the Univer-

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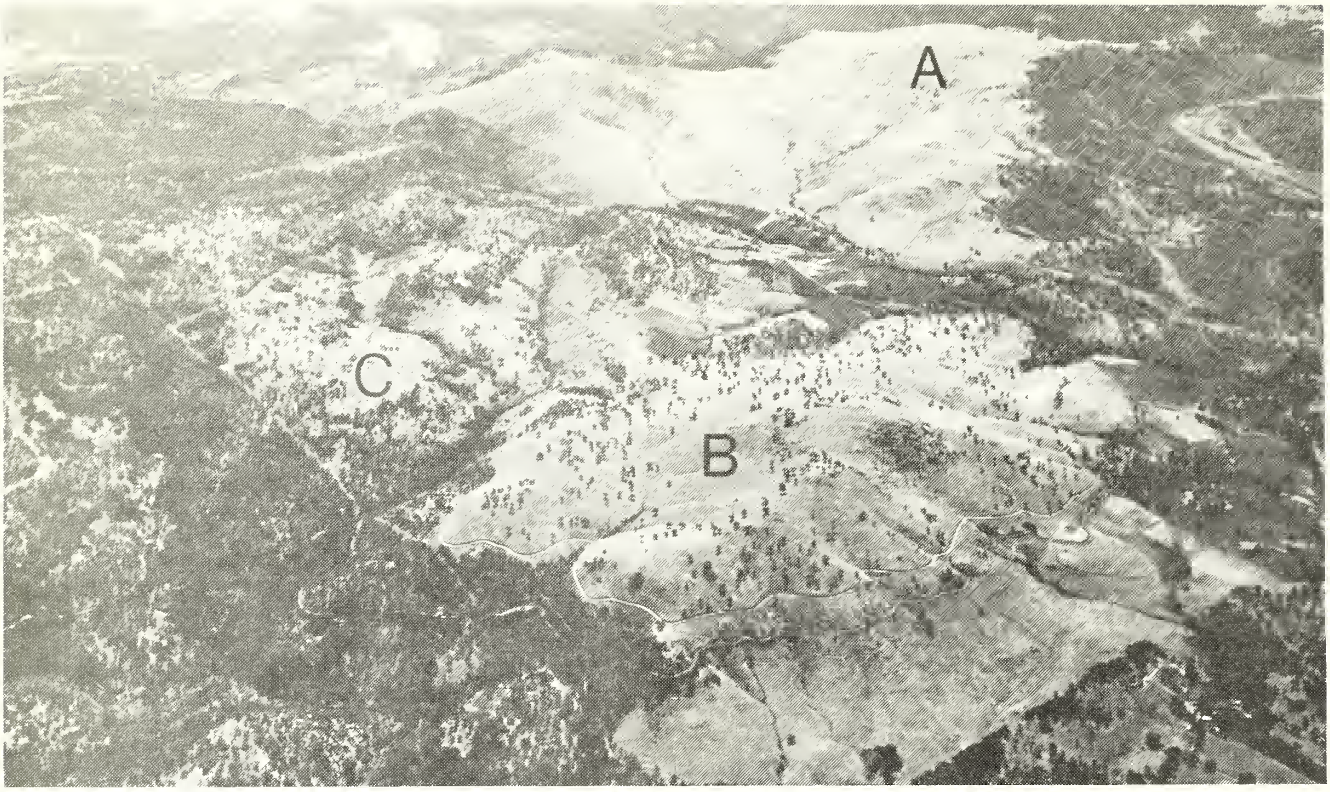

Fig. 1--Aerial view of three approaches to vegetation-type conversion at the UC Sierra Foothill Range Field Station. A: Forbes Hill; completely cleared, with woody plant regrowth completely controlled. B: Porter; scattered trees left in a random pattern; woody regrowth controlled. C: Scott; prescription manipulation as described on page .

sity of California's Sierra Foothill Range Field Station (SFRFS), Browns Valley, Yuba County, on a site of approximately 330 m elevation. This location, which is representative of the lower-foothill oak woodland zone of the northern Sierra Nevada, receives an average 825 mm of rainfall between mid-October and late April in a typical Mediterranean climate. Herbaceous vegetation is almost completely annual, a variable mixture of grasses, legumes and other forbs. Soils are mainly of the Sobrante and Las Posas series with smaller amounts of Auburn and Argonaut, i.e., mostly fine to fine-loamy, mixed, thermic Mollic Haploxeralfs or Typic Rhodoxeralfs (Alfisols).

The site used for development of vegetation type-conversion (VTC) criteria was variable in topography and the vegetation was typical of lower-foothill oak woodland. It also contained a quasi-riparian area (irrigation ditch). On-ground informal surveys were used to define criteria from a multiple-use viewpoint and to prepare a map for use in guiding the clearing process. Previously, VTC at the Station had been done in one of two ways. The first used was removal of all woody vegetation employing herbicidal injection of trees, a control burn, and two to three year of follow-up herbicidal control of re-sprouting (Forbes area, Fig. 1). The second procedure differed only in leaving approximately 25 trees per hectare with minimal or no clearing on rocky outcrops and/or slopes in excess of 30-40 percent (Porter area, Fig. 1). Subsequently, the new criteria were employed in additional VTC to increase the beef cattle carrying capacity of the Station (Scott area, Fig. 1). Because VTC at the Station occurred over a period of nearly 20 years and the areas were assigned to a number of different research projects, no systematic study was made to determine the comparative productivity potential for the different approaches used (complete conversion to prescribed partial conversion).

The rangeland fertilization study site (part of Forbes area, Fig. 1) had been completely converted from an oak woodland with shrub understory by herbicidal injection of the oaks (1961-63) followed by a control burn in 1968. It subsequently was divided into 16 fields of roughly equal size (13.2 ha). Reseeding was done using a mixture of subterranean (*Trifolium subterraneum* L.) and rose (*T. hirtum* L.) clovers during the period 1971-1974. Various range utilization and livestock

Table1--Fertilizer treatments applied in 1982 to an area completely type-converted from 1961 to 1968 and re-seeded from 1971 to 1974.

1.	Control				
2.	45 $kg\ ha^{-1}$	N	--	--	
3.	90 "	N	--	--	
4.	45 "	N,	34 $kg\ ha^{-1}$	P, 37 $kg\ ha^{-1}$	S
5.	90 "	N,	34 "	P, 37 "	S
6.	- -	-	34 $kg\ ha^{-1}$	P, 37 $kg\ ha^{-1}$	S
7.	- -	-	67 "	P, 74 "	S

management experiments employing beef cattle have been conducted since that time.

The treatments applied to a completely type-converted annual rangeland site (Forbes area, Fig. 1) are given in Table 1.

Nitrogen was applied as urea; phosphorus and sulfur as a mixture of 0-20-0-12S and 0-25-0-10S on October 5 and 6, 1982. The experiment was conducted for a three-year period (1982-83 to 1985-86). Beginning mid- to late-November, each field (replication) was uniformly set-stocked with steers (initial weight, 215 kg) at 1.65 to 3.30 ha per steer. As periodically monitored forage levels increased seasonally, the stocking rate was increased to a maximum of 0.44 ha per animal. Other details of the experiment have been presented elsewhere (Raguse et al., 1984).

RESULTS AND DISCUSSION

Vegetation Type Conversion

In concert with increasing societal concerns about environmental quality and wise management of renewable natural resources, complete type-conversion has evolved to selective, prescribed manipulation of woody vegetation to leave a mosaic pattern. As a minimum, the UC Sierra Foothill Range Field Station now employs the following criteria:

1. Leave strips of all woody vegetation in natural drainageways to reduce erosion.

2. Leave all woody vegetation on rocky outcrops.

3. Leave scattered groups or corridors of trees (including all age-classes present) for aesthetic values, wildlife habitat, and livestock shade.

4. Use appropriate special conversion measures when specific wildlife management objectives exist.

5. Appropriately modify conversion when the area is part of a visually sensitive landspace.

6. Avoid clearing of slopes in excess of 30-40 percent to minimize erosion hazard, except as needed to aid in livestock surveillance and handling.

7. Completely clear areas best suited for range or pasture related agricultural operations (e.g., reseeding, fertilization, agroforestry, irrigation).

Indirect Impacts of Vegetation Removal on Wildlife

Wildlife habitat, in an area used for livestock grazing, is altered by VTC when it changes botanical composition of the vegetation and its three-dimensional profile. Removal of the oak/pine/shrub overstory to maximize herbaceous forage for livestock grazing reduces available cover and forage. In general, both cover and nutritional needs for deer and other game species can be satisfied by managing for mixed-age seral and mature plant series, creating habitat interspersion (Salwasser 1976). Vegetation manipulation, therefore, has potential as a positive wildlife habitat improvement tool.

Advantages to Leaving Woody Vegetation in Place

Brush and tree eradication on foothill range also removes the roots of woody vegetation. These constitute a major subsurface stabilizing element of a slope (Burgy and Papazafiriou 1971). VTC also amplifies the impacts of precipitation and wind on the soil surface. The opportunity to avoid future soil loss and gully formation problems should provide adequate incentive for retaining groups of trees on steep hillsides, on rocky outcrops, or in natural drainageways.

There are clear differences of opinion among researchers as to the direct and/or secondary benefits of either leaving or removing deciduous oaks, blue oak (*Quercus douglasii* H. & A.) in particular, and more research is needed. There have been only a few studies done on the relationship between oaks and range forage production (e.g., Holland and Morton 1980; Kay and Leonard 1980; Murphy 1980). Those which have been done had used somewhat different approaches or have been done in geographically-different areas. The presently-recommended approach to VTC on foothill blue oak grass-woodland, as employed by the UC SFRFS seems to be a valid compromise between the the two extremes of accepting little or no forage production under a dense canopy of trees and brush vs. complete conversion with total suppression of woody plant regrowth.

Results of Fertilization on Type-converted Foothill Rangeland

The largest differences in livestock product yield occurred during the first year of the three

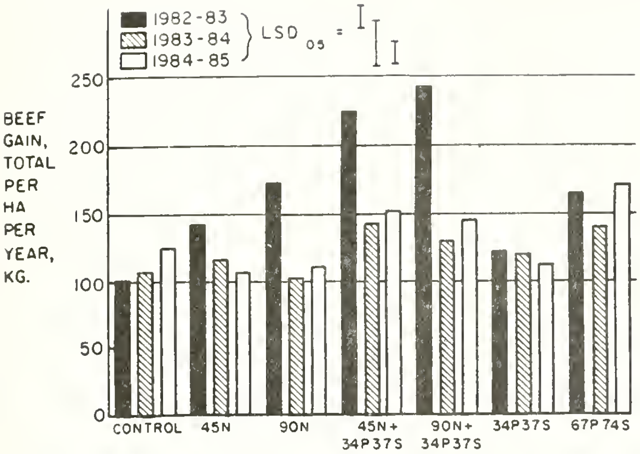

Fig. 2--Beef liveweight gains per ha as a seasonal total for each of three years.

and, within the fertilizer treatments, were largest for the nitrogen-phosphorus-sulfur combination (Fig. 2). The higher of the two phosphorus-sulfur treatments markedly enhanced growth of the resident annual legumes. Second-year animal gain responses were similar for all treatments, in part reflecting the previous high-rainfall (1100 mm) season. In the third year the two NPS and the higher PS treatments were highest with the 67P-74S response exceeding all other treatments (Fig. 2). Comparisons may be grouped arbitrarily into four categories, as livestock gain thresholds of 100, 150, 200, and 250 kg ha^{-1} $year^{-1}$. Cleared rangeland similar to that used in this experiment with a legume component should produce liveweight gain at the threshold level of 100 kg ha^{-1} $year^{-1}$. This assumes good grazing management but with little or no fertilization employed. To attain the 150- to 250-kg threshold levels required higher fertility levels and supply of all three elements (in the case of 67P-74S, nitrogen provided through enhancement of symbiotic fixation by resident legumes). It is noteworthy in this regard that the higher PS treatment was the only one in which the 150-kg gain threshold was exceeded in the third year, evidence of an ongoing positive influence of this treatment on the resident legumes.

The results of this study can be placed within a larger perspective when compared to results reported for a type conversion project done in Shasta County (Johnson and Harrington 1967). In this study beef production was measured before and after type conversion under site conditions, including soil series, similar to those of the UC Sierra Foothill Range Field Station. Canopy cover prior to conversion was estimated at 60 to 80 percent, and consisted of a mixture of live oak (Quercus wislizenii A. DC), manzanita (Arctostaphylos viscida Parry), poison oak (Toxicodendron diversilobum (T. & G.) Greene) and ceanothus (Ceanothus cuneatus (Hook.) Nutt.). Pre-conversion beef gain production was 8 to 12 kg ha^{-1} following conversion but prior to full establishment of a range seeding beef production was 34 to 45 kg ha^{-1}. In effect, this establishes an additional 50 kg ha^{-1} threshold level. Even if some upward adjustment of these figures is made because of a somewhat shorter growing season in Shasta Co. and the usual uncertainties about comparability of animals and grazing procedures used, it is clear that there is a definite step-wise progression in animal level productivity as land with high levels of woody canopy cover is converted, then further improved for herbaceous forage production by seeding and/or fertilizing.

Because nearly a decade had elapsed since the last range improvement practice had been applied (re-seeding with annual legumes, 1971 to 1974), herbaceous vegetation at the SFRFS range fertilization study site had attained compositional stability (unpublished data, 1975 to 1982). Figure 3 presents an analysis of the effects of a major perturbation to the system (N and PS applications). The botanical composition (step point quadrat) of indigenous grasses and forbs, and of introduced annual legumes was compared for N-only, N+PS, and PS-only fertilization treatments (levels

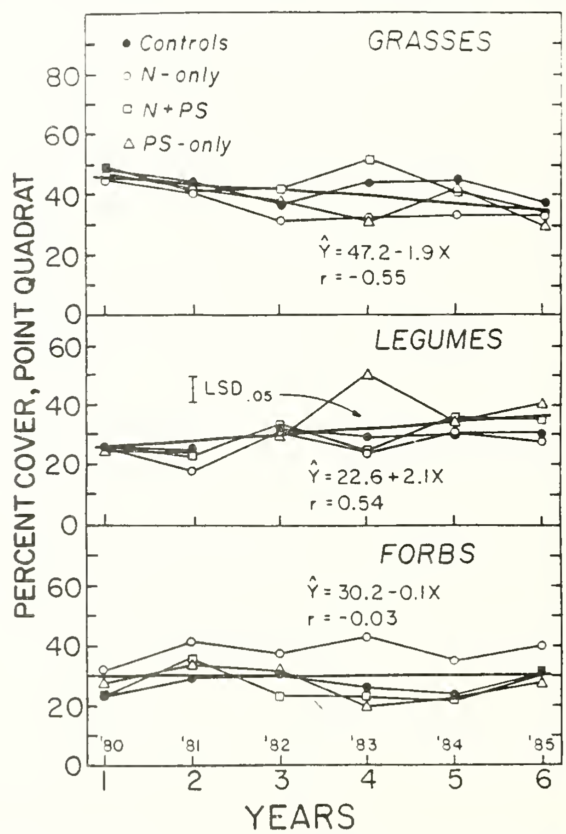

Fig. 3--Trends in percent composition of the three principal annual species groups for three years prior to the experiment and the three years of the experiment.

Table 2--Preliminary economical analysis of liveweight gain responses from selected combinations of nitrogen, phosphorus and sulfur applied to cleared Sierra Nevada foothill annual legume-seeded rangeland.

Treatment	Treatment cost	Gross income per ha above control treatment		
		1982-83	1982-83	1982-85
Control	-	-	-	-
40N	41.50	-6.00	6.10	-19.80
90N	71.70	-3.20	4.20	-23.50
45N34P37S	78.80	54.60	127.00	138.40
90N34P37S	109.00	65.00	73.80	87.80
34P37S	37.10	-28.40	-32.40	-52.80
67P74S	62.90	-8.60	37.80	109.00

Note: Actual costs of fertilizers were used, plus $10.50/ha application costs ($21.00 for the NPS treatments), and interest charges at 12% for eight months. Gross income was calculated as - (No. head sold x sale wt x sale price) - (No. head purchased x purchase wt x purchase price), using prices for the dates of entry and removal from the Cottonwood, CA Sale Yard as reported in the USDA Livestock Market News.

combined) for the three-year period prior to the experiment vs. the three years of the experiment. The only significant departure from control conditions was for legumes in the PS-only treatment in the season of fertilizer application (1982-83). Over the six-year period, there was a slight downward trend for grasses which was approximately balanced by a slight upward trend for legumes. There was no consistent trend in the proportion of forbs. Thus, it was obvious that under appropriate grazing management there is a remarkable degree of stability in the herbaceous annual vegetation community. Practically, this means that range fertilization can be employed to enhance livestock production without unduly jeopardizing a desirable botanical composition of the forage.

Economic analysis of the results (Table 2) showed that important variables in determining whether a given treatment proved profitable were: initial cost of treatment, level of PS-only treatments, stocking rate adjustments, and the general legume-enhancement response to the phosphorus-sulfur treatment. Nitrogen, phosphorus and sulfur all needed to be supplied, with nitrogen provide either directly or through symbiotic fixation by annual legumes.

Gross income (per-acre basis) was calculated by subtracting materials and application costs and interest charges. Market purchase and sale values of stocker steers at the Cottonwood Sale Yard were used to estimate returns. Three-year totals were highest for the 45N-34P-37S, 90N-34P-37S and 67P-74S and averaged $112 her ha. The remaining treatments (45N, 90N and 34P-37S) all showed negative returns (compared with the non-fertilized control) and averaged -$32 per ha.

Given the location and conditions of the experiment and assumptions of the economic analysis, the current economic feasibility of applying appropriate fertilizers to type-converted foothill annual rangeland was established. However, in order to achieve high levels of biological and economic efficiency, careful attention must be given to utilization management and year-to-year weather variations may significantly alter responses to resource inputs.

CONCLUSIONS

1. As California foothill oak woodlands have been converted (historically), emphasis has been directed primarily toward the single-use goal of livestock grazing. This led to efforts to make the type-conversion process as complete as possible.

2. Societal concerns about resource conservation, costs of manipulation, multiple-use objectives, and aesthetics all have fostered a more analytical and prescription-oriented approach to the use of type conversion as a range improvement practice.

3. Within the context of grazing use, a better understanding is needed of how to best manage livestock utilization with seasonal changes in forage production and quality. This involves decisions about the qualitative nature of the livestock system used as well as a more comprehensive basis for managing stocking rates. Increasing the efficiency of this transfer and conversion process can reduce the extensiveness of type conversion employed and lend additional stability to plant communities already converted.

4. The use of supplementary fertilization can

increase agricultural productivity at both plant and animal levels with minimal alteration of the herbaceous plant community.

REFERENCES

Albin-Smith, Teresa K.; Raguse, Charles A. Environmental effects of land use intensive range management: A northern California example. Contr. No. 187; Davis, California: Univ. of California; California Water Resources Center; 1984 July; 35 p.

Arnold, Keith; Talbot, M. W. Efficient use of annual plants on cattle ranges in the California foothills. Circular No. 870; Washington, D.C.: US Department of Agriculture; 1951 May; 52 p.

Burgy, R. H.; Papazafiriou, Z. G. Vegetative management and water yield relationships. In: Proc., 3rd Ann. Sem. for Hydrology Professors. Lafayette, Ind: July 18-30. 1971. Purdue Univ. p. 315-331.

Heady, H. F.; Pitt, M. D. Reactions of northern California grass-woodland to vegetational-type conversions. Hilgardia 47(3):51-73; 1979 April.

Herbel, C. H. Principles of Intensive Range Improvements. J. of Range Manage. 36:140-144. 1983.

Holland, V. L.; Morton, J. 1980. Effect of blue oak on nutritional quality of rangeland forage in central California. In: Proc. Symposium on the Ecology, Management, and Utilization of California Oaks, June 26-28, 1979, Claremont, CA. Berkeley, CA: Gen. Tech. Rep. PSW-44. Forest Service, USDA; 1980: 319-322.

Hormay, August L. Moderate grazing pays on California annual-type ranges. Leaflet No. 239; Washington, D.C.: Forest Service, U.S. Department of Agriculture; 1944 June; 5 p.

Johnson, Walter H.; Harington, William. Bush range improvement - a report of the cooperative Backbone Project. Shasta Co., California. University of California Agric. Extension Serv. 1967 July. 22 p.

Jones, Milton, B. Fertilization of annual grasslands of California and Oregon. In: Mays, D. A., ed. Forage fertilization. Madison, Wis.: Amer. Soc. of Agronomy, Crop Sci. Soc. of America, and Soil Sci. Soc. of America. 1974; p. 255-275.

Kay, B. L.; Leonard, O. A. Effect of blue oak removal on herbaceous forage production in the North Sierra foothills. In: Proc. Symposium on the Ecology, Management, and Utilization of California Oaks, June 26-28, 1979, Claremont, CA. Berkeley, CA: Gen. Tech. Rep. PSW-44. Forest Service, USDA; 1980: 323-328.

Murphy, A. H. Controlled Burning in Chamise Chaparral. In: Proc. of California Tall Timbers Fire Ecology Conference, 1967, 7 November. p. 245-255.

Murphy, A. H.; Jones, M. B.; Clawson, J. W.; Street, J. E. Management of clovers on California annual grasslands. Circular 564; Davis, California: California Agricultural Experiment Station Extension Service; 1973 December; 19 p.

Raguse, C. A.; Hull, J. L.; Jones, M. B.; Morris, J. G.; George, M. R.; Olson, K. D. Range fertilization in the Sierra Nevada foothills. California Agric. 38(5&6):4-6. 1984 May-June.

Salwasser, Hal. Implications of brushland management for deer. In: Symposium Proceedings: A New Look at California's Brushland Resources. Davis, California. Institute of Ecology, Univ. of California, Davis. 1976 January. p. 21-32.

Vallentine, John F. Range development and improvements. 2d ed. Provo, Utah: Brighham Young Univ. Press; 1971; 545 p.

Wolters, Gale L.; Eberlein, Gary P. Sulfur or sulfur plus nitrogen increases beef production on California annual range. J. Range Manage. 39(2):125-129. 1986 March.

Workman, John P. Range Economics. New York: Macmillan Publ. Co.; 1986. 217 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Long-Term Changes From Different Uses of Foothill Hardwood Rangelands[1]

Don A. Duncan, Neil K. McDougald, and Stanley E. Westfall[2]

Abstract: Photo stations on foothill hardwood rangelands representing different types of management and uses were established in the late 1930's on the San Joaquin Experimental Range in Madera County in central California. The stations were rephotographed 20 years later and again in 1985. After almost 50 years, the grazed areas, whether burned or unburned, show remarkably little change. They still have an open, parklike appearance with scattered oaks (primarily *Quercus douglasii*). The Research Natural Area, which has been neither grazed nor burned since 1935, presents quite a contrast, with a distinct change to woody vegetation. Digger pine (*Pinus sabiniana*) and wedgeleaf ceanothus (*Ceanothus cuneatus*) have increased dramatically. The differences in wildfire hazards between grazed and ungrazed areas are obvious in the photographs.

In the late 1930's, photo stations were established on the San Joaquin Experimental Range in Madera County in central California for the purpose of recording effects of different types of management and land use. For this paper, three photo stations are shown representing no grazing and no fire, grazing and no fire, and grazing and fire. All were rephotographed in 1959 and again in 1985.

The San Joaquin Experimental Range consists of 4,500 acres in the lower foothills (700 to 1,700 feet in elevation) in the granitic soil area, 28 miles north of Fresno. Rainfall has averaged about 19 inches, with extremes of 9 and 37 inches since 1934, when private ranch holdings were purchased by the Forest Service for use as an experimental range for grazing, livestock and wildlife research. For over 50 years, a variety of studies have been conducted by Forest Service researchers and cooperators from other state and federal agencies, organizations and universities. In 1984 the Pacific Southwest Forest and Range Experiment Station and California State University, Fresno entered into a long-term cooperative agreement, with C.S.U. assuming the administration of the Experimental Range. It will continue to be used for research and education purposes, to contribute to the knowledge of the use and conservation of California's rangeland resources. Three recent California Agricultural Technology Institute (CATI) publications update lists of all plants, vertebrate fauna and publications from 50 years of research at the Experimental Range; all are available at CATI, Calif. State University, Fresno, 93740. They are Larson and others 1985, Duncan and others 1985, and Duncan and Coon, 1985.

The story here is basically an update of the "Then and Now" publication by Woolfolk and Reppert (1963) now out of print; indeed the 1930's and 1959 photos are the same as the 1963 note. Photo Station 2 is what is now the Research Natural Area, which simply has been neither grazed by livestock nor burned since 1934 (fig. 1). Two decades later (1959) figure 2 indicates that lack of grazing and no fire favors the woody plants. The 1985 photo (fig. 3) shows a lot more of the same! The differences in wildfire hazards between this ungrazed area and the grazed areas that follow in the text and figures are so apparent that further comment is unnecessary. Most of the dramatic increase in woody vegetation is made up of digger pine (*Pinus sabiniana*) and wedgeleaf ceanothus (*Ceanothus cuneatus*). There has been little change in the scattered blue oak (*Quercus douglasii*). There has been little, if any, establishment of blue oaks with no cattle and no fire since 1934. Thus, blaming cattle grazing for lack of blue oak reproduction simply does not hold up, in this particular area, at least for a 50-year period. The same may be said of results at the Hastings Natural History Reservation in the Santa Lucia Mountains. Under the heading of oak regeneration, the Range and Public Lands Committee for the California Association of Resource Conservation Districts reported in 1986: "Much has been said about the problems of oak regeneration and much of the blame for the poor survival of our blue and valley oaks has been attributed to cattle grazing. This does not appear to stand up under scrutiny. Studies by Dr. James Griffin at the Hastings Natural History Reservation in the Santa Lucia Mountains--an area which has not had any agricultural use for over 40 years--have shown little or no change in regeneration of oaks following the removal of agriculture. He has postulated that high rodent populations may be responsible

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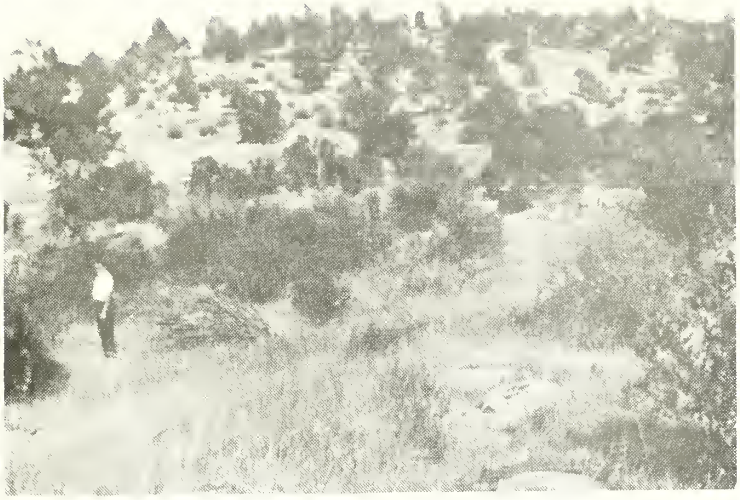

Figure 1--(Station 2 - Photo 1. October 20, 1938) at the San Joaquin Experimental Range, a view of the Research Natural area, ungrazed since 1934, and unburned since a wildfire in the late 20's.

Figure 2--(Station 2 - Photo 2. December 8, 1959) after Photo 1, another 21 years of no grazing and no fire resulted in great increases in digger pine (Pinus sabiniana) and wedgeleaf ceanothus (Ceanothus cuneatus).

Figure 3--(Station 2 - Photo 3. December 12, 1985) Much of the ungrazed, unburned area is almost impassable, with large amounts of live and dead woody vegetation. There has been little or no natural reproduction of blue oak.

Figure 4--(Station 3 - Photo 1. August 30, 1937) This station represents moderate to light livestock grazing and no fire since a wildfire in the late 1920's.

Figure 5--(Station 3 - Photo 2. December 15, 1959) Twenty-two years later, very little change was evident in the woody vegetation. Obviously, no new woody plants had become established.

Figure 6--(Station 3 - Photo 3. December 10, 1985) After 48 years, still very little change. A close look at the blue oak (Quercus douglasii) trees shows amazingly little change.

Figure 7--(Station 5 - Photo 1. August 10, 1939) This station represents moderate to close yearlong livestock grazing, with fire (after this photo was taken.)

Figure 8--(Station 5 - Photo 2. December 30, 1959) Continued livestock grazing, plus fire (in 1934) resulted in a decrease of the smaller woody plants, mostly *Ceanothus cuneatus*.

Figure 9--(Station 5 - Photo 3. December 11, 1985) A wildfire (1974) burned this area again. The weather each year has more influence on the annual plant vegetation than prior grazing or fires, or both.

for most of the seedling oak predation and loss that he has observed." Griffin (1980), at an earlier oak symposium, noted that exclusion of cattle at Hastings had not resulted in oak reproduction. At the same symposium Duncan and Clawson (1980) reviewed livestock utilization of California's oak woodlands.

Photo Station 3 represents an area grazed at a light to moderate rate (locally heavy use in some years) and no fire. Figures 4, 5, and 6 speak for themselves; there was practically no change. Perhaps the most important points in this series of photos are that blue oaks in this area didn't change much in almost 50 years, and that lack of fire did not result in any establishment of new blue oaks.

A combination of moderate to close livestock utilization and fire is shown in Photo Station 5. Several years of close utilization in the late 1930's appeared to be detrimental to the ceanothus plants in the 1939 photo (fig. 7). A wildfire removed the woody debris before the 1959 photo (fig. 8) and another wildfire occurred in 1974, before the 1985 photo (fig. 9). This series of photos also illustrates the very slow growth, (or lack of change) in blue oaks. Note the small branches "hanging down" on the right side of the closest oak in figure 8 (1959). Compare with the 1985 photo (fig. 9). Many of the small branches seem to be almost the same after 26 years.

An early photo of the rodent exclosure shown in figure 10 could not be found, but old records indicate the same thing happens on a very small area protected from grazing and fire as shown in the larger Research Natural Area (figs. 1, 2, and 3). This rodent exclosure was "mostly open," probably 75-85 percent when established in the late 1930's. When Howard (1959) reported on a hamster survival study inside the exclosure, he described the 50 x 100 foot pen, in 1950, as follows: "About 2/3 of the pen is covered with annual grasses and herbs; the remainder has a canopy of woody vegetation: One 30 foot blue oak (Quercus douglasii) a 15 foot digger pine (Pinus sabiniana), two coffee berries (Rhamnus californica), and 20 wedgeleaf ceanothus (Ceanothus cuneatus)."

The 1985 photo (fig. 10) shows this "mini-natural area" deserves a caption "bursting at the seams." We could not resist the temptation for a hasty "comparison" with Howard's description of the woody vegetation present in 1950. Today, about 1/3 of the pen is annual grasses and forbs, and 2/3 is under the canopy of woody vegetation: One 30 foot blue oak, one 45 foot digger pine, 2 coffee berries, and 29 wedgeleaf ceanothus (21 live, 2 decadent, and 6 dead).

Additional photographs will be featured in a more detailed publication for the California Agricultural Technology Institute Series (in press).

We hope this paper, with its long-term pictorial evidence of what has happened in one part of California's oak woodlands, will add in some small way toward a better understanding of this important resource. As a matter of interest, the Research Natural Area at the San Joaquin Experimental Range, along with grazed areas, is being used, by cooperating scientists from four other universities and CATI scientists in a number of investigations recently funded as Hardwood Range Research Projects. These studies include oak woodland regeneration, wildlife-habitat relationships in oak woodlands, ecology and regeneration of hardwoods rangelands, overstory effects on forage production, quality and utilization, soil characteristics on hardwood rangelands, and breeding habitat of cavity nesting birds.

Figure 10--(A "Mini-Natural Area". December 11, 1985) This 50 x 100 foot rodent-proof pen was mostly open when established in the 1930's. By the early 1950's, it was 2/3 open area and 1/3 under the canopy of tree and brush species. Today it is "bursting at the seams," with woody species, mainly Ceanothus, and is only 1/3 open area.

REFERENCES

Duncan, D. A.; Clawson, W. J. Livestock utilization on California's oak woodlands. In Proc. of the symposium on the ecology, management and utilization of California oaks. Gen. Tech. Report PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U. S. Department of Agriculture; 1980; 306-313.

Duncan, D. A.; Coon, S. L. Publications from the San Joaquin Experimental Range, 1935-1985. Fresno, CA: CATI/850902. California Agricultural Technology Institute, Calif. State Univ., Fresno; 1985; 101 p.

Duncan, D. A.; Ritter, L. V.; Newman, T. L. Vertebrate fauna of the San Joaquin Experimental Range, California: a 50 year checklist. Fresno, CA: CATI/850901. California Agricultural Technology Institute, Calif. State Univ., Fresno; 1985; 41 p.

Duncan, D. A.; McDougald, N. K.; Westfall, S. E. Effects of different long-term uses on California foothill hardwood rangelands. Fresno, CA: CATI/87____. California Agricultural Technology Institute, Calif. State Univ., Fresno, (in press).

Griffin, James R. Animal damage to valley oak acorns and seedlings, Carmel Valley, Calif. In Proc. of the symposium on the ecology, management and utilization of California oaks. Gen. Tech. Report PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U. S. Department of Agriculture; 1980; 242-245.

Howard, W. E. Survival of hamsters on California rangeland. J. Mammalogy 40(4):613; 1959.

Larson, J. H.; Stebbins, J.; Porter, W. L., Jr. A revised checklist of the plants of the San Joaquin Experimental Range. Fresno, CA: CATI/850303. California Agricultural Technology Institute, Calif. State Univ., Fresno; 1985; 38 p.

Woolfolk, E. J.; Reppert, J. N. Then and now: Changes in California annual-type vegetation. Res. Note PSW-14. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U. S. Department of Agriculture; 1963; 9 p.

Policy and Regulation

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Policy and Regulation[1]

Robert A. Ewing[2]

A public policy specifies principles and procedures which contribute to the achievement of certain objectives of a given political entity. Public policy for hardwood lands in California is being developed, and neither clear objectives nor explicit principles have been enumerated. Nevertheless, various governmental bodies in the state have adopted limited approaches to guide the use and development of these important lands.

The papers in this session on Policy and Regulation describe those programs that currently express the public interest in California's hardwood rangelands. Information is included on the current status of regulatory, research, extension, and other programs. Landowner and industry attitudes towards these governmental efforts are presented as one measure of their success.

Policies for California's hardwoods may involve several levels of government depending on who owns the land, what type of program is being applied, and what is the local level of concern for the resource. Several principles can be employed to suggest the most effective mix of authorities and programs. Taken together, the papers provide a framework for analyzing the development of a coherent statewide approach and suggest the leadership requirements to implement such a strategy.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

The State's Role on California's Hardwood Lands[1]

Kenneth L. Delfino and Robert A. Ewing[2]

Abstract: Paper explores and evaluates the traditional role the state government has adopted for addressing California's hardwood resources. To ascertain whether present authorities and programs are sufficient, four criteria are applied. Analysis shows that: 1) the state has sufficient justification and legal authority to adopt a hardwood strategy; 2) programs need to be based on a vision of the future; 3) government action must involve a variety of programmatic tools; and 4) leadership is important to ensure continued cooperation among the various agencies and interest groups involved.

State government involvement with forest and rangeland management concerns began shortly after statehood. In 1885, California established the nation's first Board of Forestry to control wildland fires and to stem the effects of flood damage brought on by California's severe Mediterranean climate and our steep, rugged terrain. In the ensuing years, the Board and the Department of Forestry, with authority granted by the Legislature, have developed policies and programs to ensure that over 35 million acres of the state's private land base receives adequate fire protection, remains productive, and is managed to meet environmental standards. Almost all of California's private, non-federal hardwood range and conifer land falls, in one way or another, within this area of state responsibility.

This background is helpful when considering proposals that may expand the role of the state in hardwood management and protection. While much of the recent policy discussion has centered on the question of extending California's Forest Practice Program to include hardwoods, the Board and Department already have experience through other mandates to address specific concerns related to hardwoods. In addition, several sections of the water and the fish and game code apply to activities on rangeland. The University of California, through its agricultural experiment station and extension programs, currently provides information and technologies for improved range and hardwood management.

This discussion indicates that the principal question facing the state on hardwoods is not "should the state have a role," but rather, "are present authorities and programs sufficient for ensuring the state's interests and should the state's role be strengthened, reduced or modified in some manner?"

This paper addresses this question through a review of several criteria useful in judging the efficacy of any government program. These criteria are:

1. Are current and anticipated programs directed at real problems and can they be justified in legal and economic terms?

2. Are program goals well-articulated and reflected in program administration?

3. Are the instruments of government action sufficiently broad to address the goals?

4. Does the program have adequate leadership, funding and staffing?

5. Are the benefits and costs of the program being adequately monitored?

JUSTIFICATION

The question of justification is critical because we believe strongly that the state should not look for problems to solve merely as an excuse to enlarge the scope of government. Our thinking closely parallels traditional tenets of economic policy in this regard.

From the standpoint of economic policy, government may need to intervene in the private sector when there is evidence that the institutions of the market have failed to provide the most efficient allocation of society's resources (Musgrave and Musgrave, 1973). Such market failures are thought to occur when a given market is not functioning properly or when no market exists to take into account the gains and losses from various transactions or activities.

A given market can breakdown when individuals or firms do not receive the necessary information and incentives to invest in profit-making activities, and in cases of high risk or uncertainty.

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Activities that have effects not accounted for in a market context are referred to as externalities or public goods. An externality occurs whenever transactions between two parties confer a benefit or a cost, usually a cost, on a third party which is not taken into account in the deliberation of the first two parties. Public goods are generally those conditions or services which benefit many people but for which few are willing to pay. Examples of public goods in the resource area include preservation of species, protection of wildlife habitat, clean air, water quality and aesthetics. Since markets do not generally ensure the production of public goods, the argument goes that government should somehow ensure that these services are provided or protected.

These concepts of market failure, public goods and externalities can provide guidance in the development of public policy for California hardwoods. Several hardwood studies commissioned by the Board of Forestry have attempted to review the Board's obligations and define problems in this light.

A 1982 report by a Board study committee entitled Forest Practice Regulation in California Hardwood Types (Cox et al., 1982) pointed out that hardwoods are an underutilized resource in California. The report also states that existing policies discriminate against hardwoods for restocking forestland and preclude options for their future management. The report presented several options for the Board to consider in eliminating the bias against hardwoods and for dealing with inconsistencies or inadequacies in the Board's Forest Practice Rules.

A second report came to the Board from its Hardwood Task Force in December 1983 (Pillsbury et al., 1983). The report made several findings. First, more research is needed in several key areas. Second, the Board should oversee all harvesting of hardwoods in California--with the proviso that controls should match the needs of the landowners. Third, hardwood harvesting can adversely affect soil and water resources; some additional regulation and education are needed. Fourth, some hardwood species are not regenerating well and care should be taken to leave ample residual stands of trees after harvesting. Fifth, hardwood harvesting can adversely affect wildlife habitat; especially in critical areas, sufficient trees should be left to provide for viable habitat. And last, trespass and firewood thefts are a problem and more easily enforceable laws are needed.

The 1983 task force report was both strongly supported and criticized. The Board chose not to act on the report. Rather, they sought additional information and research on hardwoods. With the cooperation of the Departments of Forestry and Fish and Game, the University of California, the State University system, and landowners, additional information became available. This material is summarized in a report for the Board entitled Status of the Hardwood Resource of California (Mayer et al., 1986) which was published this summer.

Without going into detail, this status report reinforces several of the points made by the task force and defines certain underlying trends which merit public attention. The report indicates that the two most significant forces at work on California hardwood resource are the continuing pressure of urbanization and the troubled economic state of the timber and livestock industries.

All these reports lay out a justification for some public action on the state's hardwood lands. In essence, they show a pattern of private investment which may not be sufficient to maintain longer term resource productivity. There are also problems with externalities in regard to soil and other resources and the lack of regeneration of certain hardwood species. Finally, wildlife habitats are threatened in some areas.

Beyond the evidence in these reports, another impetus for public action comes from an examination of the Board's legal mandates.

The Board already has broad authority to regulate the commercial harvest of all species of timber under the 1973 Z'berg-Nejedly Forest Practice Act. To extend regulations to cover hardwood harvesting simply requires designation of these species as "commercial." For a variety of reasons, the Board has chosen to give only limited designation of hardwoods as commercial. Not the least of these is that commercial use of hardwoods has been sporadic and inconsistent over the state. The result is that in most areas of California, harvesting of hardwood timber is not regulated.

Nevertheless, under existing regulations, the Department can and does regulate some hardwood harvesting. The ability to regulate lies in the definition of timberland in Public Resources Code Section 4526. Timberland is defined as land which is "available for and capable of growing a crop of trees of any commercial species..." Thus, harvest of any species from land now or previously occupied by commercial species may be regulated. Regeneration following such cutting must be with commercial species, but the cutting practices, erosion control, watercourse and lake protection rules cover all species. Each operation may not require a written timber harvest plan if a notice of exemption is filed. But forest practice rules will still apply.

As an example, hardwood cutting may be indirectly controlled or curtailed through restrictions on cutting in buffer zones adjacent to water courses and lakes on timberlands. Since shade canopy restrictions do not depend on species, economic realities usually result in hardwoods contributing a larger share than conifers to such reserved canopies. Restrictions on cutting snags and bird nest/habitat trees apply equally to hardwoods and conifers.

The Board has designated a few hardwood species that can become commercial if the timber owner designates them for management. This allows these species to be counted for regeneration, and brings them under silvicultural restrictions. In this manner, a number of pure stands of hardwoods, not growing on or near conifer lands, have been brought under regulation.

Senate Bill 856 passed in 1982 allows counties to recommend rules to the Board to solve localized problems. The special rules adopted for Santa Cruz County define "minimum impact" so that a number of fuelwood operations otherwise exempt from timber harvest plan preparation now require written plans.

Finally, counties may regulate on their own any activity not otherwise covered by the Forest Practice Act or Board rules. Several counties already have regulations or ordinances covering hardwood removal. In the absence of statewide policy or direction, this local activity will probably increase.

GOALS

This treatment of hardwoods from a legal and policy perspective reveals the authority and need for some public action. But successful action is dependent upon an adequate vision of the future. Such a vision was effectively made in Policy Options for California Hardwoods (1986), a report by Department and Board of Forestry staff. In summary, the vision outlined in the report is as follows:

1. The hardwood resource, whether on conifer or hardwood rangelands, should be protected and enhanced.

2. Range and timber stand improvement will continue--but such activities should take account of sensitive environmental areas and serious wildlife damage.

3. Land will continue to be converted to intensive agriculture and residential/commercial development--but conversion should be directed away from environmentally sensitive areas.

4. Governmental involvement in land management decisions of private landowners should be minimized and, in so far as is possible, supportive of their needs.

INSTRUMENTS OF GOVERNMENT ACTION

This statement of goals is significant because it extends the scope of the hardwood problem to include the various social, economic, and landownership trends affecting the resource base. This broadened perspective necessitates a review of public policy tools beyond regulation including research, monitoring and assessment programs, strategies to relieve pressures for hardwood removals, improved management information, and better coordination among public and private agencies.

Research holds a continuing and important place in coming to grips with the hardwood resource. For example, some questions related to regeneration and the dynamics of wildlife populations can be answered only with further research.

Since 1983, much progress has been made in research on hardwoods. Key factors and trends have been identified which position the Board and other authorities to formulate much more efficient strategies. Together with the University of California, the Department of Forestry in the current budget year has been able to devote over $500,000 to competitive grants for the most high-priority research in hardwoods. Sixteen projects in the areas of regeneration ecology, wildlife habitat diversity, and institutional and economic studies have received funding. To the extent that money continues to be available, research can remain a viable strategy.

Given the lack of information about hardwoods, monitoring and assessment are also key policy approaches. Work already completed on hardwoods has identified such variables as regeneration of certain oaks, changes in wildlife populations, shifts in hardwood markets, acres of conversion to intensive agriculture, and increased residential development. These are indicators of pressures on the hardwood resource. A number of more specific suggestions have been made to implement monitoring schemes on each of these variables.

The Department of Forestry's Forest and Rangeland Resources Assessment Program (FRRAP) is mandated to provide improved assessment information on hardwood resources and is planning to work with other agencies and with landowners to this end. In particular, FRRAP is developing procedures to monitor the costs and benefits of the various public hardwood programs being implemented.

Another necessary policy approach is to emphasize strategies that seek to relieve the pressure to remove native hardwoods. This could apply to all species or just those experiencing regeneration problems. A number of strategies to lessen pressure to remove hardwoods have been suggested by Doak and Stewart (1986) in a recent report entitled A Model of Economic Forces Affecting California's Hardwood Resource: Monitoring and Policy Implications.

Three strategies illustrate this approach:

1. Increase landowner awareness of gains in property values associated with hardwood retention and management;

2. Provide economic incentives for landowners to retain hardwoods; and

3. Broaden sources of landowner income.

The last objective could be accomplished through development of improved markets for various products from hardwood lands. A study by William Sullivan at Humboldt State University (undated) indicates that hardwoods do have great potential as lumber products. Tanoak has characteristics suitable for the furniture market. With some assistance, processing and marketing techniques can be perfected for tanoak and other species. We must be careful that we not destroy or waste a resource for short-term purposes just because it currently has low value. In the future these species could provide a valuable resource which might be cultured and grown just as redwood and pine are now grown. The Department of Forestry is developing a hardwood marketing and utilization program and will increase this effort in the future.

Lastly, means to improve the delivery of information to landowners are explored by several other speakers on this panel. In particular, Pete Passof and Bob Callaham will review the development of the University of California's new hardwood education effort. Tim O'Keefe and Sharon Johnson are to discuss strategies for working with landowners to help increase their management options. Each of these programs are important. Two additional agencies, the U.S. Soil Conservation Service and Resource Conservation Districts, deal with rangeland owners and should not be overlooked.

LEADERSHIP

Our review of current state policy for hardwoods reveals reasonable progress on several fronts. While a few issues remain to be resolved, progress has been made in defining the scope of the problem, determining direction, and developing various program tools. Forward movement is likely to continue as a result of renewal of commitment and leadership on the part of the various parties involved.

Leadership is a term that recently has made its way back into the policy literature (Bennis and Nanus, 1985). For several years, the idea of leadership had given way to a focus on larger scale social and economic trends and programs. Now the importance of leadership and self-directed action is again being recognized.

Leadership is important in the hardwood area because it provides the capacity to ensure continued cooperation and coordination among those who are affected by a given policy. The Board of Forestry, the organizers of this symposium, the University of California, and several local groups have provided adequate leadership to this point. But more will need to be done in the future.

The protection of the state's interests in hardwoods involves a mix of programs and strategies. Theoretically, the most effective approach would be to develop common goals and to allow each individual and agency to respond voluntarily to these ends. In reality, this is easier said than done because of different missions, objectives, political constituencies, and historical relationships. Thus, leadership is required both to set goals for the future and to ensure reasonable compliance on the part of all concerned with the management of California hardwoods.

CONCLUSION

To conclude, recent policy discussion on the state's role in hardwood resource protection has focused on the need to regulate. Certainly the question whether or not to regulate is uppermost in the minds of landowners and interest groups. But regulation alone is not a sufficient strategy for dealing with the forces that bear on California's hardwood resources.

Programs of education, fire protection, resource assessment, marketing, and planning are required to meet the needs of landowners, the public, and future Californians. The state has been developing such tools for over one hundred years, and significant experience and capacity already exist. We have room for improvement, but we are not starting from scratch.

REFERENCES

Bennis, Warren; Nanus, Bert. Leaders. New York: Harper and Row. 1985. 224 p.

California State Board of Forestry. Policy options for California's hardwoods. Sacramento, CA. September 1986. 25 p.

Cox, P. Chair. Forest practice regulation in California hardwood type. California State Board of Forestry report. Sacramento, CA. 1982. 34 p.

Doak, Sam C., Stewart, Bill. A model of economic forces affecting California's hardwood resource. Dept. of For. and Res. Mgt., University of Calif. Berkeley, CA. March 1986. 148 p.

Mayer, Kenneth E.; Passof, Peter C.; Bolsinger, Charles; Grenfell, Willian E.; Slack, Harold. The status of the hardwood resource of California. Dept. of Forestry. Sacramento, CA. September 1986. 125 p.

Musgrave R.; Musgrave P. Public finance in theory and practice. New York: McGraw-Hill. 1984. 212 p.

Pillsbury, Norman. Chair. California's hardwood resource. Preliminary report of Hardwood Task Force. Calif. State Board of Forestry. Sacramento, CA. 1983. 67 p.

Sullivan, William. Economic potential of tanoak timber of the north coast region of California. A sabbitical report. Humboldt State University. Arcata, CA. Undated. 25 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Managing California's Oak Woodlands: A Sociological Study of Owners[1]

Louise Fortmann and Lynn Huntsinger[2]

Abstract: A questionnaire survey of a plot-selected sample of oak woodland landowners in California found that the most common reasons landowners gave for removing oaks were to increase forage supply and to improve access. Commonly reported oak management practices included thinning oaks and cutting mistletoe out of trees. Log-linear analysis of the weighted sample found that oak management was significantly related to living or working on the property year-round, to a belief that keeping oaks maintained property values, and to having an economic reason for living in the oak woodland. Owners who grazed livestock were slightly but significantly less likely to manage oaks, when grazing was considered independently of related factors such as large landownership and residency. Results are discussed as they relate to those of the overall survey as reported elsewhere, and within the context of population, land use, and regulatory trends in California.

Since the vast majority of California's oak woodlands are privately owned, the Preliminary Hardwood Task Force Report to the State Board of Forestry, issued in late 1983, called for broad-based public education programs, increased sensitivity to landowner views and consideration of regulating hardwood harvest (Pillsbury et al. 1983). Regulations, as well as educational programs, are less likely to be effective if they are not appropriate to the needs and interests of those who own oak property. The University of California's Cooperative Extension Service funded a statewide survey to investigate the characteristics of the owners of oak woodland, how they use their land and manage their oaks, and what factors affect their management decisions. Here we report some results of interest to policymakers concerned with oak management and harvest, and discuss them within the context of the overall survey report. While the paper addresses oaks specifically, the findings are probably applicable to hardwoods in general.

METHODS

Data were collected from a random sample of oak woodland owners using a standard 4-wave mailed survey (Dillman, 1979). Usable questionnaires were received from 126 of 166 eligible respondents for a response rate of 78 percent. More than 792,509 acres were included in the sample, over 10 percent of California's 7.6 million acres of privately owned hardwood range (Passof and Bartolome, 1985). The sampling frame was a pre-existing set of Forest Inventory Assessment Plots (FIA), used by the Pacific Northwest Research Station of the United States Forest Service to assess hardwood volume in the state. Plots with a 10 percent canopy of oak species were considered to be oak woodland. The plots include 36 of California's 58 counties, ranging from the coast woodlands to the Sierra foothills, and from 30 miles north of the Mexican border to Siskiyou County.

Because owners of larger parcels are more likely to be selected by the grid method, the sample over-represents owners of larger properties relative to their proportion in the population of oak woodland owners as a whole. Therefore, in some analyses we controlled for three property size categories: "parcels under 200 acres," "parcels 200 to 5000 acres," and "parcels over 5000 acres." Other statistics have been calculated using a weighted sample, based on the weighting proposed for "systematic selection at grid intersection points" (Wensel, 1983). Each case is weighted based on the inverse of its probability of being selected for the sample using the grid system. Management of oaks was analyzed using log linear modeling procedures, which allow examination of the individual effect of categorical independent variables on a dicotomous dependent variable. Independent variables were selected using discriminant analysis, univariate F ratios, and the significance and magnitude of each variable's contribution to the model. Cutting living oaks was analyzed using chi-square procedures.

RESULTS

The average owner in the sample was 57 years old, had been a county resident for 28 years and owned 3538 acres. Ownerships under 200 acres accounted for 0.3 percent of the land in the survey, 31.6 percent of the respondents and an estimated 98 percent of all ownerships. Ownerships of 201 to 5000 acres accounted for 11.5 percent of the land in the survey, 46.5 percent of the respondents, and an estimated 1.7 percent of all ownerships. Ownerships over 5000 acres accounted for 88.2 percent of land in the survey, 21.9 of the respondents and an estimated 0.1 percent of all ownerships.

Over half of all respondents (56 percent) reported managing their oaks. As shown in Table 1, the most frequent routine practices were

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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thinning oaks (24.5 percent), cutting mistletoe out of trees (15 percent), and managing to maintain a set oak stocking level (14.2 percent). The practice most likely to be undertaken only once was thinning oaks (10 percent). The practice least likely to have been tried was aerial spraying (2 percent).

Model-Based Analysis: Oak Management

To examine some of the factors which predict whether or not the average landowner will manage oaks, landowners who practiced any of the oak management practices listed in Table 1 were distinguished from those who did not. These two groups were then compared using log linear modelling techniques with the weighted sample. Unfortunately, it was not possible to differentiate between owners who managed oaks for different goals. Some management techniques, such as thinning, may be used both to encourage and discourage oaks. Most landowners who manage oaks use a combination of encouraging and discouraging practices.

Table 1—Management Practices (Pct. of Owners)

Practice	No	Once	Routinely	No Answer
Poison oaks	93.3	0.8	4.2	1.7
Thinning oaks	64.2	10.0	24.2	1.7
Planting oaks	92.5	4.2	1.7	1.7
Maintain oak stocking level	81.7	1.7	14.2	2.5
Cut oaks, treat stumps	83.3	4.2	10.0	2.5
Thin softwoods to promote oaks	85.0	3.3	8.3	3.3
Girdle oaks	95.8	1.7	0	2.5
Aerially spray oaks	97.7	0.8	0	2.5
Manage oak sprouts	85.8	0.8	10.8	2.5
Burn scrub oaks	85.8	7.5	5.0	1.7
Cut mistletoe out of trees	76.7	6.7	15.0	1.7

Independent variables selected for the model shown in Table 2 were: writing a letter to the government about public policy, living on the oak woodland property, keeping oaks to maintain property values, having livestock graze on the property, and reasons for living in the oak woodland.

Using a .05 level of significance, living or working on the property year-round, feeling that maintaining property values was an important reason for having oaks, and not grazing livestock were significantly associated with managing oaks. An economic reason for living in the area was significantly associated with managing oaks, while having no predominant reason for living in the area was significantly associated with not managing oaks.

Landowners who write letters about public policy have about equal chances of being an active or inactive manager of oaks.

There is a 73 percent chance that owners who live or work year-round on their property manage their oaks (p=.021), while there is a 62 percent chance that those who live on the property part time (p=.166) or are absentee owners do not manage oaks. Owners who live on their property full-time, therefore, are much more likely to carry out some sort of oak management practice than those who are only part-time residents or absentee owners. There is an 82 percent chance that those who consider the increased value of their property an important reason for having oaks will manage oaks (p=.004). Owners who are aware that the presence or absence of oak trees can have a great effect on the value of their property are more likely to be actively managing their oaks than not managing them.

Table 2--Oak management response to ownership attributes (weighted sample)

Variable	Coefficient	p	Antilog
No oak management	-.353		0.49
Tried to influence public policy			
No	.160	.161	1.14
Yes	-.160		0.877
Live/Work on property			
12 months	-.499	.021	0.36
Part-time	.254	.166	1.66
Absentee	.245		1.63
Oaks increase property value			
Important reason	-.764	.004	0.217
Not important reason	.764		4.608
Livestock grazing			
No	-.348	.023	0.498
Yes	.348		2.006
Motive for living in area			
Economic	-1.07	.003	.116
Neither predominates	.731	.022	4.312
Aesthetic	.348		1.9917

Likelihood ratio x^2 = 6.14, d.f. = 57, p = 1.000

There is a 67 percent chance that those who do not have livestock grazing on their property will manage oaks ($p=.023$). Although landowners tend to be livestock producers and also to be more active managers, allowing livestock to graze on the property does not appear to be positively associated with actively managing oaks considered independently of these factors. If seasonal grazing practices, removing oaks for forage, and other more directly grazing related practices were included in "oak management," results might be otherwise, but by the criteria given above, those who do not have livestock grazing on their lands are more likely to manage oaks than not to manage them.

There is a 90 percent chance that those who live in the area mostly for economic reasons will manage oaks ($p=.003$), while those who live there for no predominant reason have an 82 percent ($p=.022$) chance of not managing oaks. Those who live in the area mostly for aesthetic reasons have a 66 percent chance of not managing their oaks. Owners who most value the recreational and lifestyle opportunities of the oak woodland are less likely to manage oaks than those who value it most as a means of earning a living.

Table 3--Reasons for removing oaks among landowners who cut living oaks.

Reason	Percent Respondents
Firewood income	18.5
Increase forage	51.2
Increase waterflow	25.6
Improve access	47.8
Clear for development	23.4

Cutting Living Oaks

Seventy-three percent of the respondents reported that they had removed living oaks from their property within the last five years. The most common reason given for removing oaks was to increase forage production (Table 3). Second was to improve access for livestock and vehicles. while firewood income was only given as a reason by 18.5 percent of respondents who cut oaks.

Too high a proportion of landowners cut living oaks to permit the effective use of log linear models. Chi-square analysis of the weighted sample was used to examine the factors influencing the "average" landowner's tendency to cut oaks. Landowners who placed high value on oaks for controlling erosion, having more forage beneath the canopy, and conserving water were less likely to cut living oaks ($x^2=6.63$, 9.91, 33.64; $p<.01$). Those who valued oaks for their beauty, for increasing the value of their property, and for fuelwood were more likely to cut them ($x^2=17.36$, 19.04, 9.76; $p<.01$). Landowners who value oaks because they facilitate production are reluctant to cut them. Values for oaks which are not production-related, such as natural beauty or property values, are not necessarily indicative of a reluctance to cut them.

Landowners who have livestock on their land, or who sell products from their land, are more likely to cut living oaks ($x^2=5.93$, 9.97; $p<.01$). Landowners with an annual income over $50,000, and owners of land which has been in the family fewer than 20 years are less likely to cut living oaks ($x^2=63.43$, $x^2=43.59$; $p<.001$). Landowners who own property less than fifty miles from town are more likely to cut living oaks than those who live further away ($x^2=77.25$; $p<.000$). Landowners who reported having greater than 50 percent oak canopy cover were more likely to cut living oaks ($x^2=31.42$; $p=.000$). Landowners who agree with the statement that "we are gradually losing our oak trees in California," and those who agree that "oak use should be regulated in California," are less likely to cut living oaks ($x^2=5.96$, 49.77; $p<.05$).

Landowner Attitudes

A major policy question is whether the "oak problem" can or should be addressed through regulation. A majority of the respondents (83 percent) felt landowners had the greatest influence on oak management and 86 percent felt that it was appropriate that they have the most influence. Forty-six percent felt the State Board of Forestry had the second most influence and 51 percent felt that the Board appropriately has this much influence.

Eighty percent of the respondents agreed with the statement that protecting water quality should be a state responsibility; fewer, 64 percent, agreed with the more inclusive statement that the state has a responsibility to protect natural resources. Only 20 percent of owners agree with the statement that the state has the right to regulate resource management on private land, but 38 percent agreed the state has the right to regulate resource management on private land if it pays compensation. Forty-six percent of the respondents agreed that we are gradually losing our oak trees in California, yet only 30 percent agreed that oak use should be regulated in California. A majority of respondents strongly agreed with landowners' rights to spray herbicides aerially (52 percent) or insecticides (54 percent) on their own land. Almost three-fourths of the surveyed landowners (73 percent) agreed or strongly agreed that citizens should be able to use natural resources on their own land without asking state permission. Sixty-five percent agreed that regulation leads to the loss of essential liberties. Only 11 percent agreed that the state does a good job of consulting citizens before making natural resource decisions.

DISCUSSION

The survey found that landowner behavior was most easily discussed in terms of a comparison of owners of small (less than 200 acres) properties and owners of large (more than 5000 acres) oak woodland properties (Fortmann and Huntsinger, 1985). Each of these groups own about a third of the oak woodland, but they differ in many important characteristics, including both their management practices and their attitudes about oak regulation and harvest.

Landowners with large properties generally produce livestock or farm products on oak woodland. Most often, it is they who have land zoned under the Williamson Act, and who sell fuelwood. These landowners spend all or part of their year on the property, where they are active managers. Typically, their oak property has been in the family for longer than fifteen years. For a variety of reasons, often as a means of achieving other goals, they cut and remove living oaks from their lands. They generally disagree with the statement that "oaks are being lost in California," and agree that "state regulation results in a loss of essential liberties and freedoms." Most of them belong to some sort of resource-based organization, commonly, a livestock association.

The second type of landowner holds land in a smaller parcel, from less than one acre to a few hundred. They also occupy around a third of the oak woodland. Few have land enrolled under the Williamson Act, indeed, few are eligible to do so; few sell firewood. Less than a third sell products of any kind from the land, and the majority of their income often come from investments or retirement funds. As a group, they are slightly better educated than the larger landowners, and many more of them are absentee landowners.

Fewer owners of small properties cut living oaks for any reason, and overall, they tend to carry out less active management of their oak trees. Less than half have lived in the same county as their property for 15 years or more, and they tend to be younger than the larger landowners. Fewer of them believe that state and federal regulations lead to a loss of essential freedoms and are "bringing the country closer to socialism." Almost two-thirds feel that we are losing our oak trees in California, and more than one-third believe that oak use should be regulated in California. While 32 percent of the largest landowners had contact with an advisory service about oaks within the last 2 years, only 14 percent of the smaller owners had.

Oak Harvest and Land Use

The most frequently given reasons for cutting oaks were production related, most often livestock production related—for increasing forage, access, and waterflow. The owners of more than 41 percent of the oak woodland reported that they thinned oaks and the owners of almost 11 percent burn scrub oaks. More than two-thirds of the oak woodland is owned by those who have livestock grazing on the property at times (Fortmann and Huntsinger, 1985), making the objectives of increasing forage, access and waterflow critical components of landowner decisions on the majority of the oak woodland. The fact that landowners with oak canopy cover greater than 50 percent were more likely to cut oaks is similar to the results of a survey of ranchers in Tulare County (McClaran and Bartolome, 1985) and is probably due to the relationship of canopy cover to forage production. At less than 50 percent oak canopy cover, the grasses in the understory are similar in productivity to those out in the open. Gains in productivity from oak removal are questionable, and even more so when the loss of mast, browse, and shade are considered.

The fact that landowners who valued oaks because of the oaks' contribution to the continued productivity of their property were less likely to cut them indicates that the practices of these landowners can be influenced by their understanding of the role of oaks in resource productivity. Education programs and research that contribute to this understanding could have great impact on oak management, especially on large properties where the owners are most likely to use their land for production.

Selling firewood was given as an important reason for cutting oaks by less than a fifth of those who did cut oaks. However, 28 percent of the oak woodland belongs to those who report that they do sell firewood (Fortmann and Huntsinger, 1985). Owners of large parcels were much more likely to sell firewood than owners of small properties, reflecting either less opportunity or the integration of firewood sales with the benefits of increased forage production or the production of other resource values. Selling firewood may be used to offset the costs of removing oaks for imporoved forage production. further data analysis may better define these relationships. Only three-fourths of large landowners who sold firewood said the income was important to them.

Valuing oaks for reasons that were not production-related was not a good predictor of reluctance to remove oaks—in fact, respondents who reported valuing oaks for increasing the value of their property, or for their beauty, were more likely than not to remove living oaks. This may be due to the fact that the natural beauty and monetary value of properties may be enhanced by the removal of some oaks, creating a park-like effect. However, owners of small parcels were less likely to cut oaks, and they tended to value oaks and living in the oak woodland for reasons that are not production related. While they were less likely to cut oaks, they were also less likely to manage oaks in any way. Because of the low rate of regeneration of many oak species, and the damage that residential activities can cause to oaks, such apathy is likely to have a negative effect on the oak population on these smaller properties. It is probable that educational programs that inform these landowners how oaks enhance the quality of life they seek in the oak woodland will encourage more active involvement with oak regeneration and care. The low rate of return of a postcard requesting additional information about oaks may be due to a perception that Cooperative Extension is for agriculturalists.

Rural Population Growth

Between 1970 and 1980 the non-metropolitan population of California increased 42 percent compared to a growth rate of 15 percent in the previous decade (Hope and Blakely, 1986). With this growth has come increased demand for housing resulting in the conversion of farms, forests and rangelands to housing sites. Subdivisions and other forms of development have created a new source of pressure on oak woodlands.

Almost a quarter of landowners who cut living oaks reported that they did so to clear land for development. Slightly more than 9 percent of the oak woodland is owned by those who have subdivided part or all of their property within the last five years. Half or more of all ownership categories were within 5 miles of a subdivision, and those living closer to town were more likely to cut oaks. The proximity of residential areas creates a better fuelwood market, and reduces the cost of transport. It also creates conflicts, as lifestyles and values clash. Suburban oak woodland residents may feel that livestock detract from the natural beauty they seek in the oak woodland. Owners of large properties may find that the newer, suburban oak woodland residents interfere with their production related activities. Suburban dogs may harass livestock. Vandalism of buildings and equipment may increase. What the urban resident sees as the legitimate right to regulate and to affect the management of vast expanses of wilderness may appear to the rancher to be interference by outsiders in his/her own backyard.

Regulation

In general, respondents recognize a state responsibility to protect natural resources, and, to some degree, the existence of a problem with oak management. However, they are highly protective of their rights to do as they please on their own land. They do not appear particularly willing to grant the state the right to address problems on private land through regulation.

Can the oak problem be solved without regulation? At least one facet of the problem cannot be solved by extension efforts and goodwill alone, that of land conversion either for agriculture or housing, the latter having a reasonably permanent effect. At a minimum the solution to the land conversion problem involves controlling land subdivision and improving the economic viability of current uses of this land. This is likely to require regulation.

Is regulation a workable option? Much has been made of rural resistance to regulation. Some Cooperative Extension county directors have suggested that if regulations were about to be enacted, owners would cut down their oaks in protest and defiance. The data in this survey indicate a general dislike of regulation in general and opposition to oak regulation in particular. However, the data also indicate that many respondents have already taken advantage of such regulatory devices as the Williamson Act and that respondents value oaks on their land for a variety of economic, aesthetic and environmental reasons. It seems likely that in most cases practicality would override ideology in the response to oak regulation, depending, of course, on the precise nature and objectives of such regulation.

CONCLUSIONS

Oak woodland owners in California have been shown to be a heterogeneous group of people whose oak management practices reflect the use of their property, their major income sources and the amount of time they spend on their property. Many of these factors vary with property size. This has clear implications for future actions. Recommendations about oak management practices must be compatible with the production strategies used on economically productive land. They must also be compatible with the level of interest, skills, capital, labor and equipment possessed by landowners who do not use their land for economic production. The acceptability and adoptability of different practices for different categories of owners, the proper role of government and the appropriate means of citizen participation in solving the hardwood problem are in need of research.

Acknowledgements: This research was funded by a grant from California Cooperative Extension's RREA fund. We wish to acknowledge the assistance and advice of J. Clawson, S. Doak, H. George, J. Gerson, P. Muick, P. Passof, R. Standiford, P. Starrs, W. Stewart, R. Tuazon, C. Washburn, W.E. Waters, W. Weitkamp, L. Wensel, and many Cooperative Extension staff.

REFERENCES

Dillman, D.A. Mail and telephone surveys: the total design method. New York: Wiley; 1979. 325 p.

Hope, James; Blakely, Edward. A rural development agenda for California. Sacramento: Senate Office of Research; 1986. 98 p.

McClaran, M.P.; Bartolome, J.W. The importance of oaks to ranchers in the California foothill woodland. Rangelands 7(4):158-161; 1985.

Pillsbury, Norm; Timmons, J.; Mayer, K.; Libeau, H.; Plumb, T.; Marsh, B.; Del Porto, N.; Wade, R.; Phillips, P.; Slack, H. California's hardwood resource: preliminary report of the Hardwood Task Force; Dec. 6, 1983.

USDA Forest Service. California P.I. Manual. Resources Evaluation Unit. Portland: USDA Forest Service; 1981.

Wensel, Lee C. Biometrics Note #8. Estimators for use in California forestland ownership studies. Berkeley, CA: Dept. of Forestry and Resource Management, University of California; 1983.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Perspective on Hardwood Rangelands From the California Range Livestock Industry[1]

Jim Timmons[2]

Abstract: Domestic livestock grazing plays a significant role on California's hardwood lands. On lands used continuously for livestock grazing during the last 200 years, changes in vegetation cover have occurred. However, only in isolated cases has there been total or a high rate of damage to the hardwood resource. Land use conversion has been, and will continue to be, a far greater impact on blue and valley oak than either good or bad range practices. Rangeland improvement is a necessity for economic livestock management. Thus, the retention of flexible management programs are critical for range industry survival.

The association between the hardwood grassland vegetation found in the central valley, the smaller coastal valleys and foothill ranges of California, and the domestic livestock industry has endured since the introduction of cattle, sheep and goats to California in the 1760's by the Spanish. Hides, tallow and wool were the principal products. Tanoak bark peeled and dried was one of the principal exports shipped from the north coast to the San Francisco and Monterey areas for use in the tanning process during the last half of the 19th century.

The management of domestic livestock on hardwood rangeland was first concentrated in the valley and foothill areas. Grazing of domestic animals had moved as far north as Shasta County by 1840. A seasonal pattern of lower elevation use during the fall-winter-spring months and a transfer of livestock to higher elevation meadows and mixed timberland for summer grazing evolved. More recently, with modifications due to irrigated pasture and intensive grazing practices and changed public land programs, more livestock have remained on lower elevation hardwood rangeland throughout the year.

Just as there are traceable patterns in the evolution of domestic livestock use of California's rangelands, there are also identifiable changes in the vegetative composition of these lands. The annual grasses and forbs that predominate the hardwood grassland ranges of today were once native perennial grasses. Excessive grazing pressure and, in many instances, the changing use patterns of the people who have populated this state have affected the vegetative composition.

Fire, both as a natural phenomenon and as used by native Californians, once maintained a balance between woody and herbaceous cover. The attempted exclusion of fire by man and the use of fire as a management tool have both expanded and reduced the ranges of conifer and hardwood species. The need for fuel and lumber has altered the balance between woody and herbaceous cover since the settlement of California. A good example can be found in impacts on the foothill ranges during the gold rush of the mid-1800's. Many acres in this area that appear as oak-grass woodlands or hardwood-brush ranges today, once were conifer stands. These were cut for mine timbers and lumber, and little trace of pine or fir trees remains.

Farming and California's increasing human population pushed the livestock industry from the valley floor into the foothills. This caused ranchers to develop practices opening the hardwood canopy for increased forage production. The best available tool for this purpose was fire and it has been used with varying influence on hardwood rangeland for the past 100 years in California.

However, land that has remained in use for forage production, supporting both domestic livestock and wildlife, still carries heavy stands of oak species and other related hardwoods. In many respects the range livestock industry has been the protector of the hardwood rangeland resource.

We have gone through periods of time when attempts to convert hardwood land or when a need for fuel and fiber have had special significance. The depression of the 1930's and the intensely high fuel costs of the early 1980's exerted special pressures on the hardwood resource as a low cost source of home heating fuel. Both of these periods coincided with times of economic hardship in the livestock industry. Utilization of hardwoods for fuel purposes provided supplemental income to rangeland owners.

The conversion of rangeland to other uses and increased livestock production during and after World War II prompted interest in range

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[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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improvement efforts to increase carrying capacity. This led to emphasis throughout the late 1940's and 1950's on range improvement practices to increase forage production. Prescribed burning to reduce competition from woody vegetation was and remains the most common practice. Mechanical alteration and chemical treatment to prevent sprouting of undesirable vegetation became recommended practices. Conversion from dense hardwood cover to open range can produce a 3- to 4 fold increase in carrying capacity. Beginning in 1945 the Department of Agriculture's Agricultural Stabilization and Conservation Service (ASCS) offered payment to land owners for clearing rangeland. From 1948 to 1952 more than 55 million acres of woodland were cleared in Amador, Calaveras, El Dorado, Placer, Mariposa and Tuolumne Counties. It is estimated that between 1945 and 1973 about 890,000 acres of hardwood rangeland were converted to open grassland through ASCS sponsored projects (Bolsinger in press).

Rangeland clearing was the major cause of reduction in hardwood acreage on rangelands between 1945 and 1973. Since then, residential and commercial development has been the leading cause in the decline of hardwood acreage. Of the oak woodland acres lost since 1966, an estimated 46% was due to residential and commercial development, 39% to road and freeway construction, and only 15% to rangeland clearing for both firewood harvest and range improvement (Bolsinger in press).

Chemical treatments are no longer a widely used practice due to limited cost effectiveness and environmental concerns. Range improvement programs, highlighted through local county range improvement committees, have dramatically changed current range management practices. Recommended practices still include the use of prescribed burning, mechanical alteration, and limited vegetation treatment to increase available forage and water yield.

There is no doubt that California's domestic livestock industry is dependent on forage production from woodland-grassland associated areas throughout the state. The vegetative type of greatest significance is California hardwood rangeland. This land base, though larger in the past, today includes approximately nine million acres of woodland that has ten percent or greater hardwood canopy cover, but is also not capable of growing economical quantities of industrial wood.

Hardwood rangeland vegetation includes deciduous and/or live oak with minor amounts of other hardwood species and an understory of forbs and grasses. Livestock grazing has been and remains the best method of harvesting this resource. It is significant to note that agriculture is California's dominant industry and livestock production is the second leading segment in total revenue return. However, due to our population, California must import more than 60 percent of the red meat consumed.

The increase in population and accompanying land use changes have greatly affected hardwood rangeland acreage in California. At one time, the nine million acres described as hardwood rangeland was estimated to be as large as 12 to 15 million acres (Wieslander 1946). Conversion to intensive agricultural crop production and urbanization has not only greatly reduced the acreage of available hardwood rangeland but such conversion has greatly reduced the extent of the oak woodland type.

Land use change is the major cause of the loss of the hardwood resource and related grazing acreage. Some may think it natural to point the finger at the range livestock industry for the declining extent of hardwood cover since, in most cases, grazing was the historical use prior to conversion. But, the fact remains that land continuously used for domestic livestock production still carries high volumes of hardwood species.

Studies conducted in Mendocino County reported the annual harvest of hardwoods from conifer-hardwood land to be only four percent of the annual hardwood growth in the county (Bolsinger in press). I suspect the impact noted by comparable studies of harvest and growth on the hardwood rangelands would show a similar small proportion of harvest to growth throughout the state.

It is also important to note, as mentioned earlier, that harvesting hardwoods from rangeland has been taking place as long as grazing has been practiced. Periods of economic stress for the livestock industry or conditions supporting increased values for wood products have temporarily caused periods of increased harvest. There was greater dependency on wood as a fuel source in the last century and first half of this century than today. A much smaller urban population caused far less impact on the resource. We do know that numerous examples can be cited where oak has been removed from the same land more than once, and where landowners are currently producing trees for future generations of the same family to harvest. We look forward to this cycle being repeated again and again.

Changing economic conditions will influence harvesting of hardwoods. We have seen these cycles before. Examples exist where a financial crisis of an individual landowner becomes the justification to remove hardwoods. In such cases, it should be clear that the range industry respects a person's rights but may not condone, and will not defend, such management practices if they go against good land stewardship.

Significant variation in stand and species composition on hardwood rangelands makes the application of general rules or simplified management practices very difficult. Some of the confusion that exists about appropriate management of oak species statewide is illustrated by the controversy about forage production under oaks.

In northern California, it has been noted the removal or reduction of blue oaks increased forage production (Kay and Leonard 1980, Johnson et al. 1959) while in areas of the south central foothills and south coast, forage production has been observed to increase under an oak canopy (Holland 1973, Duncan and Reppert 1960, Duncan 1967).

Also, there are differences of opinions among livestock raisers about the value of forage associated with hardwood cover. It is generally accepted that forage found under the hardwood canopy is of lower quality than forage on open land. However, forage production under the hardwood canopy tends to stay green longer in the spring and green-up earlier in the fall. The earlier fall feed has greater impact on forage value than the other influences of the hardwood canopy.

Direct forage production from hardwoods results from sprouts that grow after cutting or burning. This browse and acorns are of greater importance to sheep, goats and wildlife than to cattle.

The greatest concern of livestock managers is maintaining the hardwood canopy cover in balance with production of understory vegetation to provide quality forage. Thinning hardwood stands can make marked changes in available forage that benefit domestic livestock and many species of wildlife as well. The maintenance of a high level of production of forage throughout the year for grazing livestock cannot be accomplished without the removal of competing vegetation. However, economic, practical and personal concerns all play a part in management decisions that determine vegetative composition on grazing land.

The attention that is being paid to the vast hardwood resource remaining on rangelands today reveals that most ranchers have long had management objectives that involve modification but retention of much of the hardwood component. The shelter and shade values of hardwoods for domestic livestock require such consideration. Whether intentional or coincidental, flexible management decisions on the part of the landowner result in multiple use objectives that benefit domestic livestock, wildlife, water yield and aesthetic values. A livestock operation can never be as single-purpose oriented as other resource users often are.

Today, public attention is focused on the pressure exerted on California's renewable resource land. This issue has been raised many times before in California's short history. The pressure of a continually increasing population, one that will exceed more than 30 million people before the turn of the century, is the greatest problem our resource land faces today.

The initiation of regulation on hardwood rangeland to protect the hardwood resource is simply addressing the symptom and ignoring the problem which is land use change. In fact, restrictive regulation on hardwood rangeland would diminish flexible land management, potentially encouraging acceleration of land use changes and, in the end, defeating the purpose to which it was directed.

In summary, we must recognize that domestic livestock grazing plays a significant role on California's hardwood lands. A relationship between hardwood vegetation and domestic livestock grazing has existed for over 200 years. On most of the land used for grazing livestock there have been changes in the vegetative cover, but in only isolated cases has there been a total or high rate of damage to the hardwood resource. Economic conditions will affect hardwood harvest as they have in the past. Land use conversion has been, and will continue to be, a far greater impact on the extent of blue oak and valley oak than either good or bad range practices. The livestock industry is extremely dependent on hardwood-grassland range as a source of forage. Rangeland improvement is a constant necessity because we are dealing with a renewable resource that is changing both due to human and environmental effects. The retention of flexible management programs and the opportunity for individually selected practices are critical for range industry survival. Range livestock management on land supporting hardwoods is a highly productive form of multiple use management, in that wildlife, watershed and recreation values are most often enhanced in association with livestock production.

There is no question that emphasis on research must continue and that rangeland owners must evaluate and recognize the results of available research for hardwood rangeland. Extension education must continue with greater emphasis for the benefit of both landowner and public alike.

We are not scientists and don't approach the problems with analytical and statistical solutions. We have gained a deep appreciation for and understanding of the land and the resources that provide us a living.

Further, we make no apology for past practices that were acceptable in their time. Nor, do we condone or defend resource damaging operations. We do submit that the vast acreage of hardwood rangeland in California must remain flexibly managed by the livestock industry with recognition of other values produced, and unencumbered by regulation.

REFERENCES

Bolsinger, C. L. The hardwoods of California timberlands, woodlands, and savannahs. Portland, OR: Pac. NW Forest and Range Exp. Stn., Forest Service, USDA (In press).

Holland, V. L. A study of vegetation and soils under blue oak compared to adjacent open grassland. Berkeley, CA: Dept. Botany, Univ. of Calif.; 1973. Ph.D. dissertation.

Johnson, W.; McKell, C. M.; Evans, R. A.; Berry, L. J. Yield and quality of annual range forage following 2, 4-D application on blue oak trees. J. Range Mgt.; 12:18-20; 1959.
Kay, B. L.; Leonard, O. A. Effect of blue oak removal on herbaceous forage production in the north Sierra foothills. In: Ecology, Management and Utilization of California Oaks. Gen. Tech. Rep. PSW 44. Berkeley, CA: PSW Forest and Range Exp. Stn., Forest Service, USDA; 323-328.
Duncan, D. A.; Reppert, J. N. A record drought in the foothills. Misc. Pap. 46. Berkeley, CA: PSW Forest and Range Exp. Stn., Forest Service, USDA; 1960.
Duncan, D. A. Blue oak canopy effect on herbage yield on central Calif. foothill rangeland. Abs. paper 20th Annual Mtg. Amer. Soc. Range Mt.; Seattle, WA. 1967.
Wieslander, A. E.; Jensen, H. A. Forest areas, timber volumes and vegetation types in California. Release 4. Berkeley, CA: CA Forest and Range Exp. Stn. For. Surv., For. Serv., USDA; 1946.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

An RD&A Strategy for Hardwoods in California[1]

Robert Z. Callaham[2]

Abstract: The situation surrounding research, development, and applications (RD&A) on hardwoods has many deficiencies that point to recommendations for remedial actions. Many problems require attention by RD&A, but these problems and their priorities have not been identified and made known to scientists and specialists. Systems are needed that would provide current, statewide information about who is working where, on what problems, and with what output. Information analysis--gathering, analyzing, and repackaging--is needed to make available information useful. Conferences every seven years do not meet the need for information exchange and technology transfer. Political support will be needed if RD&A directed at hardwoods is to grow. A new California Hardwood Council should be formed to help meet these needs.

Typically at a conference such as this, you sit and listen to a stream of scientific and technical papers. Too seldom, to my way of thinking, do you hear from practical people who are trying to apply technology to solve their problems. Very rarely do you hear from someone who was asked, as I was, to examine and report on the process of research, development, and application (RD&A) that led to the papers. That is my assignment here: to analyze the situation surrounding RD&A on hardwoods and to recommend strategies for improvement.

Before launching into my subject, I want to define some of the terms I will be using. Research, development, and applications of technology are the three steps that lead to innovation (Callaham, 1984). First, research, via scientific inquiry, begins with the unknown and creates new knowledge and methods. Second, development starts with new products, processes, or systems, and strives for practicality by adapting, testing, evaluating, and modifying. Third, application puts proven technology into practical use as social or technical innovations. Extension, a term familiar to all of you, includes both development and application. These are the integrated phases of RD&A. Another term is scientist-year (SY). This measure of input to R&D includes full costs for one year of a journeyman scientist plus all supporting workers, services, and facilities. Major research organizations currently are spending about $170,000 per scientist year.

THE HARDWOOD RD&A SITUATION

Failure of past efforts to manage and utilize hardwoods largely resulted from a lack of technology. The extent and value of the resources were poorly known. Markets, except for use as fuel, are poorly structured or inaccessible. We are only beginning to learn the extent and value of hardwood resources and to appreciate their potentials for growth and yield. Technology for reproducing, growing, harvesting, and utilizing hardwood resources is increasing, but still is inadequate to the need. In short, we should provide for hardwoods a legacy of research, development, and application that is as substantial as the one we have built for conifers during the past eighty years.

Hardwoods, because of their lesser economic importance, have taken a back seat to conifers as a focus for RD&A in California. But the first hardwood workshop at Claremont (Plumb, 1980) evidenced the need for more attention to hardwoods. The ensuing conference on eucalypts focused on a group of fast-growing exotics (Standiford and Ledig, 1983). Now this conference attests to a widespread and continuing interest in hardwoods.

However, we have only a foggy picture of efforts directed at RD&A for hardwoods. Has anyone estimated the past and current input to and output from such activities? For example, Muick and Bartolome (1985) estimated that the level of effort on oaks during 1983 was 15.2 scientist years committed to 68 studies, at a cost of $2.5 million. Current research, development, and application efforts are scattered and not of great magnitude. Worrisome to me is that these efforts on oaks and other hardwoods may not be focused on major problems.

What we know and have available as a body of technology, for the most part, has not been summarized, evaluated, and focused on problem solving. Several functions are missing if we are to build an adequate technological base for management and utilization of hardwoods in California. This conference could significantly impact this situation. Improvements will only happen if individual participants here commit themselves to develop an effective RD&A program for hardwoods.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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MANAGING RD&A

During my 28 years as a manager of research and extension, I have developed a set of precepts for approaching each RD&A situation. First, the scientific and technical problems requiring RD&A must be identified and prioritized and explained to scientists and decision makers. Second, some system must be developed to obtain current information about what is being done now to solve priority problems. Third, direction or coordination must be provided for people working on the same or similar problems. Fourth, some system must be developed to gather, catalog, and make available scientific and technical information. Fifth, effort must be expended to gather, analyze, and repackage available information to meet practical needs. This essential, and too often neglected, function is called information analysis. Sixth, frequent and varied opportunities must be provided for exchange of information among scientists and specialists and their innovative clients and users of technology. Seventh, decision-makers and legislators must be informed and convinced of the importance of the situation and then motivated to improve on it.

STATUS OF RD&A ON HARDWOODS

Identifying Problems and Priorities

Let us examine the first of these precepts as it relates to RD&A on hardwoods. The all-important identification of specific problems and assignment of priorities has not been done adequately for hardwoods. California's Hardwood Task Force identified 19 major issues for consideration by the California State Board of Forestry (1983). Fifteen of the 19 issues exposed broad issues, but not specific problems, requiring research, demonstrations, or applications. Ken Mayer, in his appendix to the report of the task force, listed 15 problem areas for research. Muick and Bartolome (1985), after their survey of RD&A activities directed at oaks, identifed only four specific problems for RD&A.

Wide-ranging reviews of forestland problems requiring RD&A occurred in 1979 (California State Board of Forestry, 1979) and again in 1985.[3] Both reviews disclosed only a handful of problems relating to hardwoods. Many problems deserving attention were suggested at the symposium on oaks in 1979 (Plumb, 1980) and at the eucalyptus conference (Standiford and Ledig, 1983), but unfortunately they are buried within 78 technical papers and the memories of participants at those symposia. Here at San Luis Obispo, 92 papers certainly must have identified many problems needing attention. But once again, a list of problems needing research and extension will not be forthcoming. Without a list of priority problems, pressures for needed work cannot be exerted on scientists on the one side and sources of funding on the other.

The need is to identify those problems where demands for solutions are sufficient to justify investments in RD&A. Individuals will always point to problems of their own choosing, but such problems may not have sufficient socioeconomic importance to justify expending scarce resources for either research or extension. Unless a significant number of people care about a problem we should shy away from spending time and money on it.

Information for Managing RD&A

With regard to the second precept, we lack a statewide system for identifying who works where, on what species and problems, at whose expense, and with what cost and output. Muick and Bartolome (1985), spending only about $8,000, conducted a unique survey and described what has been done and is being done related to oaks in California. USDA's Current Research Information System (CRIS) provides such information only for scientists employed by USDA's Pacific Southwest Forest and Range Experiment Station and the University of California's Agricultural Experiment Station, plus a few studies at Humboldt State University. Scientists in other federal agencies, elsewhere at UC, and in other state or private employ are not included in CRIS. Cooperative Extension has a related internal managerial information system called CEMIS. So anyone can ask CRIS or CEMIS to paint their partial pictures of the current activity related to hardwoods in California. But a large part of the RD&A iceberg would be unexposed.

The Research Advisory Committee of the California State Board of Forestry (1986) has recognized the need for systems like CRIS and CEMIS to be expanded statewide. We certainly would profit from having a managerial information system, with updates perhaps annually or biennially. It would answer our questions about the extent, nature, and output of the current RD&A efforts. But statewide systems, being costly to build and maintain, will not be in our foreseeable future unless influential people rise up and demand them.

Directing and Coordinating Work

My third precept takes me into potential conflicts. Academicians in their chosen work are above direction, and they submit grudgingly to coordination. Whereas, scientists and specialists employed by federal, state, and private organizations grudgingly accept managerial direction, redirection, and coordination of their work. Having worked in both arenas, I respect their differences, yet as a manager, I want more efficiency and effectiveness from the scattered, piecemeal efforts directed at hardwoods.

[3]Participants identified 286 forestland problems at a workshop in Berkeley, California, May 22-23, 1985, organized by the Wildland Resources Center, University of California.

Reviewing the report on oaks by Muick and Bartolome (1985), I found that the level of research and extension being expended on each problem was grossly inadequate if we expect practical solutions within a decade. A critical mass of scientific and technical effort is usually required to solve practical problems promptly.

Our studies in USDA Forest Service showed that the RD&A process consumes much time and effort. At the Pacific Southwest Forest and Range Experiment Station our average cost to achieve one innovation was 8.5 scientist-years, or $1.4 million, using current costs (Callaham and Hubbard, 1984). The average cost to achieve one major national innovation by USDA Forest Service was 25.2 scientist-years, or $4.3 million, using current costs (Callaham, 1981).

Let us assume that these results pertain to researchers outside of USDA Forest Service, as I feel they do. Obviously we should stop scattering effort, a few tenths of scientist-years on each problem, and try to block it up. This would mean a coordinated, cooperative RD&A program for hardwoods aimed at solving only a few, critical problems, and leaving many important problems unattended.

Availability of Scientific and Technical Information

Finding output of technology from past and current RD&A efforts often is difficult. Part of what is known has been included in forthcoming silvicultural summaries by USDA Forest Service and in earlier forest products papers from the University of California. The soon-to-be-published bibliographic summary by Griffin, McDonald, and Muick (1986) will list publications about oaks. Lacking are similar bibliographies for other genera or for topical areas.

Libraries and special library services constitute another dimension of problems. Practitioners often do not have adequate technical libraries or special library services. Needed is an expansion of WESTFORNET, a special library service for USDA Forest Service, to meet needs in the private sector.

Information Analysis

Knowledge and methodology related to hardwoods have been pulled together, evaluated, and repackaged only sporadically. One exceptional case that makes my point is the recently published "Preliminary Guidelines for Managing California's Hardwood Rangelands," by Peter Passof, W. James Clawson, and E. Lee Fitzhugh (1985). Cooperative Extension met the need for these guidelines by directing those authors to produce, within a three-month period, a synthesis of available information for use by landowners.

The aforementioned summaries of silvicultural information about hardwoods in California, soon to be published by the Forest Service, exemplify the kind of gathering and synthesizing of information that needs to be done. I submit that a proceedings--of the type that came from the oak and eucalyptus conferences and that will come from this conference--only comprises a collection of recent findings. The essential functions of information analysis --gathering, evaluating, summarizing and repackaging--are not fulfilled by such a proceedings. We need volunteers to analyze information on hardwoods for selected audiences.

Inexpensive and more effective means than this conference should be utilized for gathering people and for analyzing and delivering technology. Practitioners, the people responsible for managing land and resources, do not attend conferences such as this in the proportions that we would like. They use different means than technical conferences to meet their needs for available technology. Industrial associations, groups of landowners, or other organizations should rise to meet this need for better forums for technology transfer.

Information Exchange

The sixth precept pertains to the need for interaction and communication among people who generate, extend, and apply hardwood technology. Muick and Bartolome (1985) concluded that:

> Communication at several interstices is not occurring. More frequent exchanges of both information and views are needed. Such exchanges are needed in two dimensions: within the scientific community, and between the scientific community and the public. Given the excellent research accomplished by the scientific community, a two-dimensional effort by Cooperative Extension to educate the public and to stimulate communication among scientists should have substantial payoffs.

A conference such as this one provides a stimulus for investigators to summarize and present what they know. This resembles a one-time marketplace where those who demand technology can meet those who supply it. However, delivery of technology requires regular, recurrent, and varied markets. Someone or some group should sponsor frequent, and certainly less formal meetings on timely topics related to hardwoods.

Gaining Support

The seventh precept points to the essentiality of gaining high-level support for a hardwood RD&A program. Such a program cannot grow or be focused without additional funding. Highly placed decision makers control the relevant purse strings. They must be convinced to redirect people, funds, and other resources from elsewhere or to provide them from new sources. Building on the enthusiasm and support for hardwoods generated by this conference, a small group of forceful proponents for hardwoods should lobby and otherwise exert influence to finance needed RD&A programs.

SOME NEEDED ACTIONS

Several missing or inadequate functions need attention. The paramount need is for a continuing organization that would oversee and support a wide variety of interests related to hardwoods, including research and extension. Such an organization would need to meet annually or biennially. Perhaps someone or some group will come forth after this conference to build such an organization. Are enough people concerned about hardwoods to create an action organization? Let me suggest that the Southern California Watershed Fire Council, the Forest Vegetation Management Conference, or the California Forest Pest Action Council might serve as models for action. Will anyone here set up an organizational meeting of a California Hardwood Council?

Returning now to my first precept, someone or some group periodically should identify and assign priorities to problems related to hardwoods in the state. My proposed hardwood council would be ideally situated to identify and prioritize problems for attention by people in research and extension.

Second we must have a current managerial information system for research and extension on hardwoods. Such a system would identify who, at what location, is spending how much to work on each species or problem. It might also list significant output from the total RD&A effort, including publications, demonstrations, and training. My estimate is that an elementary system--only for hardwoods and utilizing telephones, mailed questionnaires, and microcomputers--would cost about $15,000 annually. Would any organization be willing to provide such sums during a four- or five-year period of development and trial?

Information analysis for hardwoods needs specific attention. Gathering, evaluating, summarizing, and repackaging available technology related to important problems facing us today should have our highest priority. I submit that organizations that use or want such repackaged technology should commission recognized authorities to analyze information pertaining to hardwoods.

Coordinating and focusing scattered, inadequate efforts is another major need. Having been around scientists for many years and knowing the difficulties associated with redirecting their work, I am not hopeful of redirecting much effort. However, what can be done should be done by supplying incentives--big carrots, meaning money, and small sticks.

The last need I would identify is for more effort in extension. As I judge our current situation, applying available technology is relatively more important than conducting more research and development. From my perspective, I see a severe imbalance. Many people produce technology through research and development and too few put it into practice. I would favor a significant expansion of specialists and advisors in Cooperative Extension concerned with both hardwoods and conifers.

CONCLUSIONS

Several functions need to be provided or improved if we are to have an adequate program of research, development, and applications directed at hardwoods. Individuals, groups, and organizations should commit specific efforts to the hardwood cause. Participants at this conference need to make the case for more attention to hardwoods. Lobbying will be necessary if hardwoods are to receive increased financial support for RD&A. Volunteers should come forward or be tempted with monetary carrots to analyze available information about hardwoods and to build systems for tracking what is going on in research, development, and application efforts. Most important, people should be brought together regularly and frequently to talk about problems and to exchange information. Annual or biennial meetings of a California Hardwood Council should be organized to help meet these needs.

REFERENCES

California State Board of Forestry. California hardwood resources: preliminary report of the Hardwood Task Force. Sacramento, Calif., 1983 December. 67 p. + Appendix.

California State Board of Forestry. Forest and rangeland research in California: interim report by the Research Advisory Committee. Sacramento, Calif., 1986 October. 77 p.

California State Board of Forestry. Wildland research program needs and policies for California: report by the Standing Advisory Committee on Research Programs. Sacramento, Calif., 1979 June. 82 p. + Appendix.

Callaham, Robert. Z., tech. coord. Criteria for deciding about forestry research programs. Gen. Tech. Rep. WO-29. Washington, DC: U.S. Department of Agriculture; 1981 July. 52 p.

Callaham, Robert Z. Managing for application, not just for research and development. J. For. 82:224-227; 1984 January.

Callaham, Robert Z.; Hubbard, Richard L. Evaluation of research achievements by an experiment station. Final Report. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1984. 39 p.

Griffin, James R.; McDonald, Philip M.; Muick, Pamela C. California oaks--topical outline and bibliography. Bibliographies and Literature of Agriculture. Washington, D.C.: U.S. Department of Agriculture. Accepted for publication, 1986.

Muick, Pamela C.; Bartolome, James W. Research studies in California related to oaks. Berkeley, Calif.: University of California, Wildland Resources Center; Report 7; 1985 May. 37 p.

Passof, Peter C.; Clawson, W. James; Fitzhugh, E. Lee. Preliminary guidelines for managing California's hardwood rangelands. Berkeley, Calif.: University of California, Cooperative Extension; 1985. 92 p.

Plumb, Timothy R., tech. coord. Proceedings of the symposium on the ecology, management, and utilization of California oaks, June 26-28, 1979, Claremont, Calif. Gen. Tech. Rep. PSW 44, Berkeley, Calif.: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980 November. 368 p.

Standiford, Richard B.; Ledig, F. Thomas; techn. coord. Eucalyptus in California. Gen. Tech. Rep. PSW69. Berkeley, Calif.: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1983 June. 128 p.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Developing an Educational Program to Address the Management of California's Hardwood Rangeland[1]

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Abstract: Paper traces the development of the University of California's efforts to produce educational programs addressing the management of oak grass woodland over the past 35 years. It mainly focuses on current efforts under the new Integrated Hardwood Range Management Program including the UC Hardwood Range Manual, "Preliminary Guidelines for Managing California's Hardwood Rangelands." A four point educational strategy with several program goals, is offered as part of future University planning.

For the last 35 years the University of California (UC) has been in the forefront in developing educational and research programs oriented toward the management of hardwood rangeland. In 1951, the UC Hopland Field Station, in southern Mendocino County, was purchased in response to the perceived need that little field work had been done on range management problems. Concern for the multiple uses and values of rangelands was raised in the original report requesting the establishment of the facility. This same report called for a coordinated effort among University staff and suggested that the effort to increase the productivity and condition of California rangeland would take considerable time (Murphy, Love, and Weir 1976).

Soon after Hopland Field Station was established, UC scientists developed tree and brush management techniques to improve range production. Chemicals were evaluated for their usefulness in controlling woody vegetation. Thinning trees by chemical frilling was found to be economically feasible and to increase forage production. These techniques, and others, were effectively extended to other parts of the state. The Agricultural Stabilization and Conservation Service saw the value of these cost-efficient range improvement practices and offered incentive payments to ranchers who wished to voluntarily participate in the federally-sponsored Agricultural Conservation Program. An accurate statewide estimate of oak woodland acreage which was treated and cleared beginning in the 1950's is difficult to obtain due to the lack of complete records. We can conclude that the University's early efforts to educate ranchers and land managers about the usefulness of chemicals in controlling woody vegetation was indeed successful. Many thousands of rangeland and brushland acres were treated and made more productive in response to the ranchers' desire to increase livestock carrying capacity. These early educational efforts focused on improving forage production and thus there was little or no incentive to leave significant numbers of trees. It is important to note, however, that these early UC efforts never recommended complete removal. In fact, reviewing some of the early Extension leaflets shows that leaving "some" (exact value not recommended) trees for shade and esthetic value was recommended in the mid 1950's long before heightened public environmental awareness of the late 1960's and 1970's.

Earthday, in 1970, and increasing energy prices in 1973 resulted in wood and wildlife values taking on more importance. Individuals wishing to be more energy self-sufficient started to heat their homes with fuelwood. Increased demand for firewood was met with increased prices. Instead of eliminating trees in favor of forage, more selective harvesting methods began to capitalize on firewood and wildlife values. Trespass fees for visitors to hunt deer and quail began to be recognized as a new form of income.

In 1979, the USDA Forest Service recognized this emerging land management trend and sponsored a symposium in southern California. It brought together over 200 people to discuss current and past knowledge about managing and utilizing California's oaks. The published Proceedings (Plumb 1979) has continued to serve as an important reference to those seeking answers about oak trees.

As most know by now, the California Board of Forestry created a Hardwood Task Force (HTF) in 1983 and asked that it study and prepare a report in response to several emerging issues being raised by the public. The HTF concluded that more education, research, and regulations were necessary in order to remedy a number of perceived problems (Pillsbury 1983).

Beginning in May, 1983, Cooperative Extension (CE) conducted several inhouse training sessions for the benefit of its livestock and range farm advisors, to acquaint them with current information on the advantages of multiple use management of hardwood rangeland. In early 1985,

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UC was encouraged to develop a fresh, new educational approach and a well coordinated research program in response to the HTF's recommendations. The University was also asked whether its efforts would effectively mitigate the need for new regulations directed at the owners of hardwoods. Such regulations are problematic because the State's livestock interests are strongly opposed to any restrictions which would infringe on their ability to manage the land as they see fit. The issue then was whether the University could design and implement an aggressive educational program which would effectively appeal to landowners so that they would voluntarily comply with best management practices also acceptable to a broader public.

AN INTEGRATED HARDWOOD RANGE MANAGEMENT PROGRAM

The University decided to accept this interesting challenge and prepared a comprehensive document calling for a phased approach in both education and research (Passof and Bartolome 1985). The proposal was designed after UC's highly regarded Integrated Pest Management program, which called for an interdisciplinary approach to problem solving and involved specially trained field researchers. The IPM program has been considered successful because personnel from both the Agricultural Experiment Station and Cooperative Extension have worked together to find compatible (integrated) solutions to many pest problems affecting several important crops. These findings have been well documented in excellent pest management manuals which are used daily by farmers and licensed pest control advisors.

Our Integrated Hardwood Range Management Program called for an immediate redirection of effort on the part of UC personnel to begin the process of assembling information on what we currently knew about oak woodland management and translating it for the benefit of users. Two publications were produced last year in response to this internal mandate. Muick and Bartolome (1985) prepared a summary of past and current research studies related to oaks. The report provides comprehensive information on who the researchers are and what they're doing as well as an estimate of their funding levels. The second publication, titled "Preliminary Guidelines for Managing California's Hardwood Rangelands" (Passof, Clawson, and Fitzhugh 1985) was mainly designed to assist ranchers in the multiple use management of their oak woodlands.

A longer term phase of the program called for a 10 year plan of extension and research activities focused on those management problems having high priority. The plan called for new Extension positions at campus and field locations. It also recommended an applied field research program based on a competitive system in which individuals, agencies, and educational institutions could submit projects for consideration. The proposal received administrative endorsements from the University of California and the Department of Forestry (CDF). As it worked its way through the political process, the Integrated Hardwood Range Management Program received authorized first year (FY 1986-87) expenditures of $1,000,000 by the University and CDF. CDF's portion ($350,000) was only funded for one year with opportunities for more monies pending successful results. Hence, it was decided that the CDF only would handle short term research and demonstration projects. The UC portion was funded for a 10 year period, and thus would handle the hiring of new staff as well as carry the longer term research projects. A general Policy Advisory Committee comprised of broad interests was jointly appointed by UC's and CDF's top administrators. The Committee met in May, 1986 to review the current status of various hardwood range research projects and prioritized several new projects for Fiscal Year 1986-87.

HARDWOOD RANGELAND MANUAL

Since the purpose of this paper is limited to a discussion of our educational efforts rather than research projects, let's now discuss the UC hardwood rangeland manual which was prepared for ranchers and professional resource managers. Its main theme, "Preserve Your Options," suggests that resources such as wood, wildlife, water, etc. will gain value in time. By setting up a management plan which provides for the leaving of some trees for the enhancement of wildlife and riparian areas, the owner may be giving up short term income prospects in favor of larger profits in the future.

The manual's guidelines are advisory and have no legal standing. The authors tried to focus on those practices which make economic sense to the owner. For example, emphasis is placed on the management of several game species (deer, turkey, wild pig, and quail) for recreational hunting to gain needed income. While there may well be opportunities to capture income from other recreational pursuits, i.e., birdwatching, camping, hiking, and photography, these are not dealt with in the publication. If tree regeneration is desired, the manual suggests that protecting oak sprouts from animal damage may be more practical than attempting to plant seedlings or acorns.

The manual attempts to offer useful management recommendations based on the physical location of the property and three site specific factors: principal oak species, slope, and degree of canopy cover. Once defined, each site description contains information on potential wood, wildlife, and forage productivity as well as a multiple use management (MUM) index rating. This index may be used by the owner to prioritize management activities on land units. As an example, in the Central Coast counties, a dense live oak stand on a gentle slope has a much greater total income opportunity for an improvement thinning (MUM=8) than a very open blue oak stand existing on a slope over 30 percent (MUM=3).

The manual also provides useful information on estimating the volume of wood in oak stands, guidelines for marking oaks to cut or leave, how to conduct a firewood operation, acorn data, ideas on ways to regenerate oaks, wildlife relationships, livestock relationships, and sources of assistance. In addition to being a compendium of information which previously was scattered among several sources, the manual's strong point is its ability to bring together a multiple use philosophy option for the owner. In assessing its educational value, the authors hope that it inspires owners to develop a more site specific ranch management plan. Ideally, those owners having such a professionally prepared plan would be in a better position to cope with changing economic, social, and technical conditions.

Nine months after its release, one thousand copies of the manual were distributed to landowners and resource managers throughout the state. An evaluation questionnaire was prepared and distributed by CE to a representative sample of the people who received a copy of the manual. Results obtained from this investigation will be very helpful in redesigning a second edition planned for the future. Although it may be too early to adequately assess the usefulness of the publication, UC was anxious to demonstrate its desire to evaluate its effectiveness in reaching clientele with educational materials. Based on the immediate criticisms received from respondents, training programs will be revised.

Clearly, the manual has some weak points which need improvement. It tends to ignore site-specific soils and weather information in developing predictions for wood and forage production. The manual tends to reflect a statewide or shotgun approach which needs more local focus. Currently we are encouraging our county based staff to develop more site-specific recommendations by working closely with local ranchers and cooperating agencies.

Cooperative Extension's traditional clientele usually look to the "bottom line" before deciding whether or not to adopt a new practice. The manual only offers broad economic data to assist the rancher in developing management alternatives. It's apparent that we need to have better benchmark data before we will see ranchers willing to make noteworthy changes in their operations.

The manual has already been used in a number of worthwhile educational projects. Inspired by the manual, a Butte County rancher asked the local livestock farm advisor for help in setting up a firewood sale. The farm advisor contacted CE forestry and wildlife specialists to assist in the marking of the trees to be harvested. Special wildlife corridors were provided and those trees having excellent acorn production identified. Thinning of the remaining trees was done with an eye toward harvesting about 5 cords/acre. Income from the sale of firewood was to be used to offset range improvement costs such as seeding and fertilization. The manual's guidelines were followed to achieve benefits for wildlife habitat, wood, and forage production. Less than a year following the start of the project, Farm Advisor Bob Willoughby hosted a field meeting to show local ranchers and residents the results of the study. The rancher now intends to use the principles demonstrated on the 10 acre site for additional fuelwood harvesting this year.

Information contained in the manual was made a part of a series of press releases to local media in Tehama County in a cooperative effort by CE, CDF, the Soil Conservation Service, and the California Department of Fish & Game (DFG). The resource professionals saw a need to convey factual material to the ranching community and the general public about multiple use management opportunities. In Madera County, Farm Advisor Neil McDougald is using the manual in conjunction with the local Range Improvement Association's control burning projects. Individual sites are classified and photographed prior to the controlled burning and then followup measurements and photos are to be taken after the treatment. This study will track the response of woody vegetation, forage, wildlife, and livestock following a range improvement burn.

OTHER EDUCATIONAL EFFORTS

Other educational efforts on the part of UC include a statewide survey of oak woodland owners to determine their management practices and attitudes about oaks (Fortmann and Huntsinger 1986). The results of this survey are discussed elsewhere at this symposium.

Federal dollars from the Renewable Resources Extension Act are funding a comprehensive type-mapping of oak stands in Calavaras County and following up with a local survey of landowners. The data base is derived from county Soil-Vegetation maps and the Assessor's records. This type of information will be most helful in designing and directing a localized educational program, and will show the usefulness of the Soil-Veg approach to other areas. Impressed with the results of a Colorado study involving esthetic values associated with several conifer stocking levels, UC initiated a similar venture utilizing various photographic scenes of blue oak trees (Colorado Forest Service). Realty experts from Ukiah and Santa Rosa, California were asked to provide appraised land values for small parcels having few to several trees/acre. Results from this pilot effort are included at this symposium. UC believes that once a landowner understands the additional dollars which a few oaks may bring to a property, there will be less economic incentive to clearcut all the trees.

CE personnel publish many newsletters. They're an excellent way of reaching people who may be living long distances from, and out of direct reach of, the professional. In early 1986, events were starting to rapidly occur in terms of the Integrated Hardwood Range Management Program. It was decided that an educational newsletter focused on up-to-date information was needed to start networking with people interested in oaks. Titled "Oaks 'n Folks," the newsletter has produced one issue mailed to about 250 readers and has already had more than 50 requests from people wishing to be placed on the mailing list.

CURRENT PLANS

Up to this point, discussion has centered on our past accomplishments of working with traditional clientele groups. As previously mentioned, the Integrated Hardwood Range Management Program was envisioned as a fresh, new approach to education. We soon decided that the Program required statewide visibility but also needed to be responsive to the local situation. We could not afford to put new people into every county with significant hardwood range acreage. We opted for five Area Natural Resource Specialist positions and found one farm advisor willing to redirect his program to a sixth area. Our position vacancy announcements emphasized the need for a strong multi-disciplinary background plus good research and communication skills. These Specialists have been hired and are now on the job. They will be called upon to provide special expertise in wildlife, range, and woodland management. By working with local farm advisors, professional resource managers, local government, ranchers, small "ranchette owners", and environmental interest groups, the Area Specialists will become the focal point for applied field research projects, demonstrations, and other significant educational activities.

Allow me to introduce you to each member of this new Hardwood Range Team. Starting here in San Luis Obispo County, we have Bill Tietje, who has an academic background in wildlife management and some prior experience with Wisconsin's Cooperative Extension. He will be covering the central coast counties. Bob Schmidt is stationed at the Hopland Field Station and will cover the north bay and north coastal counties. Bob's background is in integrated management of vertebrate pests. Doug McCreary is a forestry regeneration specialist and will be stationed at the Sierra Foothill Range Field Station east of Marysville. Doug will be handling the north Sierra counties from Yuba to Shasta. Next is Bob Logan, another forester, with 10 years of Extension experience in Oregon. Bob will cover the "Mother Lode" counties that extend from Nevada to Mariposa. The next member of the team is Neil McDougald, CE's existing range livestock advisor in Madera who will redirect a part of his program to the south Sierra counties. Tom Scott will cover the southern California counties from his office on the Riverside campus. His background is in wildlife management and he has had previous work experience in local planning in San Diego County.

So what's new and fresh about this approach? The program makes a strong commitment to working with non-traditional clientele groups such as the small, absentee oak-woodland owner, woodcutters, real estate developers, and groups of environmental activists having a special interest in protecting oak-woodland resources. There is some evidence to suggest that CE personnel believe that much of the public outcry about oaks has developed in response to the activism of certain environmental groups. Regardless of this perception, it also appears that CE staff have not made a significant effort to contact environmentalists and learn more about their concerns and how our educational approach can address these concerns. This is indeed a problem that will demand our time and attention.

Over the years, Cooperative Extension personnel have functioned as professional educators prepared to respond to any requests. In terms of our new effort, CE, where it is appropriate, will be taking a more aggressive stance, and not necessarily waiting in the wings for an invitation to participate.

AN EDUCATIONAL STRATEGY

So here we are, four plus months into a new educational program which addresses the management of California's hardwood rangeland. Let's briefly discuss our four point educational strategy for the future:

1. We want to be able to convince most landowners, woodcutters, and developers that taking extra measures to leave and protect some minimum number of oaks is in their own best interest. This interest is undoubtedly economically oriented so we will have to clearly document how additional dollars may be either gained or saved by trying new alternatives. We intend to measure our progress in gaining acceptance for these concepts by a carefully planned monitoring program aimed directly as these clientele groups.

2. We also need to work with the general public and conservation groups to promote public awareness that multiple use management of oak woodland means sustaining all of the resources on hardwood rangeland. It's fine to harvest oaks and game species and graze the available forage, but not to excess. We recognize that there is a legitimate concern for items such as a lack of regeneration or critical wildlife habitat and will diligently work toward finding ways to mitigate these problems. Our goals here are to encourage more public participation in community oak tree plantings,

as well as expand the availability of nursery-grown oak seedlings. With new research, we want to demonstrate methods that significantly increase oak regeneration. We want to be able to assist local planning groups in redirecting subdivisions away from areas of special concern.

3. Recognizing that there will soon be new information on all aspects of hardwood range management, we will incorporate that data into a revised manual which offers the rancher additional guidelines. Already underway is a new project to develop an educational brochure directed to those landowners having small wooded tracts. These people are not interested in livestock/forage production or selling trespass rights for hunting. We strongly suspect that this type of clientele wants information on ways to enhance and protect the oak resource because of its pleasing esthetic value. By this time next year, work on the manual revision will be well underway with the new version ready about July, 1988. Our time schedule to publish and distribute the brochure aimed at the small tract owner is July, 1987.

4. We all know the educational job is not over when the publication is handed to the reader. We need to be able to evaluate our efforts which means we have a responsibility to constantly monitor evidence of change in attitudes, behavior, and practice among our identified clientele. This will be a most difficult task but absolutely necessary. We all want to know if education can be an effective substitute for regulation. Much interest and many dollars are riding on our results. CE has made significant strides in other areas in affecting changed management practices. For example, in 1978-79, CE identified ground squirrels as a major pest of almonds. In Kern County, economic losses exceeded $378,000. Field trials conducted by CE led to the registration of aluminum phosphide as a burrow fumigant. CE then extended that new information by the use of meetings and publications. By 1985, CE estimated that Kern Co. growers had reduced crop damage from ground squirrels by 80 percent, thus representing an annual savings of over $340,000. In addition, aluminum phosphide is now being used in 70 percent of the State's counties.

   As another example, CE discovered 10 years ago that less than 10 percent of the treated wood found in retail yards met industry standards for preservative treatment. Unsatisfactory durability results in construction failures, high replacement costs, and losses due to serious injury. In response to this problem, CE conducted intensive applied research, prepared publications, and held meetings for the benefit of varied clientele with the objective of increasing the percentage of treated wood products meeeting industry standards. By 1984, compliance was close to 100 percent and due to this successful research and educational effort, users of pressure treated wood products in California save $6,500,000 annually.

We have set several five year goals for this program. Allow me to briefly share a few of them with you so you can see where we are heading.

* Practical techniques will be readily used to protect young oaks from damage or mortality, thus improving regeneration.

* Many communities will be conducting oak planting activities thus building public awareness toward maintaining oaks.

* The DFG's "Ranching for Wildlife" program will be as well accepted as the CDF's Vegetation Management Program.

* Resource professionals will be routinely employing special maps and computer models when planning wildland projects.

* Expansion of intensive agriculture and subdivisions into hardwood range areas of special concern will be insignificant.

* Multiple-use management of hardwood rangelands will have a much greater recognition by the public and private sectors.

* Underutilized hardwoods such as tanoak and exotics will find a greater share of the California firewood market.

In conclusion, UC has put together a well conceived educational strategy which is designed to address many of the issues raised by the Hardwood Task Force. It has taken us almost three years of planning to bring our new people on board and to get many projects underway. Experience shows that it may take several more years before users will adopt a new idea and put it into practice. We want both to try to reduce this time period and to request the assistance of the broader community in accomplishing this goal.

REFERENCES

Colorado State Forest Service. Dollars and sense about your trees. Undated pamphlet. 17 p.

Fortmann, Louise; Huntsinger, Lynn. California's oak lands: owners, use, and management. Dept. of For. and Res. Mgt., Univ. of Calif. Berkeley, Calif. January, 1986. 78 p.

Muick, Pamela C.; Bartolome, James W. Research studies in California related to oaks. University of California Wildland Resources Center, Report No. 7. 1985. 37 p.

Murphy, A.H.; Love, R.M.; Weir, W.C. Building a research program:1951-1976. California Agriculture. Univ. of Calif. Div. of Agric. Sciences. 30 (7):5-6. July 1976.

Passof, Peter C.; Bartolome, James W. An integrated hardwood range management program. University of California Wildland Resources Center, Report No. 6. 1985. 18 p.

Passof, Peter C.; Clawson, W. James; Fitzhugh, E. Lee. Preliminary guidelines for managing California's hardwood rangelands. Univ. of Calif. Pub. 21413. 1985. 92 p. illus.

Pillsbury, Norman., chair. California's hardwood resource. Preliminary report of the Hardwood Task Force. State Board of Forestry, Sacramento, California. 1983. 67 p.

Plumb, Timothy R., tech. coord. Proceedings of the symposium on the ecology, management, and utilization of California oaks. June 26-28, 1979. Claremont, California: Gen. Tech. Rep. PSW 44, 368 p., illus. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Dept. Agric. Berkeley, CA.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Forest Landowner Motivation and Identification in the Central Coast Area of California[1]

Timothy O'Keefe, Bill Weitkamp, and Ben Parker[2]

Abstract: The California hardwood resource is most widely owned by private landowners. In most cases, these landowners are primarily concerned with livestock or agricultural use of the land. On most of this land the oak and other hardwoods have frequently been ignored and often subject to systematic removal. However, as beef prices have declined in recent years, some ranchers are beginning to recognize the value of the oak resource. More of the hardwood resource is being exploited for fuelwood. Some of these hardwood stands are being managed by owners, but, unfortunately, many stands are totally unmanaged.

In order to correct this hardwood management problem in the Central Coast area, a joint continuing education program has been developed for landowners. This program, intended to bring basic management information to forest landowners, was sponsored by the Cooperative Extension Service (CES), the California Department of Forestry (CDF), and the Natural Resources Management (NRM) Department at Cal Poly, San Luis Obispo. These programs have included both evening lecture/discussion sessions and Saturday field trips. During the past two years sessions dealing with fundamental management, wood energy, and Christmas tree management were conducted in the San Luis Obispo area. On the average, about 30 landowners participated in each session.

Program development for these forest landowner workshops was based on marketing principles of audience identification and a "triage" for resource allocation. All program evaluations indicate an increased level of resource awareness and management interest. On this basis, the seminar coordinators feel confident that there has been significant program return, in terms of landowner awareness and management activity. Landowner interest and management activity in this Central Coast area has increased significantly.

On a national basis and throughout the State of California, the question of motivating non-industrial, private forest landowners to undertake better management practices is a continuing dilemma. The use of information/education workshops to motivate forest landowners is not in itself a new approach. For many years, such landowner workshops have been used throughout the country and throughout much of California with varying degrees of success. However, until recently, no such forest landowner workshops had ever been offered in the Central Coast area.[3] In 1984-86, the series of landowner workshops which were jointly sponsored by the Natural Resources Management Department, (Cal Poly), University of California Cooperative Extension, and the California Department of Forestry, San Luis Obispo, represents a local pioneering effort. Thus far, a total of three landowner workshops, with different themes, have been presented in the Central Coast area.[4] Each of these workshop efforts have been successful, and landowner reaction has been very positive.

The purpose of this paper is to describe these workshops, the workshop results, and a useful system of forest landowner audience identification.

WORKSHOP STRUCTURE

Thus far, there have been three workshop programs, each on a different theme, in this Central Coast forest landowners workshop series. Each workshop has been organized the same way, based on two evening programs during each week separated by a Saturday field trip. Thus far, this organization of time and scheduling seems to have the widest audience appeal. More detailed consideration of audience characteristics will be developed in the section dealing with forest landowner identification.

Each workshop, scheduled about a year apart since 1984, was designed around a different theme in order to attract a wide variety of participants. In sequence, these themes were (1) General Woodlot Management, (2) Fuelwood Management, and most recently (3) Christmas Tree Management. Each of the evening programs were developed on the basis of half-hour

[1] Presented at the Symposuim on Multiple-Use Management of California's Hardwood Resources

[2] Professor of Forest Resources, California Polytechnic State University, San Luis Obispo; Cooperative Extension, California Polytechnic State University, San Luis Obispo; California Department of Forestry, San Luis Obispo.

[3] Personal discussion with Mr. Fred Frank, CDF, San Luis Obispo.

[4] Central Coast Area of California for this workshop series is limited primarily to San Luis Obispo County.

lecture topics and panel discussions. In addition, in all presentations there was a heavy use of A-V materials, like slides and films. Throughout each evening program, restricted to about three hours in total length, audience questions and participation were encouraged. In addition, a coffee break was provided in the middle of each evening program and prior to each field trip, in order to encourage participant interaction.

Specific workshop discussion topics included such items as tree identification, woodlot improvement, harvesting techniques, management for wildlife and recreation values, fuelwood measurements, oak and eucalyptus management for fuelwood, marketing, regeneration, and Cristmas tree management and marketing. The workshop instructors, all working on a volunteer basis, were drawn from Cal Poly, CDF, locally and Sacramento, and Cooperative Extension, locally and from other parts of the State.[5] The cost of mimeographed reference material for workshop participants was covered by a small registration fee, or on a direct sales basis, through the Extension system.

The Saturday field trips, which were about five hours in length with a lunch break, were all developed around a series of three or four visits to local landowners designed to illustrate a particular management strategy or problem. The informal, unstructured nature of these field trips was particularly helpful in providing a forum for active participant discussions. Based on participant reaction, it is evident that a great deal of informal learning takes place as a result of participant discussion and exchange.

For each workshop there was an average of about 30 participants who came from communities that included San Miguel on the northern part of the county, to Santa Maria just over the southern county line. As a result of several month's planning prior to each workshop, the technical programs were generally well constructed and well presented.

Publicity for the individual workshops covered a range of activities. News releases were sent to all local papers in the county and in some adjacent counties. In addition, articles about the workshops also appeared in the Farm Bureau newsletter, and direct mail notices were sent to a local county list of about four hundred.

Workshop evaluations were developed on both a formal and informal basis. Informally, after different program segments, direct discussion with participants provided a great deal of useful and very timely evaluation. On a formal basis, a written evaluation was developed for each workshop. Evaluation results, both formal and informal, showed high participant satisfaction with almost every program element. Depending upon the individual style, some topics were rated more favorably than others. Almost all elements of every field tour were rated very helpful. Most participants expressed strong interest in longer and more frequent workshop programs. In addition, both professional foresters and resource managers who attended the workshops as participants or instructors were equally enthusiastic. In total, the summary evaluations indicate that this first series of Central Coast forest landowners workshops was indeed successful and very well worth the collective effort and time involved in developing and presenting each workshop.

FOREST LANDOWNDER IDENTIFICATION

The structure of a forest I&E (Information and education) program is, in part at least, a marketing process. For this reason, in order to generate a successful program, it is important to understand and to apply some basic marketing strategies. The success of this Central Coast woodlot workshop series is based on the following two concepts:

1. Clear and specific audience identification.

2. Application of the "triage" procedure.

The process of audience identification was based on experience and the use of workshop evaluations. In addition to workshop evaluations, profile information was developed from a participant interest questionnaire.[6] The results of these questionnaires can be summarized as follows: in terms of size of landownership, about half of the participants were medium size owners with 10 to 100 acres, and about 1/3 were small land holders, with less than 10 acres. Other factors, such as age, income source, education level, and land tenure were also considered. Based on this survey, it seems clear that the "average customer" for woodlot seminar information is actually two different kinds of individual:

1. an older, more experienced, long term resident on larger land holding with a goal to manage the land for profit and possible speculation, and
2. a younger, less experienced, short term resident on smaller land holdings, with mixed (management or aesthetic/recreation) goals.

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[5] Special thanks is due to staff and faculty of CDF, CES, and NRM/Cal Poly who donated time and energy to make the Workshop series so successful. Mr. Mike DeLasaux, NRM/Cal Poly, was particularly helpful in Workshop organization and presentation.

[6] Developed in Spring 1986, NRM Wood Energy Class, FOR 438; students G. Thompson, L. Mello, and B. Layton.

On this basis, it is clear that successful forestry workshop programs in the future must be developed around program elements that will address the interests and goals of both participant types. For more information about the results of this participant survey, refer to Appendix A, Summary, Result of Survey Central Coast Forest Landowner Workshop Participants.

In addition to the marketing concept of "know thy customer", there is also another important strategy that can be used to predict results when a specific target audience is developed. On the basis of workshop experience and participant evaluation, it is clear that the "triage"[7] principle can be used to develop a target audience concept in connection with the potential audience for this forest landowner workshop series. The marketing application of triage is usually defined in three groups, as follows:

1. High order clients; individuals who will take the initiative to obtain information on their own with little or no additional attention.

2. Medium order clients; uncertain individuals that require a great deal of time and attention. These individuals will potentially manage the woodlot area, but probably only with external help and/or incentives.

3. Low order clients; those individuals who have little or no potential for information transfer efforts; low interest and motivation.

On this marketing basis, it is clear that a most productive strategy will involve concentration of time and effort in that second category of medium order clients. It is in the medium order of potential clients where obviously the greatest return on effort will be realized

In a similar way, it is possible to target various segments of the potential woodlot audience, using this triage system. For example, some individuals who participate in these forest landowner workshops are clearly "sold" on the concept of forest management. These individuals represent a first level or high order in this triage application. In the case of these individuals, very little additional information or assistance is needed. They are selfmotivated and will continue to seek out and to implement available forest land management strategies.

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[7] The "triage" concept is derived from the French military medical system for classifying military casualties for treatment priority, based on survival probability. This concept has been applied to marketing in audience classification and is used here in those terms.

At the other end of the triage, there are also some individuals who have little or no interest in any type of sustained forest land management. Many of these individuals seem to be looking for a "get rich quick, with little effort" system to solve their land management problems. Therefore, it is most unlikely that any serious information or education program will motivate these individuals to undertake a sustained forest management effort. For this reason, spending any amount of I&E resources on this category of individuals is not likely to be very productive. However, it is important to note that the application of woodlot I&E effort to this low order group may be justified in order to save these individuals from waste of time, money and land on poorly designed woodlot activities.

However, the large intermediate group of land owners that fall in the middle of our triage represents, obviously, the most productive segment of our potential woodlot owners audience. These are the individuals who lack information but do have genuine interest in developing some sustained, long range forest land management. For this reason, the application of relatively scarce I&E resources made in this intermediate category of individuals is most likely to produce a relatively high return on investment of time and effort.

Of course, application of triage in this marketing sense will not solve all the problems of either audience identification or development of the target elements from the full potential audience. Use of this triage marketing concept represents only one tool or technique for audience analysis that can be helpful for a workshop planning job.

SUMMARY AND CONCLUSIONS

In the Central Coast area, recent experience indicates that the workshop format is a useful way to bring technical information and motivation to forest landowners. As a guide for planning future workshop programs, the limited participant data now available does provide the basis to develop an audience profile. In addition, development and use of the triage marketing concept will also be a helpful workshop planning technique that will enable planners to focus more specifically on the most productive target segment of the general audience.

The workshop organization and technical presentations all seem to be meeting audience needs and interests. However, further planning work will be needed in the future to select additional topic themes for future workshops. In addition, as more experience with various workshop programs is accumulated, it is likely that some changes in format and presentation will be made. For example, if experience demonstrates a substantially new audience each year, it may be useful to move into a "carousel"[8] format. Another change in future workshop format may involve video taping each workshop, for later presentation, in half-hour segments on a self-learn basis. Of course, this change in workshop format and presentation will require additional time and funding, which must yet be developed.

In summary, in the Central Coast area, the workshop format has been a useful method to inform and motivate forest landowners. Participant analysis continues to be an important element for workshop success and some future changes in workshop operations and format will probably increase the level of productive workshop results. Thus far, cost of these workshops to participating individuals and the general taxpayer has been very low. Therefore, based on participant response and workshop coordinators evaluation, it is clear that total workshop benefits have greatly exceeded cost. For this reason, the workshop format will continue to be a very important element in the full matrix of information programming for the forest landowner in the Central Coast area.

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[8] For a continuing turnover in workshop audience composition, a carousel concept is intended to provide a foundation of one basic woodlot management workshop each year, with one or more specialized workshops also offered during the year.

REFERENCES

Zelcheck, H. and O'Keefe, T. 1983. Another Way to Reach Small Woodlot Owners. Journal of Forestry.

APPENDIX A

Summary

RESULTS OF SURVEY CENTRAL COAST FOREST LANDOWNERS WORKSHOP PARTICIPANTS

1. Landowner types:	Approximate Percentages
a. large landowners - +100 acres; community residents over many generations	20%
b. medium size landowners - between 10 and 100 acres; frequently more recent land buyers	50%
c. rural/suburban landowners, with 1 to 10 acres; most frequently very new landowners.	30%

2. Age, income source and education

   a. Most of the smaller more recent landowners who are younger (under 40 years), obtained most of their income (+80%) from sources other than land management.

   b. Landowners with medium and large size holdings tended to be older and to obtain more of their total income from land management or land related business.

3. Social structure

a. Almost all participants were married and the family unit was an important part of the total land management strategy.	90%
b. Most participants were resident land owners.	95%

4. Economics and experience

   a. In the large and medium size landholdings, the objectives of most owners included management for profit and possible speculation.

   b. Many small landowners expressed similar objectives. However, a significantly larger number (about 70%) of small landowners are also interested in such land use goals as recreation/aesthetics.

   c. Practical land management experience was a characteristic almost totally in the medium and large ownership category; most of the small landowners (90%) had recently moved out of a more urban background.

5. Land tenure

   a. The highest length of extended land tenure (+30 years) was associated with the largest size land owner.

   b. For both the medium and small category of landowners, the length of land holding time was very similar. About 80% of the individuals in these categories had held the land less than 20 years.

More precise information about the workshop participants derived from this participant profile, will improve the design of future programs. In addition, as further details become available to allow a refinement of this participant profile, it will be possible to identify both the major audience elements, as well as missing elements of the full potential audience.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

The Hardwood Management Issue: County Perceptions of Use, Change, Problems and Regulation[1]

Norman H. Pillsbury and Julie K. Oxford[2]

Abstract: Senior planners for all 58 California counties were asked to respond to a series of questions about current hardwood issues. The purpose of the survey was to obtain data reflecting the attitudes and perceptions of county planners about use, change, problems and regulation of California's hardwoods.

County planners report that the greatest use of hardwoods is for wildlife habitat, and second, for commercial fuelwood operations. Most planners think the rate of change in future hardwood use will be low. When queried whether they perceive problems with the hardwoods, half answered that they do, while the other half were not aware of any problems.

If faced with regulation, planners felt that most of their citizens would prefer county control, while most planners themselves thought the State Board of Forestry should be the regulator.

The many issues in hardwood management and protection are important to both the owners and managers of lands where hardwoods grow. These issues are also important to the organizations and governments responsible for protection and management. Several important studies and reports have been completed in the past 5 years which provide pertinent inventory and assessment data, and summarize social, political and technical information about hardwoods. A brief description of the major reports follows. The California Board of Forestry has commissioned two task forces to study and examine a wide range of hardwood related topics. The first task force focussed primarily on hardwoods and their relationship to the forest practice rules (Cox, *et al* 1982). The second task force was charged to take a state-wide view of hardwoods in California including topics such as products, rules and regulations, rangeland and wildlife interactions, supply and demand, ecology, people pressures, research, and educational needs (Pillsbury, *et al* 1983). Based in part on the needs surfaced by the task force, an extensive study on the assessment and inventory of the state's hardwood resource has been completed by the Pacific Northwest Forest and Range

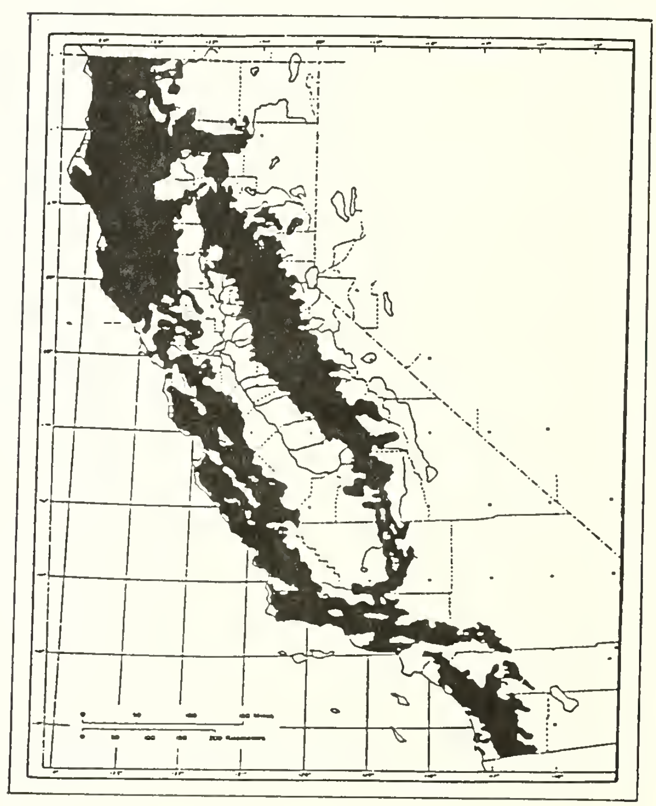


Figure 1 --- Geographic range of the major hardwood species in california.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

[2]Professor of Forestry and Department Head, and Graduate Research Assistant in the Natural Resources Management Department, respectively, California Polytechnic State University, San Luis Obispo, California.

Experiment Station, Portland, Oregon, by Bolsinger (in press). This report addresses important topics including ownership, acreage, regeneration, size, distribution and stocking levels. Also responding to the need for information, Fortmann and Huntsinger (1986) undertook a survey to examine how owners of oak woodlands manage their land and oaks and what factors influence their management decisions. And lastly, two recent reports to the California Board of Forestry by Mayer and others (1986) and Board of Forestry staff summarizes previous reports, provides an update of the status of the hardwood resource of California since the 1983 Hardwood Task Force report, includes a current list of hardwood information being developed, and developed a series of policy options.

One group which has not been contacted about their views on the hardwood issue is the county planners. The objective of the study reported here was to obtain information and insight into the views held by county planning departments in California. Because most counties in California have some hardwoods, (Figure 1), there is an increasing interest in their management and protection at the local government level. A few counties have passed or are planning to pass hardwood regulations. Because of the increasing interest at the county level, an important component of the hardwood management issue is the counties' perception about the resource and what, if any, concerns they have. This study investigates the perceptions counties have about hardwood use, change, problems and regulation.

METHODS AND SURVEY FORMAT

The purpose of the survey was to obtain data that reflects the attitude and perception of the senior county planner about several important aspects of the hardwood resource in California. Perception data was initially obtained by a questionnaire mailed to each senior planner of the state's 58 county planning offices. The senior planner was selected because proposals for guidelines or regulations of this nature would either be developed by the staff, or be analyzed with recommendations being made to the board of supervisors. Although the board of supervisors may or may not adopt their staff recommendations, they count on their planning department staff for background data and analyses. In addition to an initial mailing a follow-up telephone call was made to each county to informally discuss the questionnaire. The final response was 57 out of 58 counties or 98%.

SURVEY RESULTS AND DISCUSSION

Which counties have hardwoods?

Of California's 58 counties, all have some native hardwood trees and 71% have stands covering 5% of the county or more. Figure 2 shows the distribution of counties by the amount of hardwood forest they have.

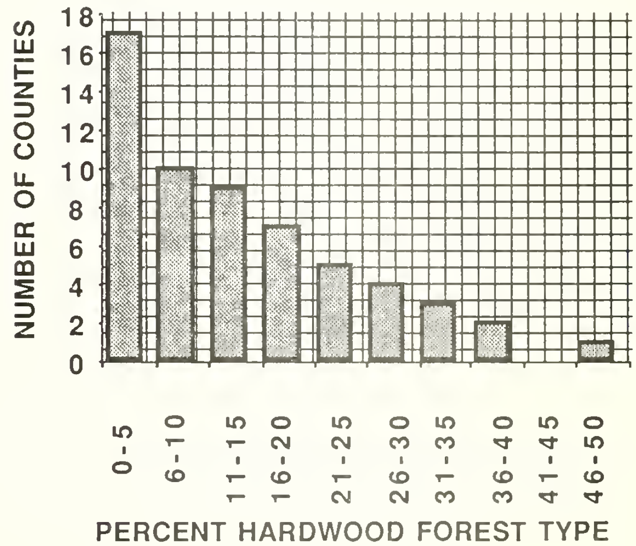


Figure 2 - Number of counties by percent hardwood forest type.

What do county planners think hardwoods are used for?

The uses they think the hardwoods have include, in ranked order, wildlife habitat, income from commercial firewood operations, various wood products, use for home burning only, and aesthetics.

The importance of each use was subjectively assessed and given a rating of low, moderate or high for each county based on information provided by the county planner. For example, of the 43 respondents who listed wildlife habitat as a use, 21 indicated it was of high importance while 13 and 9 rated it as moderate and low importance, respectively. The weighted importance of each use was estimated from a linear equation of the form:

$$Y = aX_1 + bX_2 + cX_3 \quad \text{Equation [1]}$$

where:

Y = weighted score of importance,
a,b,c = subjective weights of low, medium, and high ratings. Selected weights are: a(low)=1, b(moderate)=3, and c(high)=5.
Xi = number of counties of each rank, a, b, c.

The weights assigned to the three ratings are subjective and assume a rating of high (weight=5) is five-times more important than a rating of low (weight=1). Other weights were tested with similar results. The use of equation [1] more accurately assesses the relative differences among the 5 uses listed above. This relative difference is shown in figure 3 and indicates that the use of hardwoods for wildlife habitat is about twice as important as for income from firewood, which is about twice as important as using hardwoods for home burning, wood products or aesthetics.

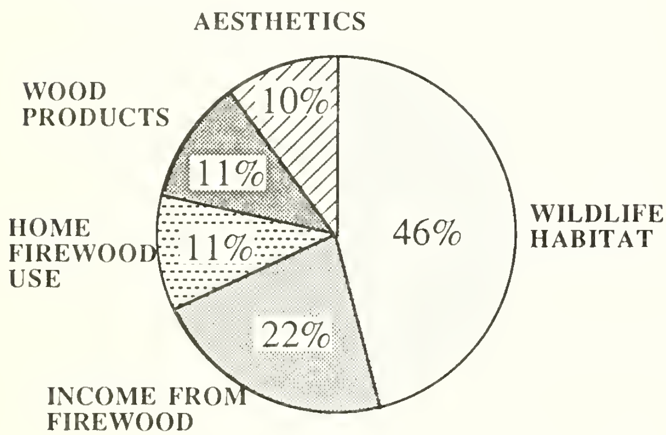


Figure 3--Relative differences among the importance of uses of hardwoods in California counties, based on equation [1].

The majority of the counties who said wood products was a use were from northern counties where the majority of tanoak and black oak is located, while the majority of the counties who said that hardwoods were important for aesthetics are those in other coastal areas or regions that include large cities. The use of hardwoods for livestock forage was not seen as important in any county.

To gather some information about the future rate of hardwood demand, we asked them how they would predict change in hardwood use occurring in the future.

When asked their views about the relative change in the rate of consumption or removal of hardwoods, somewhat over half (56%) thought the current level of demand for the trees or the land would change slowly, while 44% said that moderate or rapid changes in the current consumption rate would occur in the near future. Only 1 county planner suggested that the level of fuelwood demand was proportional to the cost of other fuels.

Do county planners see current problems with their hardwood lands?

County planners were asked if they saw management problems on their hardwood lands. Their response, shown in Table 1, was approximately equally divided between those that did and those that did not see a problem.

Table 1--Number of counties which have management problems on the hardwood lands.

County planner perceptions	Number of counties	Percent
No problems exist	27	47
Problems do exist	30	53

If it was indicated that problems do exist, they were asked to describe what they were. The most common problems listed were loss of wildlife habitat, stream damage, and surface erosion. A summary of problems described are shown in Table 2.

Table 2--Problems in hardwood lands as perceived by county planners.

Perceived problems in hardwood areas	Number of counties selecting response
Loss of wildlife habitat	13
Stream Damage and erosion	11
Theft/Vandalism	4
Water quality	3
Agriculture encroachment	2
Use of herbicides	1
Lack of regeneration	1

Note: Since more than one problem could have been given by each county planner, the number of responses cannot be summed.

While it seems probable that more than one county planner must be aware of the regeneration problems, lack of regeneration was mentioned only by one planner. Slightly less than half of the planners responding were not aware of any problems in their counties.

HARDWOODS AND REGULATION

To learn about views and perceptions regarding possible regulations of hardwoods several questions were asked.

First, we asked county planners what feelings they perceived the citizens of their counties had about possible regulation of hardwood cutting. The planners' perception of the county-wide attitude toward possible regulation showed that about one-half (47%) of the citizens of their counties would oppose them, compared to about one-fourth who thought their citizens would favor regulation. Nine county planners (16%) had no idea what their citizens might think while 8 (14%) recognized a split among their citizens but couldn't predict the majority view (Figure 4).

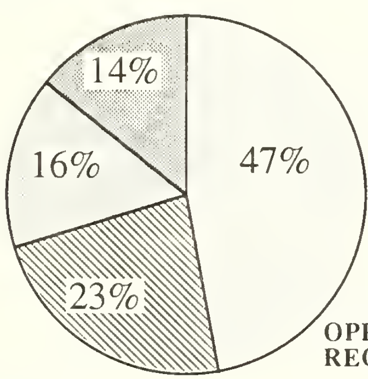


Figure 4--How county planners' perceive public attitude toward regulation.

Most county planners who thought their citizens would favor regulation are from coastal or high population counties. However those planners who thought their counties would oppose regulation include counties having both high and low population, and occupy both coastal and inland areas. If planners thought their citizens opposed regulation they were asked to list the reason(s) why.

Table 3--Reason that planners thought their citizens would oppose regulations.

Reason	Number of counties
1. Citizens opposed to organized regulation in general.	18
2. Citizens see no problems, therefore no need for regulations.	11
3. Citizens think other agencies are managing and regulating hardwoods and are doing fine.	2
4. Citizens think it is okay to regulate commercial conifer species but not other species.	1

Note: Since more than one reason could have been given by each county planner, the number of responses cannot be summed.

Planners who felt their citizens favored regulations felt that they did so because of concern about the issues listed in Table 2.

A follow-up question asked planners to assess who their county residents might choose to regulate hardwoods if regulations were adopted.

There was a lot of uncertainty on this question, but most felt that their citizens would prefer local county control, rather than state Board of Forestry control, by a margin of about 7% (46% county to 39% state). About 15% thought their citizens had no preference about who should regulate the resource but rather it would depend on the specific circumstances.

Table 4--County planners' perceptions of public attitude toward regulation.

Who should regulate	Number of counties
County (local control)	21
Board of Forestry (state control)	18
Either state or county (no preference)	7
No response	12
	58

How do the county planners personally view the need for regulation of hardwoods in California

A rather different picture emerged when the planners were asked how they personally viewed the need for regulation of hardwoods. One-half of the county planners indicated they would be in favor of some regulation of hardwoods in California while less than one-fifth indicated that they were not.

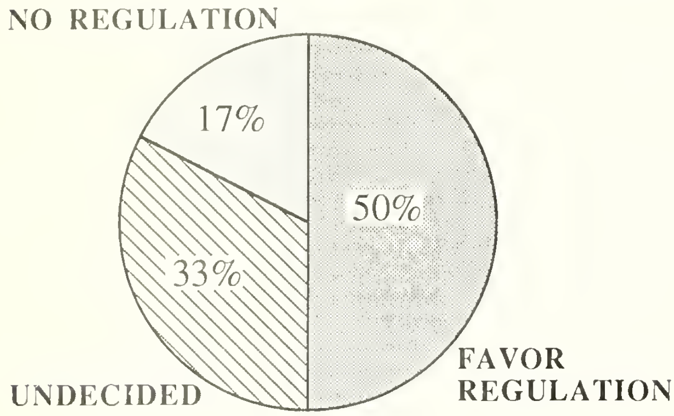


Figure 5--Percentage of county planners' who are in favor, against, or are undecided about the need for hardwood regulation in California.

Regardless of their response to the previous question, they were also asked who should regulate if regulations had to be adopted.

Slightly over half of the county planners (52%) preferred the State Board of Forestry while 41% wanted local control and 7% had no preference.

Table 5. Who should regulate hardwoods if controls were adopted?

Who should regulate	Number of counties	Percent
County (local control)	19	41
Board of Forestry (state control)	24	52
Either State or county (no preference)	3	7
	43	100
Undecided	1	
Declined to state	3	
No response	8	
	58	

There were strong feelings on both sides of the issue of local versus state control.

What counties have or are planning regulations?

About half of the counties in California do not have any regulations which cover trees while only 6 counties have regulations that specifically address hardwood trees (Figure 6). Three counties are currently planning regulations that would address hardwoods.

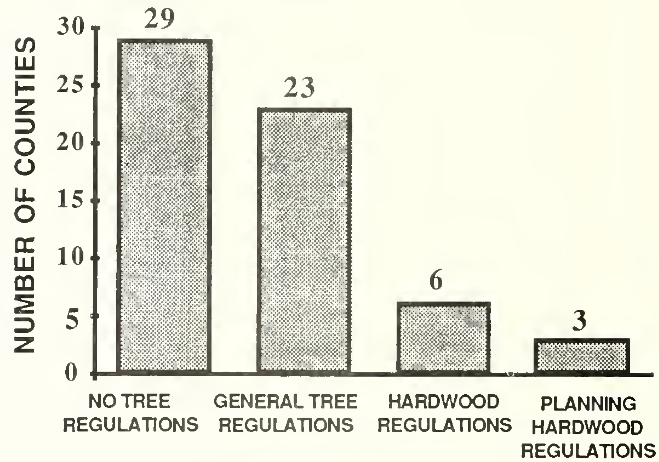


Figure 6--Number of counties having general tree and hardwood regulations in California.

Twenty-three counties have general tree regulations. These regulations vary greatly in the degree of severity. Our survey shows that some counties only address heritage trees while others have diameter restrictions and fines that can be assessed. Other examples of how tree regulations have been incorporated include:

a) an element in the wildlife conservation portion of their general plan,
b) restrictions on the removal of street trees only,
c) restrictions in protected riparian zones only,
d) restrictions in designated aesthetic corridors,
e) cutting permits,
f) restrictions in coastal zone resource conservation areas,
g) commercial fuelwood cutting operations.

The majority of the restrictions or ordinances are directed at urban or environmentally sensitive areas; only a few are actually county-wide. Very few are stand management techniques. If the counties take the lead in tree protection, it does not appear that their protection and maintenance would include active stand management.

SUMMARY OF RESULTS

1. COUNTIES UNDERSTAND THE MAJOR USES OF HARDWOODS.

All California county planners contacted said their hardwood resource was important.

They report that the greatest use of their hardwoods is for wildlife habitat, followed by commercial fuelwood operations.

It appears that county planners understand the major uses of hardwoods.

2. COUNTIES DO NOT FULLY UNDERSTAND THE REGENERATION AND SURVIVAL PROBLEMS OF SOME MAJOR HARDWOOD SPECIES

About half of the planners think that problems do exist while about half do not see problems on hardwood lands. The most common problems seen are loss of wildlife habitat, stream damage, and surface erosion. Only one planner viewed the use of herbicides and the lack of hardwood regeneration as a problem.

Eighteen of the 27 counties who indicated that no regeneration problems existed are located in counties where hardwood-rangelands are found and where regeneration is a problem. It seems that many county planners are not aware of the regeneration and survival difficulties of some hardwoods.

3. COUNTIES MORE GENERALLY FAVOR THE USE OF REGULATION (50%), BUT THINK THAT THEIR PUBLIC DOES NOT (47%).

There appears to be a difference between what county planners feel about possible regulation of hardwoods and how they perceive their populace feels about regulation.

County planners think that about one-half of their residents would oppose hardwood regulations, although only 17% of the planners said they personally opposed such regulations. Conversely, about twice as many county planners favored regulation as thought their residents would (50% of the county planners favored regulation while only 23% of their residents favored regulation). County planners think that most residents who would oppose regulations are simply opposed to any organized regulation in general or that residents do not see any problems in the hardwoods to regulate.

This difference is probably a result of previous experience with residents especially in rural areas who in the past have resisted any type of control over their lands. Yet planners and concerned citizens often see no other solution to problems they observe and, in their capacity, feel they have few, if any, alternative methods to achieve protection and wise use of the resource.

4. COUNTIES THINK CITIZENS PREFER LOCAL CONTROL BUT MOST PLANNERS PREFER STATE CONTROLS FOR HARDWOODS.

While most planners think their citizens would prefer local controls over hardwoods, most planners, would prefer that the State Board of Forestry handle regulations if they are needed. Planners felt that most of their citizens would prefer county control, by a ratio of 1.2:1, while most planners personally felt the State (Board of Forestry) should be the regulator by a ratio of 1.3:1.

It should be noted that there were some planners who had very strong feelings in favor of local controls. However, for the majority that did not, a number of reasons were expressed including a lack of time and resources necessary to manage regulations effectively. Perhaps it is for these reasons that only six counties have regulations of any kind that address hardwoods and only 3 counties, to date, have indicated they are planning to develop such regulations.

5. A LARGE DISPARITY EXISTS AMONG COUNTY PLANNERS ABOUT HARDWOODS IN CALIFORNIA

In our discussions with county planners, it was evident that there was a tremendous knowledge difference in the group. This was true even among those that are planning or have some hardwood regulations. Very few really understood the concept of hardwood stand management; fewer yet indicated a desire to explore that avenue for tree protection. Very few seem to be aware of the use of hardwood lands for grazing.

It seems that there is an important need to provide necessary and comprehensive information to the counties in California. Such information could be in a variety of forms including training sessions, reports and research results. They should focus on technical and economic forestry and rangeland issues in particular. A knowledge base such as this should aid decision making and planning activities for counties interested in or facing hardwood resource issues.

LITERATURE CITED

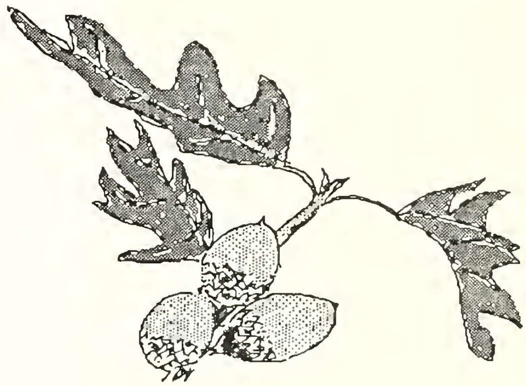
Bolsinger, C. (in press). The hardwoods of California timberlands, woodlands and savannahs. USDA For. Serv. Pacific Northwest Forest and Range Experiment Station, Portland.

Cox, P. (chair), *et al.* 1982. Forest Practice regulation in California Hardwood types. State Board of Forestry Task Force report, Sacramento. 34 p.

Fortmann, L. and L. Huntsinger. 1986. California's oak lands: Owners, Use, and Management. Department of Forest and Resource Management, UC Berkeley. 78 p.

Mayer, K., *et al.* 1986. Status of the hardwood resource of California: A report to the Board of Forestry. Sacramento. 126 p.

Pillsbury, N.H. (chair), *et al.* 1983. California's hardwood resource. Preliminary report of the Hardwood Task Force. State Board of Forestry, Sacramento. 67 p.



Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Hardwood Resource Management and Enhancement: The Local Picture and Future Prospects[1]

Sharon G. Johnson[2]

Abstract: Throughout California, primarily in urban and suburban areas, numerous local groups are initiating actions to encourage the management and enhancement of California's hardwood resources. Activities as diverse as open space protection, zoning, planting projects, heritage tree ordinances, registries, conferences, and poster and photo contests are being sponsored by community groups, municipal governments, land-owners and resource managers. Successes of these efforts will be highlighted in this paper and suggestions for future direction and coordination will be made.

California's oaks and other hardwoods are currently receiving tremendous public and professional attention. Conferences, such as this one, widespread research, local ordinances, and planting programs are all manifestations of a growing interest in understanding and better managing our hardwood resources.

Although such broad attention is a relatively recent phenomena, some groups and individuals have been working on these issues for many years. In urban and suburban areas, where hardwoods are valued for their recreational opportunities, aesthetic qualities and wildlife values, some of the most active and longstanding champions of hardwood causes have been diligently pursuing local hardwood projects for decades. Unfortunately, these local efforts are often little known outside of the communities involved, severely limiting opportunities for cooperation and communication between local groups, resource management agencies, political bodies, and academic institutions.

In an effort to improve communication and cooperation between all those interested in California's oaks and other hardwoods, this paper highlights some of the activities and accomplishments of community groups, and suggests avenues for future action.

KINDS OF GROUPS

A number of different kinds of groups are interested in California's hardwood issues. Probably most visible are the large, widely known, private non-profit groups, like The Nature Conservancy and the Audubon Society, that incorporate these concerns as one aspect of a larger program. In contrast to these large organizations are the small, temporary groups that organize to accomplish a specific task, like passing a community hardwood protective ordinance, and then disband after their objectives are met. A tremendous number of these ad hoc organizations have emerged in California and dissolved or been absorbed into other civic organizations. The only record of their existence is the legacy left in the form of ordinances, parks or other community contributions.

This paper focuses on groups that fall somewhere between these two extremes. These are the small, primarily local organizations that manage on going programs concentrating on single or related hardwood issues within their communities. Such community groups may initially organize to accomplish a specific task, such as passing protective ordinances. Or, they may pursue a diversity of community hardwood activities such as planting projects, educational efforts, tree registry programs, or watching local development for projects with adverse effects on community trees.

These groups are most abundant in the more populous portions of the state where suburbanization is rapidly encroaching on the hardwood range. Table 2 lists some of these groups but is by no means exhaustive as, being local in nature, these groups are often little known outside of their own or nearby communities. I am interested in hearing from any such groups who are active and not included on this list.

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[1] Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Table 1--Partial List of California Community Groups Currently Involved in Native Hardwood Projects

ACORN (Assoc. of Calif. Oak Resource News) in San Luis Obispo
Chico 2000 in Chico
Oak Tree Coalition in Canoga Park
Sacramento Tree Foundation in Sacramento
San Francisco Friends of the Urban Forest in San Francisco
Tree People in Los Angeles
Valley Oak and Riparian Habitat Committee in Yolo County
Visalia Beautification Committee in Visalia

ACTIVITIES OF COMMUNITY GROUPS

Community groups have made impressive contributions to local hardwood resources. Their accomplishments are even more striking when considering that much of the work is accomplished by small staffs, limited budgets, and volunteers. Most efforts to date have been focused in five basic areas: 1) obtaining protective ordinances, 2) establishing "heritage tree" or other registry programs acknowledging significant individual trees, 3) planting programs, 4) community watch dog activities, and 5) public awareness and education.

1. Protective Ordinances

The efforts of many groups have focused on having their cities and counties pass ordinances that offer some degree of protection to a community's tree resources. These ordinances vary tremendously in what they protect, what level of protection is offered and their degree of enforcement. Some ordinances offer protection to individual trees, usually in conjunction with some type of registry program. Other ordinances are aimed at limiting the cutting of trees in either established neighborhoods or in new development areas. Through the efforts of active citizens and groups, numerous California cities and counties either have or are developing protective ordinances (see Table 2). Such protective measures are generally found in the more heavily populated areas of the State.

2. Registry Programs

A number of communities have established registry programs of some type that recognize noteworthy individual trees. The specifics of these programs vary widely but many register trees of impressive size, age, or those that have some historical significance (trees associated with significant historical sites or events). Many times these registry programs raise funds for continuing registry efforts, planting, or other related activities through charging a modest amount for a nomination and registry plaque to be placed on the tree. Registration itself does not necessarily give legal protection to a tree, unless coupled with a protective ordinance. But, proponents of these programs argue that such "recognized" trees are less vulnerable to inadvertant destruction.

Table 2--Partial List of California Counties and Cities with Ordinances or General Plan Provisions Protecting Hardwoods[1]

COUNTIES
Calaveras (Development Design Review)
Lake (riparian protection)
Los Angeles County
Monterey (North County General Plan)
Napa (riparian protection)
Orange (Live Oak Preservation Plan)
Sacramento
San Bernardino (tree preservation)
San Mateo (Heritage Tree)
Santa Clara
CITIES
Agoura Hills
Arroyo Grande (Landmark Tree)
Bakersfield
Burlingame (Designated Heritage Tree)
Carmel (historical element)
Chatsworth
Chico
Coalinga
Concord (Heritage Tree)
Davis (Landmark Tree Program)
Del Monte Forest
Glendale
Grover City
Laguna Beach (Heritage Tree)
Los Angeles
Monterey
Mt. View (Heritage Tree)
Oakland
Pacific Grove
Rancho Cucamonga
Roseville
Sacramento
San Mateo (Heritage Tree)
Santa Maria
Santa Barbara
Saratoga (tree protection)
Simi Valley (Landmark Tree)

Thousand Oaks
Visalia
Walnut Creek
Westlake Village

[1]Nature of ordinance or planning instrument included where known.

3. Planting Programs

Many organizations conduct planting programs that are implemented by impressive numbers of volunteers. The Sacramento Tree Foundation, for example, planted 10,000 oaks through the efforts of several thousand volunteers during Sacramento County's 1985 "Year of the Oak" program. Many of these efforts have operated in primarily urban or suburban settings with plantings along streets, in parks or along scenic roadways. Most have tended to concentrate on planting young trees rather than acorns. Seedlings are often donated or obtained at bargin rates from nurseries, or grown by youth groups, service clubs, industry, or land management agencies.

4. Community Watchdogs

A number of groups have been organized specifically to watch activities in their own communities that would adversely effect community trees, primarily native hardwoods. Such groups review development proposals, negotiate mitigation measures for projects, attend hearings, present testimony at hearings, and in some cases, file suit for violations of ordinances or other regulatory measures.

5. Public Awareness and Education

Many organizations are involved in some level of public awareness and education. At the very minimum, public awareness activities inform a larger community of the efforts of a particular group. On a much larger scale are efforts that reach a broad public through a variety of public awareness and education activities like:

--Publications, including newsletter, brochures and informational leaflets.

--Media coverage by newspapers, magazines, local television and radio.

--Curriculum development and the creation of other educational materials for classroom use.

--Conference organization and sponsorship such as those organized by the Sacramento Tree Foundation in October of 1985; the Topanga-Las Virgenes Resource Conservation District and the National Park Service in the Santa Monica Mountains in June of 1984; and the Orange County Chapter of the Audubon Society, the U.C. Irvine Cooperative Outdoor Progam and the Department of Ecology and Evolutionary Biology in March of 1983.

--Miscellaneous activities like photo and poster contests, publicity on milk cartons, "adopt an oak" programs, native tree programs at local nurseries, and "beautiful street"awards.

During the last decade the combined efforts of community groups promoting the enhancement, protection and management of local hardwood resources have touched the lives and consciousness of hundreds of thousands of Californians.

CASE STUDY: THE SACRAMENTO TREE FOUNDATION

The tremendous potential, effectiveness and creativity of local groups can be better appreciated by briefly looking at the record of the Sacramento Tree Foundation. Although any one of a number of groups is worthy of consideration, I have selected the Sacramento Tree Foundation since it embodies the spirit, dedication and scope of efforts in many California communities.

Founded in 1982 through the efforts of civic leaders, including the city mayor, the Sacramento Tree Foundation is directed by a 33 member board that sets priorities and program direction. This diverse board, composed of builders, business leaders and environmental activists, works in partnership with the city and county and generates a wealth of ideas to promote local hardwood causes. The current annual budget of $100,000 is generated in equal proportions from three sources: memberships and contributions, corporate donations and local and state grants.

When STF was founded, a far-sighted five year plan was developed to identify organizational interests and objectives. This plan still directs the Sacramento Tree Foundation today. Perhaps the most ambitious and creative expression of these objectives was demonstrated in the "1985 Year of the Oak" campaign. STF was able to obtain a resolution from the County declaring 1985 as the "Year of the Oak". The City of Sacramento also joined in resolution and, with such strong municipal support, the program took off.

The highlights of this successful venture include presentations and booths at numerous fairs and garden shows, and oak days at nurseries. "1985 Year of the Oak" logos were displayed on local milk cartons, and a "Seed to Seedling" curriculum for students from kindergarten through the 8th grade was developed. A photo contest and children's poster contests were held, and neighborhood "Beautiful Street" awards were given. A conference entitled "Living with Native Oaks," aimed at park and school maintenance personnel, professional landscapers, and homeowners was held in October and attended by almost 300 people.

The Sacramento Tree Foundation also lobbied successfully with the city for a resolution that now requires, wherever feasible, the use of native species for at least 20% of trees used in civic landscaping projects. The county is now considering a similar measure. To crown their year of success, STF reached their goal of planting over 10,000 oak trees throughout Sacramento County.

With these successes behind them, STF is now working to strengthen the county's oak ordinance and is conducting a heritage oak contest to bring recognition to the county's largest trees. It is revising the "Seed to Seedling" curriculum, collecting curriculum supplies and conducting docent training to carry the project into more county classrooms. STF is also spearheading interest for a statewide "year of the oak" program. But, being restricted by its charter to projects within Sacramento County, STF can, at this point, only spread the idea and hope the ball will be picked up by others.

FUTURE PROSPECTS

Considering the tremendous human resources of community groups and their impressive accomplishments to date, it is surprizing that communication and coordination among groups, public land management agencies, and the academic community remains so poor. The major obstacle to cooperative efforts is this current lack of communication.

Communication Needs

Improved communication among community groups, management agencies, and the academic community could enhance projects on the local level and open the door to future cooperative projects. There are several clear avenues to improve the current situation. Conferences such as this and workshops targeted at diverse segments of the hardwood constituency would promote a broad exchange of information. Increased statewide publicity, newsletters and other publications are needed to circulate between lay groups and professionals and provide a vehicle for intergroup communication.

The primary objectives of all communication efforts should be five-fold:

1) To educate a broad public as to current hardwood concerns and possibilities.

2) To promote new contacts among interested agencies, community groups and individuals.

3) To share information and ideas on successful management and restoration projects.

4) To inform the broadest possible public of current research findings, policies and legislation.

5) To publicize future events and activities.

Recently, two new newsletters have been circulated in an effort to meet these communications needs: the ACORN newsletter (Association of Oak Resource News) sponsored by the Conservation Endowment Fund and published out of the Natural Resources Department of Cal Poly, and the University of California's Integrated Hardwood Management Program's "Oaks 'n Folks" newsletter.

New Relationships and Cooperative Projects

Beyond communication, improved coordination among sectors of the hardwood constituency is also important. This logical next step has already occurred to some extent, but holds tremendous potential for greater application, considering the diverse resources of all those interested in hardwood issues.

There are numerous possibilities for cooperative projects. Their potential for sucess is well demonstrated by the ACORN planting at Lopez Lake in San Luis Obispo County in December 1985.

Case Study: The ACORN Project

The ACORN Project (Association of Oak Resource News) is funded by the Conservation Endowment Fund, a private non-profit conservation organization, and is designed as a collaborative effort with the Natural Resources Management Department at the California Polytechnic State University at San Luis Obispo. CEF made a grant to the University Foundation to hire a coordinator to implement the joint program.

For a first project, a site needing restoration was selected in consultation with the San Luis Obispo County Parks Department. Park maintenance resources were made available for site preparation and long term maintenance. Holes, for acorn planting were dug by the California Conservation Corps, materials were donated by service groups and student organizations, and University computer services were used to develop mailing lists for invitations. Youth groups, service clubs and community volunteers turned out to plant the 1500 acorns needed for the site. In total 25 agencies, businesses, youth groups, service clubs, and student organizations were involved in some aspect of this planting. Civic leaders and several hundred volunteers turned out to carry the project to its successful completion.

This example demonstrates just one configuration of contributions to a cooperative project. The permutations of such cooperative efforts are substantial and, because of combined resources, hold greater potential than any agency or group can offer alone. The success of future large scale, labor intensive hardwood projects may well be found in collaborative efforts such as these.

CONCLUSION

As interest in California's hardwood resources increases, individuals, private groups, academic institutions, and management agencies all respond with new programatic directions. California's community groups have have shown tremendous dedication and innovation in their programs to enhance and protect local hardwood resources. Improved communication and cooperation among these groups and other segments of the hardwood constituency, would promote projects that could span the state and reach a broader spectrum of Californians than any group or agency alone.

Perhaps a statewide "Year of the Oak" program, based on the successful ideas of the Sacramento Tree Foundation, could be accomplished as just such a cooperative project. Only the diverse resources, varied expertise and innovative solutions available through cooperation could meet such an ambitious objective.

REFERENCES

Mayer, Kenneth E.; Passof, Peter C.; Bolsinger, Charles; Grenfell, William E. Jr.; Slack, Harold. The Status of the Hardwood Resource of California: A Report to the Board of Forestry, September 1986; 68-70. Available from the Department of Forestry, The Resources Agency, State of California.

Meshing State and Local Roles in California Hardwood Policy[1]

Jeff Romm[2]

Abstract: An effective state hardwood policy will contain (1) a mix of instruments that are directed both toward landowner decisions about hardwood management and toward county decisions about hardwood land allocation, (2) a capacity for continuing negotiation between state and local governments of appropriate mixes for any one area, and (3) a state capacity to diversify its policy instruments over time. The paper explores four propositions about the content of a state hardwood policy that would satisfy these requirements:

1. Effective hardwood policy requires the coordination of instruments that are directed toward hardwood management and toward the control of conversion of hardwood lands to other uses.

2. Policy coordination would be most effective at or near the county level of government.

3. The mechanisms through which negotiation and cooperation between the counties and the state occur are perhaps more important components of hardwood policy than the specifics of the objective-oriented instruments the state adopts.

4. The state has particular reason in hardwood policy to develop its comparative advantage in the systematic generation, analysis and movement of information.

The analysis concludes that the locus of authority for regulation of hardwood management will move closer to county government than has been true for state forest policies generally; the locus of authority for policy toward hardwood land allocation will move closer to the state. The state would assume dominant roles in regulating hardwood land allocation and management in multi-jurisdictional riparian and wildlife habitat systems and in enhancing the economic viability of hardwood range enterprises. The counties would assume dominant roles in other aspects of hardwood policy. As a cooperative policy will be more effective than a policy that places the respective state and county authorities in an adversarial relationship, an effective state policy will provide mechanisms for cooperation and for the institutionalized growth of knowledge upon which state and county interests mutually depend. These attributes of the policy are more crucial than its instrumental specifics.

State consideration of policies to maintain California's hardwood resources implies that landowner and local treatments of these resources are perceived as having undesirable statewide impacts. The perceived impacts are of two kinds. First, the rate of hardwood removal exceeds the rate of growth; the resource is not being sustained. Second, the spatial distribution of the resource is departing from some preferred pattern; hardwood removals are concentrated in some locations relative to others. State policy will presumably be directed toward achieving desired hardwood stocking and distribution.

The effectiveness of a state hardwood policy depends upon how landowners and local governments respond to it and whether their responses favor policy objectives. In other words, it depends upon the mesh between the instruments the state applies and the motives and capacities of those who determine how hardwood resources are actually used.

The choice of effective policy instruments depends upon the state's capacities to enforce its interests and the local motives and capacities to contravene or comply with them. This choice depends particularly upon the prevailing relationships among four conditions: (1) the strength of political support for a state policy, (2) the size of state budget for policy implementation, (3) the extent of differences between state, landowner and local interests, and (4) the relative capacities of state and local governments and landowners to control or modify hardwood use. The greater the political support and budget for a state policy, the more effective direct state control can be. To the extent that the differences between state, local and landowner interests are large, or that the existing capacities for control of hardwood use are localized, a persuasive approach is more likely to be effective than direct state control.

The location of authorities between state and local governments is a key, and perhaps the central, element in this policy choice. The locus of authority will assert a formal balance among powers, interests, financial obligations, and governmental capacities that effect a state hardwood policy and its consequences. The formal balance may or may not be realistic. Its realism will determine its effectiveness. A dominating

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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state role can satisfy state objectives in some circumstances but be counterproductive in others. The same can be said for a dominating county role.

The purpose of this paper is to identify the effective balance of state and county authorities in the execution of a state hardwood policy. It approaches this purpose in three stages. The first section defines criteria for an effective hardwood policy. The second section analyzes possible distributions of state and county authorities with respect to these criteria.

The concluding section summarizes the implications of the analysis for the distribution of state and county authorities in a state hardwood policy. In brief, an effective policy will place the locus of authority for hardwood management closer to county government than has been true for state forest policies generally; it will place the locus of authority for hardwood land allocation closer to the state. A cooperative policy will be more effective than a policy that places state and county authorities in an adversarial relationship. State and county authorities will both be strengthened by state-sponsored growth of the knowledge upon which they mutually depend.

FACTORS AFFECTING THE DISTRIBUTION OF AUTHORITY FOR A STATE HARDWOOD POLICY

Which state strategy is most likely to satisfy state objectives for hardwood stocking and distribution? The question is complex for several reasons.

Multiple Objectives

Hardwood sustainability and preferred distribution are different objectives. They may or may not be complementary. State policies for non-industrial private forestland (NIPF), for example, have increased conifer stocking in some areas but will contribute to its reduction in others; a distribution-oriented strategy would have achieved a lesser but more evenly distributed impact on overall stocking levels (Romm with others, 1985). The stocking-oriented policy favors those conditions, ecological and social, that are relatively advantageous for sustainable conifer growth; a distribution-oriented policy would need to favor conditions that are less advantageous. Hardwood policies would be expected to contain similar tensions among their objectives. These tensions will vary from one place to another.

Multiple Targets

The sustainability and distribution of hardwood resources depend both upon how hardwoods are managed and upon how the lands on which they grow are allocated among possible uses (Doak and Stewart, 1986). Private landowners largely determine how hardwoods are managed. Local governments monopolize the taxation, zoning and public service instruments that control how market forces allocate hardwood lands among their possible uses. As private landowners and local governments have different motives and capacities, the same state policy instruments may or may not be suitable for both targets.

Multiple Means

The state could regulate how owners manage their lands and how counties guide land market allocations. It could promote the economic viability of owners and/or counties so as to relieve pressures to cut hardwoods and to convert hardwood lands to other uses. It could pursue technical advances that increase the economic viability of hardwood land enterprises and hardwood land retention without direct subsidy. It could use information to build a common understanding of hardwood resource values and how to maintain them. As different groups of owners and counties have different needs and constraints, no one set of means will be suitable for all (Romm and Washburn with others, 1987; Romm with others, 1985).

Diverse and Dynamic Social Contexts

The relative impacts of management and land allocation, e.g. of actions by landowners and by local governments, on hardwood resource stocking and distribution differ greatly across California (Doak and Stewart, 1986). Agricultural conversion appears to drive hardwood depletion in the Northern Interior. Urban conversion appears to do so on the South Coast and in the Central Sierra. Fuelwood harvest may be the dominant force in parts of the Sierra. No single combination of policy instruments can be expected to achieve similar, or even satisfactory, outcomes throughout the hardwood zone. Moreover, as the conditions in one place change with the growth of its population, no single combination can be expected to satisfy state interests in any locality over time.

Prevailing Patterns of State Policy and Enforcement

The state has its existing capacities and accustomed patterns of policy in the wildland resource arena (cf Vaux [1983] for an historical review). These embody both the preferred styles of state action and the judgments of feasibility and effectiveness that have been made in the past. Departures from them are likely to raise a policy's political and economic costs.

For example, the state has maintained relatively unified direct authority over the management and the allocation of industrial forestlands. For NIPF lands, it has used direct influence upon landowners when improved forest management has been its objective, e.g. through forest practice regulations or forest improvement subsidies. But it has used direct influence upon counties, e.g. in the establishment of the Timberland Production Zone, when its objective was to reduce pressure for conversion of forestlands to other uses. And the strengh of its authorities for direct influence upon counties has been directly related to the degree to which NIPF owners have devoted their land to commercial timber production. In other words, the unity and strength of state authorities have been inversely related to the pressures on forestland for uses other than commercial timber production; relative county authorities have increased in direct relation to pressure for non-timber uses.

Hardwood resources are generally prone to more diverse and intense pressures than are NIPF lands. If the prevailing pattern were extended to them, a sharper split between state authority for vegetative condition and county authority for land allocation would be expected than has occurred in the NIPF case.

The above suggest some initial criteria for choices in the formation of hardwood policy:

An effective policy would contain:

(1) a feasible mix of instruments that

- can be combined to achieve state objectives in varied local conditions,
- can affect both landowner decisions about hardwood management and county decisions about hardwood land allocation, and
- can affect groups of landowners and counties in different circumstances,

(2) a capacity for continuing negotiation between state and local governments and landowners of appropriate objectives, means, and use of separate authorities for any one area, and

(3) a state capacity to diversify its policy instruments over time in a manner that increasingly satisfies diverse needs, reduces conflict, and improves the administration of policy at acceptable cost.

These criteria have implications for the placement of authorities in state hardwood policy.

ANALYZING ALTERNATIVE DISTRIBUTIONS OF AUTHORITY

This section explores four propositions about the specific content of a hardwood policy that would satisfy these criteria.

1. An effective state hardwood policy requires coordination between instruments directed toward hardwood management and instruments that control the conversion of hardwood lands to other uses.

2. The coordination of state policy instruments would be most effective if it occurred at or near the county level of government.

3. The mechanisms through which negotiation and cooperation between the counties and the state occur are perhaps more important components of hardwood policy than the specifics of the objective- oriented instruments the state adopts.

4. A state hardwood policy must develop the systematic growth and movement of information about hardwood conditions and the impacts of policy upon them.

These propositions are explored below.

I. An effective state hardwood policy requires coordination between instruments directed toward hardwood management and instruments that control the conversion of hardwood lands to other uses.

State experience with policies for non-industrial private forestlands (NIPF) inform a discussion of hardwood policy because it derives from the nearest analogy to the hardwood "problem." The state has used direct influence upon NIPF landowners when inadequate forest management was its target. It regulates landowners' harvest practices and regeneration through the Forest Practices Act, forcing landowners to internalize social costs of their actions. It subsidizes landowner forestry investments through the Forestry Improvement Act, reducing landowner costs of satisfying social goals. In neither case has the state given local government a systematic role.

In contrast, the state has used direct influence upon counties when its objective was to slow forestland conversion. The Forest Taxation Reform Act assigned to the counties the primary responsibility for implementing the Timberland Production Zone (TPZ). The Zone protects landowners against county tax penalties that encourage the conversion of forestlands to other uses. Although the state asked the counties to confine their own fiscal options, it deferred to their control of land allocation by allowing them large discretion in how to proceed. Landowners could influence county judgments about individual parcels, but the strategies that counties adopted have determined the extent of the state's zone (Romm and Washburn, 1985).

The results of these state NIPF policies inform current design of state hardwood policy.

1. <u>State NIPF policies have accentuated rather than moderated tendencies that landowners and counties already displayed.</u>

The CFIP increased forestry investment among owners who were already investing in forest improvements. These owners have forestlands in counties that had exerted little or no tax pressure for forestland conversion (Romm and Washburn with others, 1987).

The TPZ was approached ambitiously by those counties which were relatively unaffected by conversion pressures and therefore faced little financial loss from TPZ constraints on taxation; these counties have received the bulk of CFIP money as well. The TPZ was also approached ambitiously by those urban counties in which forests had gained great scarcity value and in which taxable values of forestland residence were high. Counties with rapid forestland conversion pursued relatively unambitious strategies and produced relatively small zones; they also received negligible portions of CFIP funds (Romm and Washburn, 1985).

Statewide, the combination of CFIP and TPZ policies increased the economic viability of private forestlands in areas where economic incentives for forest management were relatively strong. It concentrated the demand for convertible land where the economic incentives for conversion were already great, and added little to support the economic competitiveness of forestry in these areas. In the long run, the policy combination will increase the state's stock of private commercial timber (Romm with others, 1985) but will redistribute the stock more strongly toward north coast, northern interior and urban counties than is presently true (Romm and Washburn, 1985). The private conifer cover of the Central Sierra will decline more rapidly than would have occurred in the absence of state policy, which has had the effect of funneling development pressures toward those areas in which these pressures are already strong.

The forest practice regulations have not been studied in the manner of the CFIP and the TPZ. If these analyses are useful guides, however, it seems reasonable to expect that forest practice regulations have had their greatest impact on those owners who were already trying to manage their forests in a sustainable manner, e.g. those in hinterland and urban areas who do not anticipate converting their lands to other uses. Furthermore, as forest practice regulations impose certain fixed costs on all harvests of three acres or more, it seems plausible to expect that they have reduced the economic viability of smaller harvests relative to large and that they therefore have had a greater negative impact on the viability of smaller NIPF than larger NIPF or industrial forest operations (See Vaux, 1983). Such patterns would increase the accentuating effects of the CFIP and the TPZ.

2. The lack of coordination between state and county NIPF policies in any one county or region has diffused and reduced their potential effects on the economic and environmental viability of forest management.

NIPF policies have accentuated prevailing tendencies among landowners and counties because they opened opportunities for those who could use them but did not sufficiently relax the constraints on those who could not (Romm and Washburn, 1985; Romm and Washburn with others, 1987). Coordination of policies might have overcome this pattern by concentrating collective policy resources for strategic effect.

The state awards CFIP subsidies to individual owners if their property has TPZ-like status, which the counties largely control, but it has no strategy for increasing forestry investment on a scale larger than one ownership. Few CFIP recipients have adjacent properties; few are selected for their possibly strategic impact on a larger area or group of owners (Romm and Washburn with others [1987] describe the CFIP process). County TPZ allocations determine whatever strategic impact the CFIP may achieve.

Counties have awarded TPZ status to areas where doing so will not create a fiscal loss for them. None has a strategy for developing the economic viability of forest management in these areas so that market forces rather than public policy will eventually support their retention in productive forest cover. Although all CFIP properties have TPZ-like status, thereby receiving the combined impact of direct subsidy and tax protection, three times as many NIPF owners invest in forestry outside of a TPZ-like arrangement than those who invest in forestry within the zone (Romm with others, 1985). The TPZ has not been designed to include owners whose actions demonstrate their commitment to or the suitability of their lands for forestry (Romm and Washburn [1985], describe the TPZ process).

The forest practice regulations apply to any harvest of three acres or more, whether inside or outside of the TPZ. CFIP funds cannot be used to comply with their regeneration requirements. In equivalent forest conditions, an NIPF owner who harvests outside the TPZ does so with all of the costs but none of the public benefits available to one who harvests within the zone; smaller ownerships are in less advantageous positions than larger ones. This distribution of policy effects presumably discourages harvesting and associated investments outside the TPZ, particularly among those who hold smaller ownerships. County TPZ allocations determine the distributive effects of the state-administered forest practice regulations on the economic and environmental viability of forest management.

None of the dominant NIPF policies is based upon a strategy to release constraints on the spontaneous growth of regional forest economies. Their separate administrations complicate the development of a strategic view and diffuse the effects of their resources on forest management and land allocation. Greater impact would be probable if, in addition to their primary objectives, (1) the TPZ were designed to promote forestry investment in areas that have general promise for timber production, (2) the CFIP were used to increase the economic viability of forestland retention in such areas, and (3) the forest practice rules were administered on a sliding scale, depending upon the potential role of a harvest in the overall economic and environmental wellbeing of an area. Such coordination of objectives is a first step toward strategy. Romm and Washburn (1985) discuss strategic possibilities in greater detail.

3. The lack of coordination between state and county NIPF policies increases the costs of conflict and administration.

The absence of coordination between state and county policies has produced characteristic tensions that suggest the vulnerability of present NIPF policy as a guide for hardwood policy design.

Urban counties and the state have fought about forest practice regulations when the counties sought to use timber harvest planning procedures for zoning purposes. These conflicts were predictable in light of the counties' dominant authorities and significant interests in land allocation. The costs of conflict and administration would presumably be reduced if the land allocation impacts of forest practice regulations were explicitly acknowledged and cooperatively planned.

State interests have argued the insufficiency of TPZ implementation in conversion-prone counties (California Forest Improvement Committee, 1980) and succeeded in legislating stronger limits upon county TPZ authorities. These stronger limits have had no effect (Romm and Washburn, 1985). Severe staff constraints commonly determine what county forest zoning and taxation policy is and can be (Stewart, 1985). The state does not compensate counties for TPZ lands, as it does for lands in the Agricultural Preserve, nor have advocates of a stronger TPZ acknowledged the fiscal impacts it would have in conversion-prone counties. CFIP subsidies for forest improvements could be viewed and treated as compensation if counties were able to share program overhead budgets and influence fund allocations for their own objectives. Instead, the state distribution of CFIP funds is controlled by landowner and county constraints (Romm, Tuazon and Washburn, 1987; Romm and Washburn, 1985) rather than by the needs that landowners and counties must satisfy to act in ways that are compatible with state objectives. The coordinated administration of CFIP and TPZ policies may reduce their cost and increase their effectiveness.

The impacts of state NIPF policies are limited by the lack of coordination of those that affect forest conditions directly and those that work through the counties to influence the allocation of land upon which forests grow. For a number of reasons, the effects of a state hardwood policy would be even more limited if policy coordination were similarly absent.

First, the contextual constraints on hardwood landowners are stronger and more varied than those affecting the owners of NIPF lands; they will dominate policy resources more forcefully. Hardwood lands are generally more accessible and more integrated within economic and social structures than are NIPF lands. They feel more strongly the influences of commodity markets, urbanization and agricultural development. The balance among these influences, and the opportunities and constraints these create for landowners and counties, vary greatly over space. Uniform state policies, even if defined separately for regions, would not provide reasonably equitable treatment for landowners and counties in diverse conditions; rather, they would tend to increase their differences.

Second, state capacities for hardwood regulation are substantially weaker than those for coniferous forests. Effective state capacities depend upon generalized knowledge. Hardwood management and its effects are much less understood than is the management of conifer forest. Knowledge about hardwoods is still too location-specific to support the general guidelines that state administration requires. Direct state attempts to improve and regulate hardwood management would be based on too little knowledge to support reasonably equitable treatment of landowners. Accentuation would be significantly greater than has been true for conifer lands.

Third, county capacities for the control of hardwood land allocation are stronger than those for NIPF lands. While the state has less experience with and knowledge about hardwood than conifer lands, the counties are in the reverse situation. They have dealt with rangeland problems and constituencies for a long time, developing useful capacities through their exercise of taxation, planning, zoning and extension functions and through their experience in resolving conflicts that affect hardwood landowners. State attempts to influence county policies are likely to have weaker impacts than those directed toward NIPF lands. For these reasons, an NIPF-like state policy toward hardwoods and hardwood lands would have less effect than the forest policy has achieved.

II. The coordination of state policy instruments would be most effective if it occurred at or near the county level of government.

Governments possess (1) general powers to make and enforce the rules of the political system and (2) functional powers that are established through these rules to satisfy specific public objectives. Various political and economic criteria have been proposed for choosing the level of government at which particular functional authorities should be placed (e.g., Fesler, 1949; Maass, 1959; Tiebout, 1961; Oates, 1972; Breton and Scott, 1978; Golembiewski and Wildavsky, 1984). All address the problem of matching motives, means and capacities to best satisfy some public interest. The following criteria may help consideration of where authorities for a state hardwood policy might be located.

1. Legitimacy and accountability: Place authority at a level of government that is accessible and accountable to those it affects.

Compliance with a policy increases and/or the costs of its enforcement decline to the degree that affected parties can expect to influence the policy if they wish to modify it. The more diverse the affected interests, thus the more complex their representation, the lower is the level of government at which an authority should be located.

2. Stability: Place policy authority at a level of government that possesses the general powers to secure equitable resolution of conflicts among the interests it affects.

The costs of a policy are inversely related to the strength of available means to resolve conflicts about it. The more intense the conflict among affected interests, the greater is the general power that its resolution requires and the higher is the level of government at which a policy authority should be located.

3. Efficiency: Place policy authority at the level of government at which economies of scale and specialization in its administration can be attained.

The effectiveness of a policy depends upon the governmental capacity for its execution. Different economies of scale and specialization characterize the administration of different functional policies. The smaller the economies of scale and specialization for some policy, the more local should be the authority for its governance; the larger the economies, the higher the authority should be located.

4. Feasibility: Place policy authority at the level of government that can mobilize the financial resources it requires.

The capacity to execute a policy depends upon the financial resources available to promote and/or to enforce policy compliance. The larger a policy's financial requirements, the higher the level of governance at which authority for it should be placed.

These criteria produce ambiguous prescriptions for the location of authority for any specific function, but they are useful starting points for deeper analysis.

The ambiguities help explain what Aaron Wildavsky has called the "marble-cake" nature of contemporary federalism (Wildavsky, 1980). As the functions of government have grown, the authorities for different aspects of specific policies have been divided among levels of government according to their comparative strengths. Thus, the federal Forestry Incentives Program provides funds for cost-share subsidy of NIPF improvements within California, but CDF staff judge the quality of landowner proposals and locally representative committees determine the allocation of funds among possible recipients. The state enforces the procedures for including NIPF lands in the TPZ and prevents the counties from excluding certain sizes and qualities of parcels that owners want to have in the zone; within these broad limits, the counties have the power to determine the extent of the zone and its permissible uses. Such mixes of authority, based upon comparative governmental strengths, have become so prevalent as to largely destroy the traditional notion of a "layer-cake" division of functions among governments.

The complex intertwines of governmental authorities work reasonably well when synchronized, but they have their own sources of conflict and cost when not. NIPF policy in California exemplifies an initial stage of intertwined authorities that have not yet had the time to synchronize, or to gain the diversity of instruments that will help that to occur. The previous section suggests the opportunity to use that experience to initiate hardwood policy on a more advanced plane than may otherwise be possible. The criteria afford one set of tests that may help specify what that means.

1. Legitimacy and accountability

Fortmann and Huntsinger (1985) provide information that helps identify the lowest level of government at which California's hardwood landowners are likely to focus their political interests. The comparative NIPF information derives from Romm with others (1985).

Hardwood landowners appear to be more likely than NIPF owners to focus their political interests in the county where their property is located. More than half of them live and/or work on their property full-time, as contrasted with about one-third of NIPF owners. Although turnover of NIPF ownerships has been extremely rapid, e.g. 50% between 1978 and 1982, it has been small among hardwood landowners, e.g. 6% in the same period. Almost twice the proportion of hardwood landowners have their property in the Agricultural Preserve than the proportion of NIPF owners who have their property in the TPZ. As a group, hardwood landowners display stronger antagonisms to state regulation than do NIPF owners.

These data can be interpreted to mean that hardwood landowners are more likely than NIPF owners to be local long-term residents and to feel that access to and influence upon government is easier at local than higher levels. On the other hand, hardwood range owners are commonly in serious economic straits because of livestock markets that are beyond county influence. Owners tend to represent their economic concerns at a state rather than county level. Their economic vulnerability reduces their resistance to opportunities that hardwood clearance and land subdivision can afford. Thus, the issues they focus at the state level express indirectly some basic forces for the decline of hardwood resources.

Environmental interests display a different pattern. They may or may not consider county government to be their accessible and legitimate agents in hardwood land allocation matters, depending upon the structure of power in their county. They generally focus on state rather than county government when arguing their specific concerns about hardwood-related declines in riparian and wildlife habitat systems, which generally extend beyond one or several counties' boundaries.

Hardwood landowners and environmental groups may share a common preference for local control of hardwood issues generally, but they appear to view the state as a more accessible and legitimate level for governing policy affecting the economic viability of hardwood ownerships and the ecological viability of riparian and wildlife systems respectively.

2. Stability

Conflicts regarding hardwoods have tended to occur between rural and urban interests. They have risen to a state level when local governments have been unable to resolve them. The lack of local resolution has several possible explanations. The urban interests involved reside elsewhere. The conflict is between the economic viability of ownerships and the ecological viability of riparian and habitat systems, both of which are state-level issues. The counties lack sufficient general powers to manage the intensity of conflict they confront. All of these reasons suggest that the lack of local resolution is directly related to the rate of urbanization. The appropriate strength of the state's role relative to the counties would vary directly with the rates- not the degree - of urbanization among counties and with the intensity of inter-jurisdictional issues that urbanization creates.

3. Efficiency

The objectives of a state hardwood policy are presumably to sustain the hardwood resource and to maintain its desired distribution around the state. Sustaining the hardwood resource can be interpreted as keeping removal rates at or below growth rates within some given area over time. Evidence is too weak to show whether current statewide ratios of hardwood removal and growth are above, at or below the sustainability criterion. Distributional issues arise if the sustainable condition, region- or state-wide, nevertheless leaves some areas or ecosystem types severely depleted. Current evidence supports the specific concerns that groups have voiced about significant losses of hardwoods (1) at the urban fringe, (2) in the riparian zone, (3) in key wildlife habitat systems, (4) in hinterland areas that are being cleared for agriculture, and (5) in fuelwood sheds of hill communities. If the different qualities of evidence are indicative, there seems reason to argue that concerns about statewide sustainability of hardwoods are really coalitions of concern about hardwood depletion in such specific conditions. While productivity interests have dominated the formation of NIPF policy, it appears that distributional objectives, i.e. the sustainability of hardwoods within relatively small and diverse areas, are likely to dominate a hardwood policy.

Distributional objectives have rather interesting implications for where the authorities for hardwood policy are placed. Maintaining riparian and wildlife habitat systems requires capacities that have clear economies of scale and specialization. No local government can regulate systems that extend far beyond its boundaries; the state has developed such capacities for related water and wildlife purposes and could augment them with relative ease. In contrast, local governments have well-developed capacities for the control of urban, agricultural and forest land uses. These capacities derive from their general powers and could be augmented to achieve a sustainable hardwood resource much less expensively than if the state were to assume a dominant instrumental role.

Thus, the efficiency criterion appears to suggest two distinct mixes of authority between local and state governments. The state would hold dominant policy authority and responsibility for multi-jurisdictional riparian and habitat systems, for much the same reasons that it dominates forest policy for industrial lands; counties would be required to exercise their land use controls to protect the boundaries of these state systems. Local governments would hold dominant authority and responsibility for the sustainability of hardwood resources outside state riparian and habitat zones; the state would be required to augment county capacities for this function.

4. Feasibility

Fiscal capacities are small in hinterland counties. They are deficit in counties that are urbanizing rapidly and do not receive significant national forest payments. They are positive in urbanizing counties that do receive national forest payments, and large in the urban counties. In their placement of NIPF lands in the TPZ, the urban counties demonstrated the will and fiscal strength to aggressively control wildland conversion when given the authority to do so. The other counties have neither the will nor the fiscal capacity to restrain what landowners and market forces would want to have happen (Romm and Washburn, 1985.). Agricultural conversion appears to be the dominant cause of hardwood decline in the hinterland counties; subdivision is the dominant cause in those that are urbanizing rapidly (Doak and Stewart, 1986). State subsidy to and direct control in the counties involved will be necessary if either process is to be regulated for hardwood maintenance.

The four criteria for the placement of authority produce different independent prescriptions for hardwood policy, but their collective analysis yields a rather cohesive conclusion. The analysis suggests the following general distribution of authority for a state hardwood policy:

1. The state would establish a riparian and wildlife habitat system. It would set limits (a) upon uses in the system, along the lines of current county land use restrictions within the TPZ, and (b) upon rates and modes of hardwood removal, as in current forest practice regulations.

The counties would administer the system within the state's limits on uses and removals.

2. The counties would retain relatively autonomous authority on hardwood matters outside this system.

The state would make available technical assistance and financial compensation for county establishment of hardwood zones. It would also establish and enforce upper limits on scales of clearance and rates of removal, possibly doing so within the administrative framework of current forest practice regulation.

3. The state would develop a program to increase the economic viability of hardwood ownerships, coordinating the program with county hardwood zoning efforts.

These results only partially support the initial proposition that the county unit is the appropriate focus for coordination of hardwood policy. Multi-jurisdictional riparian/habitat systems also appear to be appropriate. State authority for improving the economic viability of hardwood ownerships appears to be necessary.

III. The mechanisms through which negotiation and cooperation between the counties and the state occur are perhaps more important components of hardwood policy than the specifics of the objective-oriented instruments the state adopts.

The previous analysis has suggested aspects of hardwood policy in which the state and the counties would each have predominant authority. Whether or not its particular division enters hardwood policy, some such division is sure to emerge. In practice, the division means that the state and counties will possess separate authorities that can be used to complement, neutralize or contravene one another. Furthermore, such outcomes of interactive authority will vary among counties and regions. A uniform application of state authorities will arouse complementary applications in some counties and competitive ones in others. The state's inherent need to adopt a reasonably uniform approach, and the diversity among counties, mean that the interactive effects of state and county authority are bound to differ widely across the state.

Romm and Washburn (1985) have demonstrated this dynamic and its diverse outcomes in the formation of the TPZ. In timber-dependent areas, the counties treated state TPZ rules as an opportunity to secure the timberland base and increase timber-related income; they adopted ambitious strategies in forming the Zone. In urban counties, landowners treated the TPZ as a boon; the counties, to comply with public interests but avoid unacceptable losses in tax base, used their authorities to increase those portions of TPZ properties over which they maintained fiscal discretion. Urbanizing counties were most threatened by the fiscal consequences of the TPZ; they used a variety of means to limit TPZ size and maintain or increase their tax revenues from properties that entered the zone. The statewide consequences of these diverse county strategies were discussed earlier.

Such dynamics and outcomes will occur in the execution of a hardwood policy. For example, strengthened state regulation of riparian and/or habitat zones can be expected to cause a weak, or even counterproductive, county approach to other hardwood issues where county finances are severely constrained. State limits on hardwood removals and clearances may promote county measures that encourage more extensive patterns of removal that ultimately have greater impact on hardwood stocks.

One possible state response to the dynamic is to tighten state controls over county actions, i.e. to shift authority from county toward state. The analysis of the preceding section suggests that doing so is likely to reduce compliance with state authority and/or to increase the costs of its enforcement. A second possible approach is state compensation of counties for their losses. Romm and Washburn (1985) have shown in their TPZ study that this approach can be extremely expensive.

A third approach is to avoid the brittleness and cost of adversarial authorities by building into hardwood policy the mechanisms necessary for state-county negotiation of mutually beneficial uses of their respective powers. Romm and Fairfax (1985) have shown that such mechanisms reduce the influ-ence and costs of intergovernmental distributions of authority and can be expected to increase the social benefits of governmental actions. Perhaps more importantly, the coordination of policies can concentrate public resources on the twinned problems of economic and ecological viability rather than diffuse them in a manner that serves neither one.

The cooperative approach has yet to be tried in state forest policy generally, but the arguments for it in hardwood policy seem particularly strong. In contrast with forest policy, the political base for an adversarial or expensive state hardwood stance does not exist. The economic and ecological stresses that must be resolved are more intense and diverse. The state has no monopoly of the knowledge and organization that effective hardwood policy requires. The state has no federal "uncle" from whom support for hardwood interests can be expected. The choice is between a weak policy and a cooperative policy.

What might a cooperative hardwood policy contain? The following are suggestive possibilities.

(1) A cooperative hardwood monitoring program

Information is power. The power of information declines with its distance from those who can act upon it. It increases to the extent that the information can be analyzed and interpreted in a useful way. Capacities for collection, analysis and interpretation display different economies of scale and specialization for different kinds of information. The greater the economies, the larger is the probable distance between the users and the processors of information. Thus, the design of a hardwood monitoring system includes the objective of distributing informational functions among levels of government in such a way as to balance the gains and losses of moving each function nearer to or farther from the user. Such a design can be achieved in a forum of open exchange among state and county interests. Its initial template is the actual allocation of policy authorities.

(2) Cooperative planning

A plan can be viewed as a form of flexible contract. It states the conditions of an agreement at some given time. It usually includes (a) mutual objectives for the future, (b) mutual expectations about the conditions that are needed to satisfy these objectives, (c) a schedule of actions that different parties will undertake to achieve these conditions, and (d) agreeable procedures for continuous modification of the above.

A plan coordinates actions in the absence of coordinating authority. It is particularly useful in cases of bilateral power, of which hardwood policy is a clear example. A hardwood policy would include provision for state-county planning that attempts to maintain reasonable synchrony among hardwood authorities despite changes in the conditions that affect hardwood management and land allocation.

(3) Cooperative technical assistance

Technical assistance is commonly viewed as a downward flow of knowledge and expertise. Three obvious exceptions are informative. Effective agricultural extension moves as much information from the farmer upward as from the expert downward; the relative value of the two flows is a matter of considerable debate. The effective California fire protection system depends upon local as well as state and federal expertise and includes all of these parties in system planning and management. And the state water system is governed as much by the expertise in its constituent districts as by that in state centers. The structure of hardwood expertise is more analogous to that of agriculture, fire protection and water than to forestry. (Indeed, if education, public health and the like were examined, forestry might begin to appear to be the exception.) As technical assistance will be essential to an effective hardwood policy, its structural features would appropriately be stated in the policy itself.

(4) Cooperative finance

Any controls on land allocation and use affect counties' property tax bases. Counties use their controls as fiscal instruments. State controls change county fiscal structure for good or ill; as in the TPZ case, counties modify these effects by how they respond with their own instruments. In TPZ formation, approximately ten counties financed the state zone because they were not compensated and could not compensate for their losses; only several counties possibly gained slight financial advantage by establishing the zone (Romm and Washburn, 1985). The stakes will be larger in the hardwood case. An effective hardwood policy will contain provision for reasonable exchanges that allow the state to pay for its localized interests and the counties to adjust for their own.

IV. A state hardwood policy must develop the systematic growth and movement of information about hardwood conditions and the impacts of policy upon them.

Effective policy is information-intensive. The time lag between action, effect and adjustment can be long, conflict-laden and costly unless there is commitment to processes of institutional learning that translate experience into more effective modes of action.

Initial stages of a policy are more vulnerable to information shortages than later stages. Nothing is known about how chosen instruments will actually work. Start-up problems tend to push the development of evaluation and analysis to a low priority; these functions are typically neglected when they are most needed.

A cooperative policy is more information-intensive than a policy that can rely on administrative habit. Negotiated settlements are as useful as the information upon which they are based. Flexibility and mutual exchange depend upon the diversity of alternatives that are available for consideration at a given time. The growth of diverse alternatives is directly related to the rate of institutional learning.

State hardwood policy is even more vulnerable to an information shortage than other aspects of policy. California has virtually no generalized knowledge about what its hardwood resources are, what they do, and how their services can be secured through better management and policy. Knowledge about hardwoods in the state is relatively localized and site-specific. The mechanisms for collating and assessing it are relatively weak. There has been no development of economies of scale and specialization for its generation, analysis and translation into improved instruments and actions. Other than the preservation of oaks for future subdivision values, there is not even one system of hardwood management that can be recommended confidently to landowners, anywhere in the state, as an economically viable alternative to their current practices.

These realities suggest that a state hardwood policy must assign a particular priority to developing the institutional basis for the growth of useful knowledge. Three structural features indicate the possible objectives of such a focus.

1. Critical masses of organized expertise to obtain, analyze, interpret and apply information at levels where significant economies of scale and specialization can be achieved.

2. Statewide organization of expertise to satisfy needs for

(a) short-term policy analysis within government,

(b) medium-term planning analysis within government,

(c) long-term specialized research outside government,

(d) education and training, and

(e) extension.

3. State-county mechanisms for information exchange, mutual assessment of priorities, and mutual assistance.

Developing such structures is a key state role and essential aspect of an effective state hardwood policy.

THE ALLOCATION OF HARDWOOD AUTHORITIES

The analysis has produced a conclusion about the appropriate distribution of state and county authorities in a state hardwood policy.

1. The state would increase its powers over the allocation and use of hardwood lands in selected riparian and habitat zones, thereby reducing relative county authorities in these zones.

The state has a comparative advantage in regulating these hardwood land systems. The systems have state importance and are beyond the governance of county jurisdictions. The state has the ability to achieve economies of scale and specialization in these systems that counties cannot be expected to attain. The conflicts about riparian and habitat conditions require the state's general powers for resolution. The state's existing administrative and financial capacities can be more easily augmented for riparian and habitat zone regulation than can those of the counties.

2. The state would support county efforts to undertake more general forms of direct regulation of both hardwood management and hardwood land allocation. It would do so through the provision of hardwood zoning authorities, possible financial incentives, and technical and financial assistance. The counties would maintain dominant powers over hardwood lands and uses outside of inter-jurisdictional riparian and habitat zones and excepting large-scale hardwood clearances.

The counties have a comparative advantage in regulating hardwood lands other than those in the inter-jurisdictional zones. They are accessible and accountable to landowners and other local interests. They possess local knowledge of the physical and social characteristics of their hardwood resources. They have diverse capacities for land use regulation that would dominate even a strong state authority. It would be easier to augment their capacities for hardwood objectives than to create separate state capacities for these purposes.

The state's framework for existing agricultural and timberland preserves can be extended for county establishment of hardwood zones. The extension would appropriately include (1) the fiscal support that counties receive for lands counties receive for lands in the agricultural preserve and (2) the support for viable land management that NIPF policy could provide if its CFIP, TPZ and forest practice instruments were synchronized.

3. The state would establish and enforce limits on the scale of hardwood clearance and removal.

The counties' comparative advantages in other aspects of hardwood regulation become disadvantages in the limitation of excessive clearances. Excepting urban counties, their accessibility, knowledge and fiscal stress weaken their abilities to constrain significant landowner decisions. The state has existing capacities in forest and water quality regulation and in permit processes for removal of land from the TPZ. Augmenting these capacities for control of hardwood clearance would involve minor change.

4. The state would develop a program for increasing the economic viability of hardwood ownerships.

Economically viable hardwood range and woodland enterprises secure hardwood resources for society at large by resisting pressures for land fragmentation, perhaps the dominant force for hardwood depletion. Counties can use their authorities to relieve land market and taxation pressures on these enterprises, but larger sources of stress or potential opportunity are beyond their capacities.

5. The state and the counties would cooperate to synchronize their policies within a mutual strategy. Cooperation could be implemented through common systems for monitoring and evaluation, hardwood resource planning, technical exchange, and financial assessment.

Adversarial stances have been unproductive in state forest policy. They would be less productive in hardwood policy, which is a sharper case of bilateral power. The development of cooperative mechanisms would require significant changes for the state and the counties, but it is difficult to see how any state policy could be effective without such mechanisms. State-local cooperation in fire protection may provide an appropriate model.

6. The state would develop the effectiveness of state and county authorities, and of coordination among them, by growing the knowledge and expertise that they and landowners need.

The state has the financial and organizational capacity to develop a strategy for growth of the knowledge base upon which the long-term effectiveness of hardwood policy depends. The counties have access to the primary sources of information and are crucial elements of an information structure, but they are not in a position to develop attainable economies of scale and specialization that the overall structure requires.

The suggested location of authority for hardwood policy would create roles for the state and counties that depart from their accustomed roles in forest policy. The locus of authority for hardwood management would move closer to county government than has been true for state forest policies generally. The cost of exercising that authority would decline as landowners' economic opportunities grew more favorable. The locus of authority for hardwood land allocation would move toward the state through its increased control of riparian and habitat systems. Cooperative mechanisms would reduce the influence that the distribution of authorities has had upon the effectiveness of NIPF policies; they would increase the influence of the quality of information. State and county authorities would both be strengthened by state-sponsored growth of the knowledge upon which they mutually depend.

References

Breton, A. and A. Scott. 1978. The Economic Constitution of Federal States. University of Toronto Press.

California Forest Improvement Committee. 1980. California Private Forests: Policies For Renewed Productivity. State of California, Sacramento.

Doak, S. 1986. Practical Applications in Assessing The Forces Affecting California's Hardwood Resource. Department of Forestry and Resource Management, University of California at Berkeley.

Doak, S.C. and W. Stewart. 1986. A Model of Economic Forces Affecting California's Hardwood Resource: Monitoring and Policy Implications. Department of Forestry and Resource Management, University of California at Berkeley.

Fesler, J. 1949. Area and Administration. University of Alabama Press.

Fortmann, L. and L. Huntsinger. 1985. California's Oak Lands: Owners, Use and Management. Department of Forestry and Resource Management, University of California at Berkeley.

Golembiewski, R.T. and A. Wildavsky. 1984. The Costs of Federalism. Transactions Books, New Brunswick, Connecticut.

Maass, A. 1959. Area and Power. MIT Press. Cambridge, Massachusetts.

Musgrave, R. and P. Musgrave. 1984. Public Finance In Theory and Practice. McGraw-Hill, New York.

Oates, W. 1972. Fiscal Federalism. Harcourt, Brace, Jovanovich, New York.

Romm, J. *with* C. Washburn *and* R. Tuazon and J. Bendix. 1985 Forest Owners and The State: California Policy For Growing Forests On Non-Industrial Land. Department of Forestry and Resource Management, University of California at Berkeley.

Romm, J. and S.K. Fairfax. 1985. "The Backwaters of Federalism: Receding Reserved Water Rights and The Management of National Forests," in Policy Studies Review, Vol. 5, No. 2, pp 413-430.

Romm, J., R. Tuazon, and C. Washburn. 1987. "Relating Forestry Investment To The Characteristics of Non-Industrial Private Forestland Owners in Northern California," in Forest Science, Vol. 33, No. 1, pp 197-209.

Romm, J. and C. Washburn. 1985. State Forest Policy and County Land Control: Their Effects on the Formation of California's Timberland Preserve Zone. Department of Forestry and Resource Management, University of California at Berkeley.

Romm, J. and C. Washburn with R. Tuazon and J. Bendix. 1987. "Public Subsidy and Private Forestry Investment: Analyzing The Selectivity and Leverage Of A Common Policy Form," in Land Economics, Vol. 63, No. 2.

Stewart, W. 1985. A Comparative Analysis of Forestland Use Regulation in Nevada and Placer Counties. Unpublished paper. Department of Forestry and Resource Management, University of California at Berkeley.

Tiebout, C. 1961. "An Economic Theory of Fiscal Decentralization," in National Bureau of Economic Research, Public Finances: Needs, Sources and Utilization. Princeton University Press, Princeton.

Vaux, H.J. 1983. "State Intervention On Private Forests In California," in R. Sedjo (ed.), Governmental Interventions, Social Needs, and the Management of U.S. Forests. Resources for the Future, Washington, D.C.

ACKNOWLEDGMENTS

Court Washburn, Sam Doak, Raul Tuazon, Bill Stewart, Mitch McClaran, Louise Fortmann, Lynn Huntsinger, and Judy Bendix have made significant contributions to the work upon which this paper is based. Pamela Muick and Robert Ewing provided valuable comments on earlier drafts.

Poster Session

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Acorn Production by Five Species of Oaks Over a Seven Year Period at the Hastings Reservation, Carmel Valley, California[1]

William J. Carmen, Walter D. Koenig, and Ronald L. Mumme[2]

Abstract: We measured acorn production of five species of oaks over a seven year period (1980-1986) at the Hastings Natural History Reservation in Carmel Valley. Our sample of 250 individuals includes 88 Quercus lobata, 63 Q. agrifolia, 57 Q. douglasii, 21 Q. kelloggii, and 21 Q. chrysolepis. Two measures–actual counts of acorns on the tree and an overall abundance score—allow us to examine individual, population and community fruiting patterns. Individual species showed enormous annual variation in acorn production. Q. chrysolepis was the most consistent in production, and Q. kelloggii the least. The oaks which set and produce acorns in one year and those requiring two years tended to fruit synchronously within groups and asynchronously between groups. In no year was there a complete community-wide crop failure, although in 1983 only Q. chrysolepis produced an appreciable crop.

Differences between oak species in annual crop abundance, consistency of production, and duration of acorn fall are important for two reasons. First, such differences have significant impact on populations of acorn consumers. Second, the pattern of acorn production is an important component of the oak's reproductive strategy. The heavy-seeded oaks may depend on animals for effective seed dispersal (Griffin 1971, Barnett 1976). Oaks benefit from animals caching and burying acorns due to increased dispersal distances and to improved survivorship compared to passive dispersal (Carmen, in preparation). However, these cachers and other animals consume large numbers of acorns as well. Oaks therefore face the conundrum of attracting acorn dispersing animals while at the same time facing overconsumption of their seeds. The pattern of acorn production may, at least in part, be adapted to serve these conflicting ends.

Several studies on oak production in the eastern U.S. describe periodic mast years of abundant acorns followed by periods of very low production (Downs and McQuilken 1944, Goodrum et al 1971). Sork (1983) identified three possible explanations for intermittent, yet synchronous production of abundant seed crops: 1) predator satiation (Janzen 1971); 2) attractiveness to dispersers and not their satiation (Barnett 1976); and 3) maintaince of disperser populations while limiting their growth (Janzen 1971). Each of these three hypotheses, while not mutually exclusive, leads to different predictions of how individuals, populations, and communities of oaks should produce acorns, and how the populations of acorn predators and dispersers might respond to these differences.

In 1980 we began a study of the fruiting patterns of five species of sympatric oaks at the Hastings Natural History Reservation in Monterey County, California. Our intent was to acquire long-term data on acorn production and on the corresponding changes in populations of two major acorn predators, the acorn woodpecker (Melenerpes formicivorus) and the acorn weevil (Curculio occidentalis), and a major acorn disperser, the California scrub jay (Aphelocoma coerulescens). Here we summarize our data for the seven year period through autumn 1986, concentrating on population and community patterns of the oaks.

STUDY AREA AND METHODS

The 900 ha Hastings Natural History Reservation, located in central coastal California, ranges in elevation from 467 to 953 m. Oak transects were established in foothill woodland, savanna-grassland, and riparian woodland vegetation types (Griffin 1983). At the lower elevations three species of oak (Q. lobata, Q. douglasii, and Q. agrifolia) are common, joined at

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986. San Luis Obispo, California.

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higher elevations by two additional species (Q. kelloggii and Q. chrysolepis). These five species include oaks of all three subgenera (Quercus: Q. lobata, Q. douglasii; Erythrobalanus: Q. agrifolia, Q. kelloggii; and Protobalanus: Q. chrysolepis), and both evergreen (Q. agrifolia, Q. chrysolepis) and deciduous (Q. lobata, Q. douglasii, and Q. kelloggii) species.

In 1980 we selected a sample of 250 oaks scattered througout the Reservation. The sample includes 88 lobata, 63 agrifolia, 57 douglasii, 21 kelloggii, and 21 chrysolepis. Over the study period two lobata, one douglasii, and one kelloggii died and were not replaced in the surveys making sample sizes in the latter years slightly smaller. At the height of the autumn acorn crop and before acorn fall in September or early October, we measured the relative abundance of acorns on each of the 250 individuals using two methods. First, two people scanned different areas of the tree's canopy and counted as many acorns as possible in 15 seconds. We then added the two counts for "acorns/ 30 seconds", a variable which ranged between 0 and 150, the upper bound limited by counting speed. Second, the tree was placed in a category as follows: 0 (no acorns), 1 (a few seen after close scrutiny), 2 (a fair number, acorns seen readily), 3 (a good crop, easily seen), and 4 (a bumper crop).

Our ability to count acorns and score the trees varies slightly with tree size, foliage density, and acorn size. However, the large variation in acorn production among individuals within and between years far overshadows this possible error, and hence we believe our data reflect realistic variation in the relative abundance of acorns both on the individual and population level. To examine the relative degree of variation in acorn production among species and years we used the coefficient of variation based on the log-transformed 30 second counts. Log transformation was necessary for two reasons: first, to remove the correlation between the mean and the standard deviation (Sokal and Rolf 1969); and second, because an increase in the 30 second counts on the low end of the scale (e.g. from 10 to 20) represents a much larger increase in the number of acorns compared to the same incremental increase on the high end (e.g. from 120 to 130).

The timing of acorn fall over the season was measured in 1982 employing the visual methods described above. 10 trees of Q. lobata, Q. douglasii, and Q. agrifolia were sampled monthly until no acorns could be seen. In 1984, we placed 4 0.25 m^2 acorn traps under the canopies of 2 trees of Q. lobata, Q. douglasii, Q. agrifolia, and Q. chrysolepis. Acorns from the traps were collected and counted on a weekly basis from August (before acorns fall) until late June when all acorns had fallen.

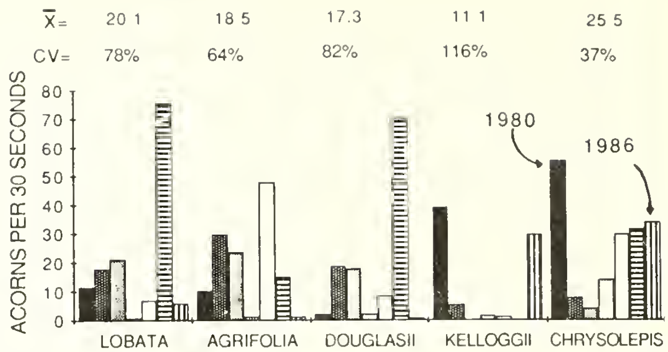

Figure 1. Acorn production (vertical bars) by five species of oaks from 1980 through 1986. Numbers above the bars are mean production and coefficient of variation over the seven years for each species.

RESULTS

Species Patterns

Mean annual acorn production by each species varied considerably over the seven year period (fig.1). However, the pattern of production differed among the species. Q. chrysolepis had the highest mean annual production over the seven years ($\bar{x}$=25.5 acorns/30 second count), and was the most consistent producer year by year as indexed by the coefficient of variation (CV=37 percent). In contrast, Q. kelloggii had the lowest production ($\bar{x}$=11.2), and was the least consistent between years (CV=116 percent).

The overall consistency of production is examined in figure 2 by comparing the distributions of acorn abundance categories for each species with all years

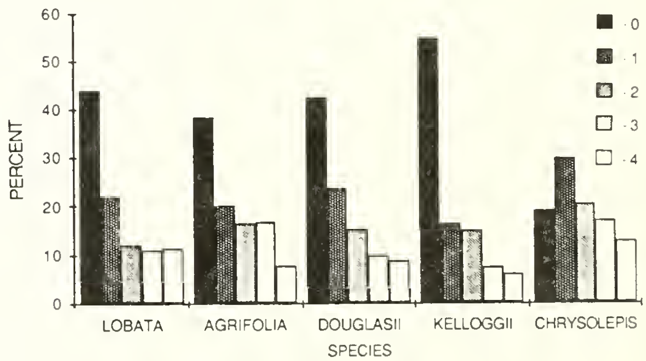

Figure 2. Overall proportion of acorn abundance categories for each species over the seven year study period. Greater consistency of acorn production is shown by a larger proportion in the 2,3, and 4 acorn abundance categories.

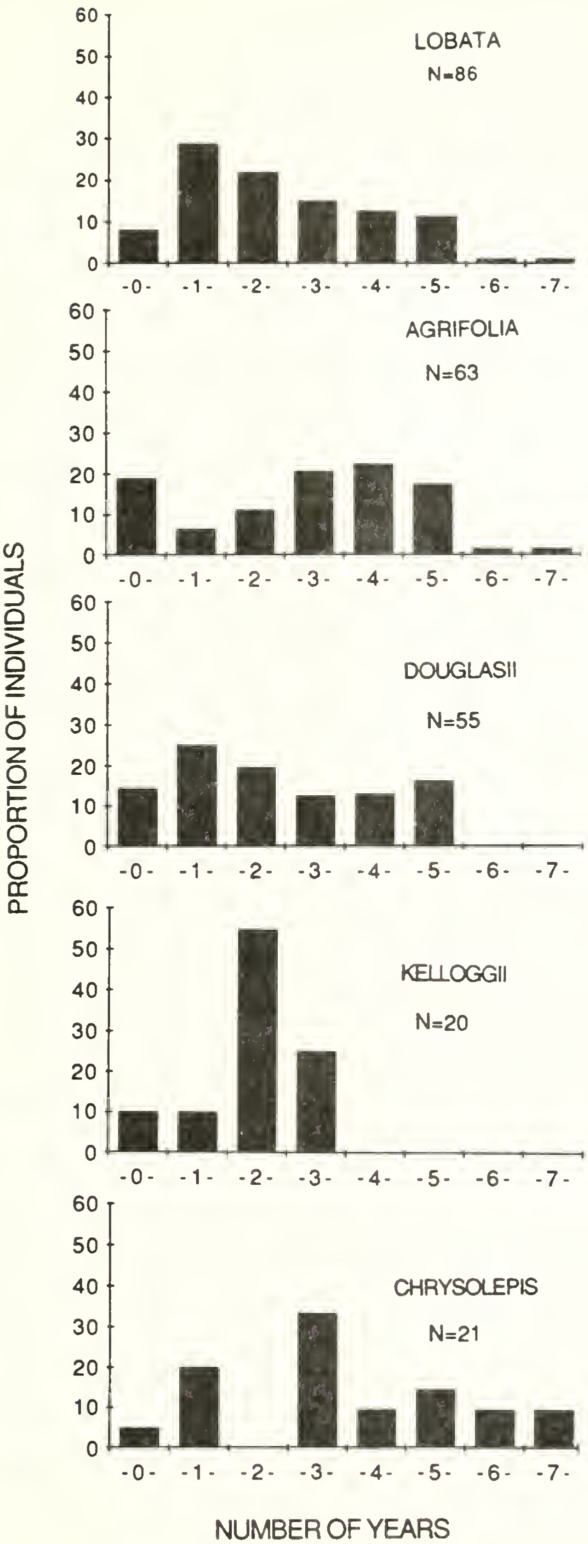

Figure 3. Number of years individual trees produced acorn crops of score 2 (a fair number) or above.

combined. Over the seven years, Q. chrysolepis had only 19 percent of the trees in the "0" (no acorns) score, and 50% with scores 2 and above. Again, Q. kelloggii was the least consistent with 55 percent of trees producing no acorns and 28 percent producing a crop of 2 or greater. The 5 species at Hastings in decreasing order of average productivity, consistency, and number of years with appreciable crops are Q. chrysolepis, Q. agrifolia, Q. lobata, Q. douglasii, and Q. kelloggii.

Mean annual values may mask significant variation in individual trees. However, these population patterns appear to reflect differences that can also be seen in the fruiting patterns of individuals. The number of years individual trees of each species produced appreciable crops follows the same pattern described above for the five species (fig. 3). For example, 43 percent of the 21 individual Q. chrysolepis trees produced acorns four or more years. The corresponding value for Q. lobata is 27 percent (23 of 86 trees) and for Q. kelloggii 0 percent (0 of 20 trees). Only seven trees (2.8 percent) out of our sample of 246 failed to produce any acorns (category 0) over the seven year period.

Sharp and Sprague (1967) suggest that the pattern of acorn production is influenced by weather conditions, and several lines of indirect evidence indicate that trees cannot produce adundant crops in successive years (Harper 1977). If this were the case we might expect that the the oaks which produce and mature acorns in one year (Q. lobata, Q. douglasii, and Q. agrifolia) and those requiring two years (Q. chrysolepis and Q. kelloggii) to produce synchronously within groups and asynchronously between groups. Correlations of mean annual production among the five species show this tendency (table 1), with positive correlations within the one and two year oak groups and negative correlations between groups. However, only Q. lobata and Q. douglasii had significantly correlated patterns of acorn production (Spearman rank correlation= 0.89, $p<.05$, table 1).

Table 1. Spearman rank correlations of acorn production by five species of oak using mean annual data (acorns per 30 seconds). N= 7 years.

	Q. lobata	Q.d.	Q.a.	Q.c.
Q. DOUGLASII	[1].89	---	---	---
Q. AGRIFOLIA	.50	.64	---	---
Q. CHRYSOLEPIS	-.21	-.39	-.39	---
Q. KELLOGGII	-.54	-.64	-.36	.50

[1] ($p<.05$)

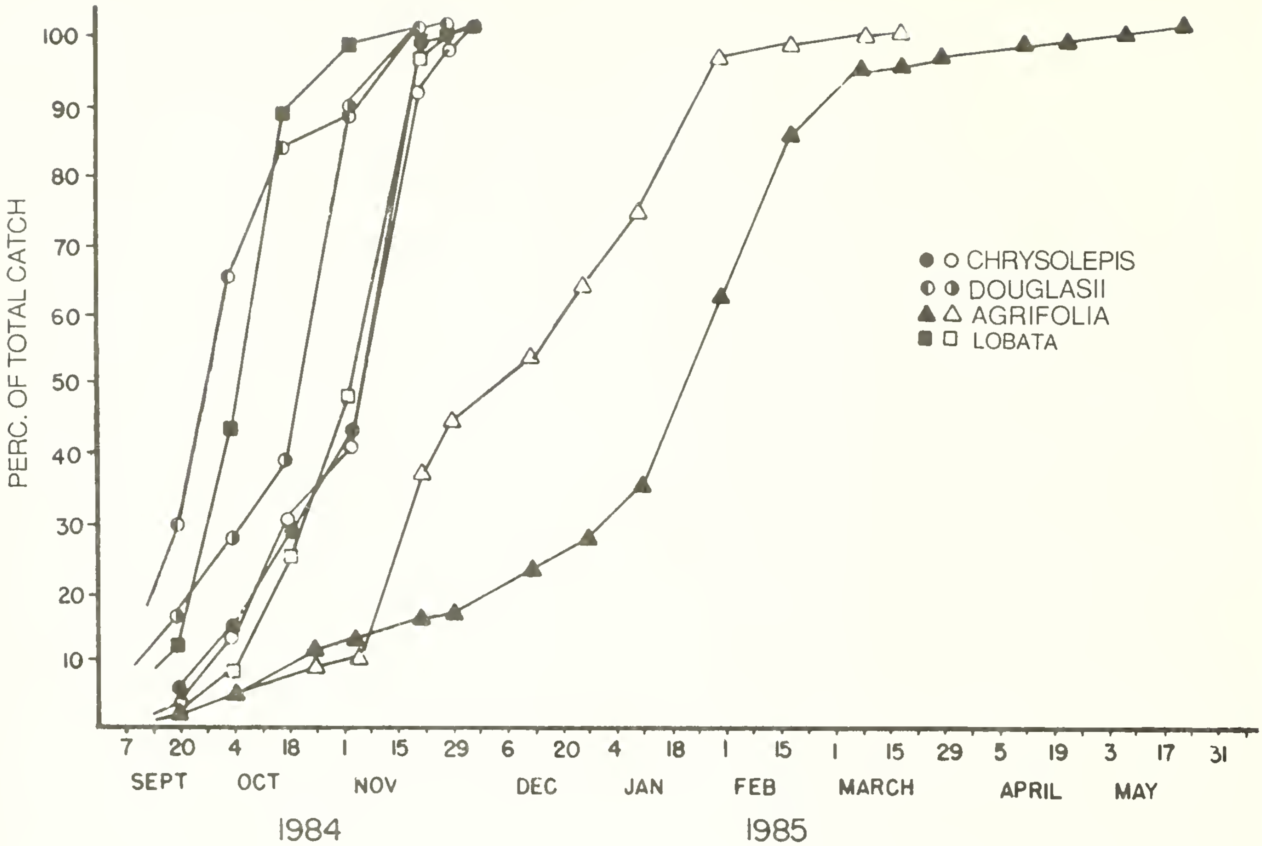

Figure 4. Seasonal pattern of acorn fall for four oak species shown as the cumulative percentage of total fall. Data are from two trees of each species using four acorn traps per tree.

We found no consistent correlations between 14 weather variables and the relative abundance of the acorn crops across these groups, nor was there a negative correlation between the size of the current crop and the previous years crop (Carmen and Koenig, unpublished data).

CROP DURATION

We monitored the timing of acorn fall of Q. lobata, Q. douglasii, and Q. agrifolia in 1982 and these species plus Q. chrysolepis in 1984. In both years Q. agrifolia acorns remained on the trees for a much longer period than the other species. In 1984 the other species had dropped more than 90% of their crops by early November, whereas Q. agrifolia still had large numbers of acorns in February, and some Q. agrifolia trees retained acorns through June (fig. 4). Acorns remaining on the trees escape high predation rates on the ground, are available to arboreal animals for extended periods, and have a much greater probability of being dispersed by acorn caching animals (Carmen, unpublished data).

COMMUNITY PATTERNS

The variation in mean annual acorn production is considerably less for the entire oak community than for each species (CV=34 percent for the oak community; CV=37-116 percent for individual species). Because the one year and two year oaks tended to produce acorns asynchronously, and even within the groups only Q. lobata and Q. douglasii had significantly correlated acorn production, low production by one species tended to be compensated for by high production by another. In no year was there a complete crop failure by all five species; however in 1983 only Q. chrysolepis produced an appreciable crop (fig. 5).

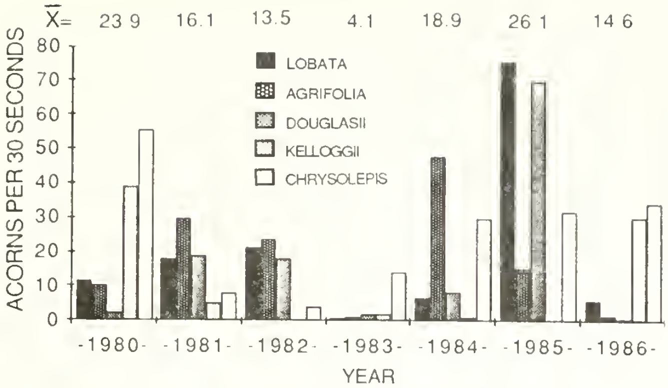

Figure 5. Annual acorn production for the five species oak community (30 second acorn counts). Numbers above the vertical bars are mean production by the five species for each of the seven years.

DISCUSSION

How often do crop failures occur and how large must the variance in production be to impact acorn predators and dispersers? Strategies of animals for coping with variable production include variable and extended diapause (acorn weevils), long distance migration (band-tail pigeons, Columba fasciata), acorn storage in specialized granaries (acorn woodpeckers), acorn caching in the ground (scrub jays), and use of alternative foods (mule deer, Odocoileus hemionus). These behaviors buffer the impacts of variable acorn production on these populations. Our data indicate that oak species tend to produce crops asynchronously, which decreases the variance in annual community-wide acorn abundance and reduces the chance of complete crop failures. Thus, as suggested by Bock and Bock (1974), in diverse oak communities crop failures by the combined species may be rare, and consequently populations of acorn predators and dispersers may be relatively high and fluctuate little. In less diverse oak communities, the variation in crop abundance is greater and the chance of a complete crop failure increases. For example, at lower elevations of the Hastings Reservation, only Q. lobata, Q. douglasii, and Q. agrifolia are common. In 1983, when only Q. chrysolepis produced an appreciable crop, acorn woodpeckers emigrated from the lower elevations (Hannon et al, 1987). Although many returned the following spring, the population was reduced over prior levels.

Q. chrysolepis and Q. agrifolia differ from the other species in two important ways: 1) Q. chrysolepis produced consistently good crops over the 7 year period, and 2) trees of Q. agrifolia retained acorns for as long as 8 months. These traits make these two species relatively more valuable to acorn consuming animals. Consistently good crops provide a reliable food source from year to year, and prolonged crop retention makes acorns available during the winter and early spring when other foods are in short supply. Wildlife managers and ecologists generally should take these factors into account when considering how human imposed and natural changes in oak community composition may influence animal populations.

These patterns, taken together with the characteristics of the acorns, may provide insights into an oak's reproductive strategy. For example, Barnett (1977) and Fox (1982) suggest that the lack of dormancy in the white oaks may be an adaptation to escape acorn predators through immediate germination upon acorn fall. The periodic large crops and the rapid synchronous acorn fall by Q. lobata and Q. douglasii, both in the white oak group, would contribute to the "escape in time" (sensu Janzen 1971) which Barnett and Fox propose for oaks in this subgenus. Q. agrifolia, with delayed germination, more reliable crops, and prolonged crop retention may rely more on "escape in space" through acorn dispersal and caching by animals. A more complete evaluation of these relationships awaits further work on fruiting patterns, acorn characteristics, and oak-animal interactions.

References

Barnett, R.J. Interactions between tree squirrels and oaks:the ecology of seed predation. Dissertation. Duke Univ. Durham, North Carolina; 1976.

Barnett, R.J. The effect of burial by squirrels on germination and survival of oak and hickory nuts. Amer. Mid. Nat 98:319-330; 1977.

Bock, Carl E., and Jane H. Bock. Am. Nat. 108: 694-698. 1974.

Downs, A.A., and W.E. McQuilkin. Seed production of southern Appalacian oaks. J. Forestry 42:913-920; 1944

Fox, J. Coevolution of white oak and its seed predators. Dissertation. Univ. Chicago, Chicago Ill; 1974.

Fox, J. Adaptation of grey squirrel behavior to autumn germination of white oak acorns. Evolution 36:800-809; 1982.

Griffin, J.R. Oak regeneration in the upper Carmel Valley, California. Ecology 52:862-868; 1971.

Griffin, J.R. Natural history of the Hastings Reservation. Unpublished MS. (On file at the Hastings Reservation); 1983.

Goodrum, P., V.H. Reid, and C. Boyd. Acorn yields, characteristics, and management criteria of oaks for wildlife. J. Wild. Mngt. 35:520-532; 1971.

Hannon, S.J., R.L. Mumme, W.D. Koenig, S. Spon, and F.A. Pitelka. Acorn crop failure, dominance, and a decline in numbers in the cooperatively breeding acorn woodpecker. J. Anim. Ecol; in press: 1987.
Harper, J.L. The Population Biology of Plants. Academic Press, London; 1977.
Janzen, D.H. Seed predation by animals. Annual Review of Ecology and Systematics 2:465-492; 1971.
Sharp, W.M. Evaluating mast yields in the oaks. The Penn. State Univ. Agri. Exp. Sta. Bull. 635; 1958; 22 p.
Sharp, W.M. and V.G. Sprague. Flowering and fruiting in the white oaks: pistillate flowering, acorn development, weather and yields. Ecology 48(2):243-251; 1967.
Smallwood, P.D. and W.D. Peters. Grey squirrel food preferences: the effect of tannins and fat concentration. Ecology 67:168-174; 1986.
Smith, C. and D. Follmer. Food preferences of squirrels. Ecology 53:82-91; 1972.
Sokal, R.R., and F.J. Rolf. Biometry. Freeman, San Francisco. 776 p. 1969.
Sork, V.L. Mammalian seed dispersal of pignut hickory during three fruiting seasons. Ecology 64:1049-1056. 1983.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Big Leaf Maple in Douglas-fir Forests: Effects on Soils; Seedling Establishment and Early Growth[1]

Jeremy S. Fried[2]

Three studies that examined the ecological role of bigleaf maple (Acer macrophyllum) in Douglas-fir (Pseudotsuga menzeisii) forests on the eastern margin of the Oregon Coast Range are summarized.

Problem 1: What are the effects of the presence of bigleaf maple trees and sprout clumps in Douglas-fir forests on soil chemistry and nutrient cycling relative to pure stands of Douglas-fir?
Findings: Litterfall biomass and nutrient content were significantly greater under maple than under Douglas-fir for every macro- and micro-nutrient on each of the 5 sites studied. Forest floor biomass and nutrient content were extremely variable and there were no significant differences among the two species. However, turnover rates for forest floor biomass and nutrients were considerably faster under maple for every nutrient on every site. Soil N and K were generally greater under maple while there were no consistent differences in amounts of Ca, Mg and P. Soil organic matter content under maple was significantly greater than under Douglas-fir on 4 of 5 sites. The greater soil nutrients and organic matter under maple may be attributed to the more rapid forest floor turnover in that system. Complete removal of bigleaf maple from commercial Douglas-fir forests could result in an overall reduction in nutrient availability because a larger proportion of the nutrient pool would be bound in the forest floor.

Problem 2: Which stages of Douglas-fir succession are conducive to the emergence and early survival of bigleaf maple seedlings? Does seed predation play a significant role? How does bigleaf maple survival depend on light intensity?
Findings: Emergence rates of seed protected from rodents averaged from 30 to 40 percent in all environments, but typically less than 2 percent of the unprotected seed emerged. Early survival is closely linked to canopy density. Thus, initial survival is highest in recent clearcuts and pole-sized stands (40-80 years) with little understory vegetation and low overstory stocking and lowest in dense, young conifer stands (15-40 years) and old stands (80+ years) with dense understory vegetation (fig. 1). Survival is related to percent sky, a canopy photo determined index of cover, as a step function with a critical light threshold of 15 percent sky, above which survival is high and below which survival approaches zero (fig. 2).

Problem 3: In which stages of Douglas-fir succession are bigleaf maple seedlings readily established, how quickly do they grow, and how are they distributed?
Findings: Natural populations of bigleaf maple seedlings are most abundant in 40 to 80 year old Douglas-fir stands (up to 10,000 per hectare) and typically were concentrated in 0.005-0.040 hectare aggregations under canopy openings 5 to 30 meters in diameter. While seedling size distributions throughout stands exhibited a strongly negative exponential form, size distributions appeared more normal (bell-shaped) within aggregations, and the range of seedling ages rarely exceeded 15 years. Seedlings grow slowly in the understory, often reaching only 25 cm after 10 years, and growth is frequently retarded by intensive browsing. Seedlings were virtually absent from clearcuts, most likely due to the density of competing vegetation and lack of seed.

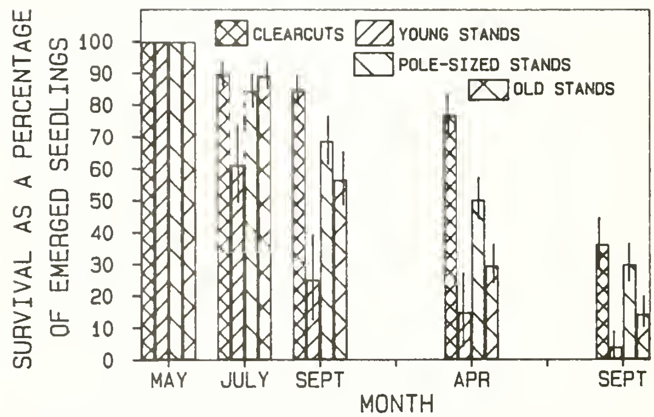

Figure 1--Survival of maple seedlings for 2 years after germination by overstory stand successional stage.

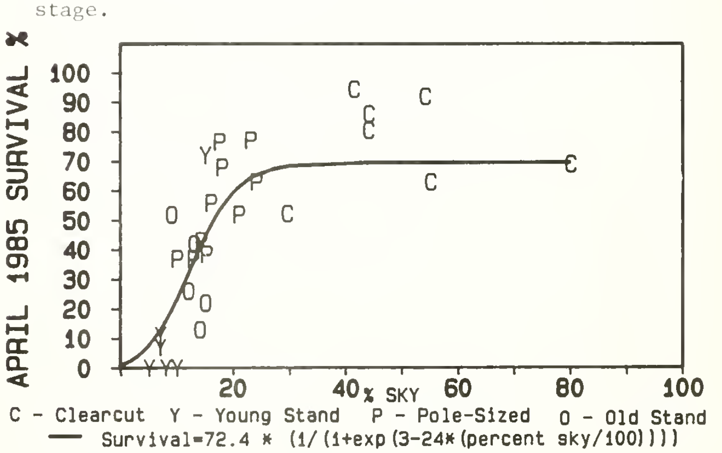

Figure 2--Maple seedling survival after 1 year in relation to canopy photo determined percent sky.

[1]Poster presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, San Luis Obispo, November 12-14, 1986.

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Current Research on *Eucalyptus* and *Casuarina* in California[1]

Miles L. Merwin[2]

Abstract: Several cooperative research programs involving government and private organizations are currently underway in California to improve the growth and yield of eucalypts and casuarinas for farm forestry. This report summarizes four current projects related to provenance trials, seed orchard establishment and saline drainage water irrigation.

Rising demand for nonfossil fuels for home heating has sparked a resurgence of interest in the planting of fast-growing exotic hardwoods on private farms and rural lands in California. Markets for eucalypt chips for paper pulp manufacture have recently started to develop as well. Both eucalypts and casuarinas have been grown overseas on farmland affected by high saline watertables, now a serious problem in portions of the San Joaquin Valley.

These factors have lead to an increase in the planting of Eucalyptus and Casuarina spp. for fuel and fiber wood production. Greater public interest has in turn led to research programs aimed at improving the potential growth and yield of eucalypts and casuarinas over a variety of environments. Four current research and demonstration trials on these trees have been initiated in cooperation with government agencies, nonprofit organizations and individual landowners: (1) provenance trials of river red gum (Eucalyptus camaldulensis Dehn.), (2) establishment of seed orchards of river red gum, (3) provenance trials of beefwood (Casuarina cunninghamiana Miq.), and (4) demonstration of saline drainage water irrigation of both species on Central Valley farmland.

RIVER RED GUM PROVENANCE TRIALS

River red gum is one of the more common eucalypt species planted in California for fuelwood, shelter and pulp chips. It is also a highly variable species, i.e. the growth rate and stem form of individual trees vary considerably both within and between provenances, or localities of seed origin. In Mediterranean climates, the Lake Albacutya (Victoria, Australia) provenance has exhibited superior growth over a wide range of sites compared to other temperate sources of river red gum (Lacaze 1978). Results of field trials of river red gum at Concord, California showed that while the Lake Albacutya source exceeded the average growth of other sources by 161 percent, other promising sources for the state were also identified from the same region of Australia (Ledig 1983). To locate the best seed source(s), adaptable to the broad range of climate and soils in California, will require more extensive field trials of river red gum provenances.

Toward that goal, an extensive seed collection of river red gum was made in 1985 in western Victoria by the C.S.I.R.O. Tree Seed Centre in collaboration with the U.S. Forest Service (Thomson and Merwin 1985). Seed was collected from 252 individual trees comprising 21 provenances in western Victoria, including Lake Albacutya (now a national park). Trees were sampled in a diversity of environments, including populations subject to natural selection pressure for tolerance of drought, frost or salinity.

Seedlings of these 252 open-pollinated families will be out-planted in spring 1987 at four sites in California under the direction of the U.S.F.S. Institute of Forest Genetics (Ledig 1986a). Plantations will be established in cooperation with the Department of the Navy at two Bay Area sites, Concord and Skaggs Island, with the Simpson Timber Co. at Anderson and with the Tejon Land Co. at Arvin, representing a wide range of soils, rainfall and temperature regimes. The trial is being coordinated with present and planned provenance trials in California of other eucalypt species, e.g. E. grandis, viminalis, globulus and nitens (Ledig 1983).

The purpose of this trial is to obtain information on variation within and between river red gum provenances, and to identify superior individuals and provenances capable of fast growth and tolerance of environmental stress (e.g. drought, frost, high water tables, and salinity). Although this process of screening seed sources will take approximately five years to complete, early results can be put to use immediately. Outstanding individual trees from the four test plantings can be clonally propagated as rooted cuttings and planted together in seed orchards. Flowering and seed production of river red gum as early as the third year has been observed in California and therefore planting stock from improved seed could be available for commercial plantations in the near future.

[1]Poster presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, Nov. 12-14, 1986, San Luis Obispo, California.

[2]Director, International Tree Crops Institute U.S.A. Inc., Winters, California.

SEED ORCHARD ESTABLISHMENT

The nonprofit Eucalyptus Improvement Association (P.O. Box 1963, Diamond Springs, CA 95619) has identified as a high priority goal for farm forestry the production of seed of the most promising eucalypt species from carefully selected sources. It has diagnosed a need to plant seed orchards in California due to the uncertainty of future supply of those Australian sources now in high demand, e.g. river red gum seed from Lake Albacutya. The availability of seedlings from superior seed-orchard seed would lead to an improvement in the productivity and economic viability of eucalypt plantations in California. With funding from the U.S. Forest Service, the E.I.A. has initiated a cooperative program of seed source selection and seed orchard establishment (Ledig 1986b).

River red gum has been chosen as the first species for seed orchard establishment because of present high demand for seedlings, easy vegetative propagation, and previous source testing in California. Although one small orchard could supply enough seed to satisfy all of the state's present annual demand for river red gum, replicate orchards will be established around the state both as protection against loss and as a test of growth performance in different environments.

In order to provide a broad genetic base in the initial seed orchard, each orchard will contain three individuals, or "ramets", each of 33 separate clones of selected trees. The opportunity for selection of superior trees from existing Californian plantations is limited because of the shortage of mature plantations of river red gum from known superior seed sources, e.g. Lake Albacutya. In view of this problem, the E.I.A. decided instead to choose the best seedling from each of the top 25 to 30 open-pollinated familes of the Lake Albacutya provenance currently being propagated for the river red gum provenance trials (described above). Also included will be the 'Dale Chapman' ('C2') clone developed at U.C. Davis, a selection from U.C. Cooperative Extension trials in Napa Co., and other selections to be made from existing Californian plantations. In order to achieve a high intensity of selection, only 1 to 2 trees showing superior size and form, for example, would be chosen in a plantation of five acres.

A total of six orchards will be planted in 1987. The orchards will be isolated from nearby groves of river red gum and related species. They will be established in cooperation with a variety of public and private landowners at: Chico (U.S. Forest Service), Davis (U.C.), Riverside (U.C.), Ardenwood (East Bay Regional Parks) and Modesto (Tri Valley Growers). After 3 years, ten to twenty clones that exhibit the best growth and form will be retained and the rest rogued out. The first seed crop following roguing will mature by summer 1990, the results of cross-pollination among tested clones. The most efficient means of seed harvest may be to fell the entire orchard, or a portion thereof, on an 8-year rotation, collecting the seed capsules and selling the stems for fuelwood. Because river red gum coppices readily, orchards will begin bearing seed within 3 to 4 years after harvest. Seed in excess of cooperators' needs will be made available to nurseries and invididuals through the E.I.A.

BEEFWOOD PROVENANCE TRIALS

Beefwood is a tall evergreen tree native to Australia that is widely cultivated overseas due to its rapid growth and tolerance of harsh conditions, including drought, wind, and salinity. It has been planted in California for windbreak, fuelwood, erosion control and amenity purposes.

Although beefwood has proven to be a successful species in California, it has not been systematically tested in the state. Toward this end, members of the recently-formed Casuarina Improvement Association (P.O. Box 888, Winters, CA 95694) will cooperate in a series of planting trials in California. The principal objective is to determine the extent of genetic variation between and within 13 provenances of beefwood collected in New South Wales, Australia. Seed was collected from native stands of beefwood (ten seed trees per provenance) in 1985 in cooperation with the C.S.I.R.O. Tree Seed Centre (Merwin & Roffey 1985). An additional aim is to select outstanding individuals that exhibit fast growth, desirable form and frost tolerance for commercial-scale propagation and future improvement programs.

Replicated provenance trials will be established at five sites in California in spring 1987. A complete set of 132 seedlots will be planted at Davis (Calif. Dept. of Forestry), Anderson (Simpson Timber Co.) and Woodland (J. Muller & Sons Farms). Six selected high elevation provenances will also be screened for cold tolerance at Oregon House (Renaissance Vineyard and Winery), a site that experiences average minimum temperatures in the range of 15-20 F. At the fifth site (Pacific Coast Producers, Oroville), wastewater effluent from a commercial fruit cannery will be used to irrigate casuarina seedlings.

One factor that allows casuarinas to grow on difficult sites is their ability to fix atmospheric nitrogen in root nodules that contain the symbiotic Frankia bacteria (N.R.C. 1984). Because strains of the bacteria specific to beefwood are not likely to be found in Californian soils, it is necessary to artificially inoculate seedlings with pure culture isolates of Frankia prior to outplanting Beefwood seedlings have been successfully inoculated under controlled environment conditions (Berry 1986) and nodulated seedlings will be planted at Davis to compare their performance with uninoculated but fertilized trees.

SALINE IRRIGATION DEMONSTRATION

Salinization of once highly productive farmland soil as a result of crop irrigation is a serious problem in the Central and Imperial Valleys of

California. According to recent estimates, 2.9 million of the 10.1 million acres of nonfederal land irrigated in the state are affected by high salinity (Backlund and Hoppes 1984). The recent closure of drainage canals serving the San Joaquin Valley due to concern over selenium pollution has forced growers to seek alternatives to disposal of drainage water from farm lands affected by high saline watertables.

The California Department of Food and Agriculture (CDFA) is currently investigating the potential use of salt tolerant trees to help mitigate problems of on-farm saline drainage water disposal (Cervinka 1986). This approach is based on the premise that trees will reduce the volume of drainage water by using approximately 5 ac-ft. per acre per year through evapotranspiration while producing an economic product (fuelwood, chips, etc.) that will offset the loss of conventional crop production on land set aside for drainage water disposal. It also presumes that soil salinity below the plantations can be managed to sustain survival and rapid growth of trees.

In 1985-86, CDFA established over 125 acres of demonstration tree plantations on 13 farms affected by high saline water tables on the Westside of the San Joaquin Valley from Buttonwillow to Mendota. The primary species currently under test are river red gum, beefwood, swamp oak (Casuarina glauca Sieb. ex Spreng.), and hybrid poplar (Populus X sp.). After initial establishment with freshwater irrigation, saline drainage water (up to 10,000 ppm) has been used. Soil salinity, groundwater depth, tree growth and heavy metal (e.g. selenium) uptake are being monitored over five years.

Funding is currently being sought for several research programs in support of CDFA's Agroforestry Program. One project would develop techniques for screening tree species for salinity tolerance in the greenhouse and then evaluate their growth, water use and heavy metal uptake over five years of saline irrigation in the field. A second proposed project would examine the economics of production and marketing as well as methods of harvesting, transporting and utilizing woody biomass from drainwater-irrigated farm woodlots. Another proposed project would explore the practical use of "biofilters" and identify plants which absorb and concentrate salts and heavy metals in harvestable form.

Acknowledgements: The author wishes to thank Tom Ledig, Institute of Forest Genetics, U.S. Forest Service, for critical review of the manuscript, and to acknowledge the work of Jeanne Martin and Laurie Lippitt, California Department of Forestry, and Roy Woodward, University of California Davis, in the production of the poster display upon which this paper is based.

REFERENCES

Backlund, Virgil L.; Hoppes, Ronald R. Status of soil salinity in California. California Agriculture 38(10):8-9, 1984.

Berry, Alison. Assistant Professor of Environmental Horticulture, University of California, Davis, CA. 1986. Personal communication.

Cervinka, Vashek. Demonstration of the capability of using the agroforestry concept to reduce the drainage problem in the San Joaquin Valley. 1986. Unpublished draft supplied by the author.

Lacaze, J.F. (Study of ecological adaptation of Eucalyptus: Study of provenances of Eucalyptus camaldulensis). In: Third World Consultation in Forest Tree Breeding, Docs. Vol. 1; Canberra: C.S.I.R.O.; 1978; 393-409.

Ledig, F. Thomas. Eucalypt improvement for California; progress and plans. In: Proc. of a Workshop on Eucalyptus in California; 1983 June 14-16; Sacramento, CA. Gen. Tech. Rep. PSW-60. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1983; 115-120.

Ledig, F. Thomas. Eucalypt research at the Institute of Forest Genetics, Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service. Eucalyptus Improvement Association Newsletter; 2-4; 1986a June.

Ledig, F. Thomas. Technical Committee report on seed orchard establishment. Diamond Springs, CA: Eucalyptus Improvement Association; 1986b. 3p.

Merwin, Miles L.; Roffey, Steven R. Seed collections of River Oak (Casuarina cunninghamiana Miq.) in New South Wales Australia. Forest Genetic Resources Information; 1985 (in press).

National Research Council. Casuarinas: Nitrogen-Fixing Trees for Adverse Sites. Washington, D.C.: National Academy Press; 1984. 118 p.

Thomson, Lex A.J.; Merwin, Miles L. Seed collections of Eucalyptus camaldulensis Dehnh. in western Victoria, Australia, May-June 1985. Forest Genetic Resources Information; 1985 (in press).

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

First Year Growth of Canyon Live Oak Sprouts Following Thinning and Clearcutting[1]

Susan G. Conard[2]

Canyon live oak (Quercus chrysolepis Liebm.) is one of the most widespread hardwood species in California. In southern California, it forms extensive closed-canopy stands intermixed with chaparral and conifer-forest communities. Many sites where canyon live oak occurs are prone to periodic severe fire. After these fires--or after harvesting--reproduction seems to be primarily by vegetative sprouting. Yet, we know little about the rate of sprout growth or about factors that affect sprouting vigor. Understanding regeneration of this species is needed for predicting responses to silvicultural treatments for enhancing fuelwood management, stand maintenance, and wildlife habitat improvement.

This poster paper reports preliminary data on sprouting characteristics of canyon live oak after clearcutting and thinning in southern California. The study objective is to evaluate the effects of these treatments on initial growth of stump sprouts.

The study area is at 1500 m elevation in the San Bernardino National Forest in southern California. Last burned about 100 years ago, it is dominated by a closed-canopy forest of canyon live oak, which grades into interior live oak (Quercus wislizenii A. DC. var. wislizenii) on ridgetops and shallow soils. Occasional big-cone Douglas-fir (Pseudotsuga macrocarpa [Vasey] Mayr.) and white fir (Abies concolor [Gord. and Glend.] Lindl.) are scattered throughout the study area.

Two harvest treatments (clearcutting and thinning) were laid out in a randomized complete block design with three blocks. Thinned plots are 30 by 40 m; clearcut plots are 20 by 30 m. Because there were two thinning treatments in the experiment (one in which thinning was the sole treatment, another in which the understory on thinned plots was later burned), there are twice as many thinned plots as clearcut plots. Understory burning was conducted after the data reported in this paper were obtained.

Thinning reduced basal area from 240 ft^2/acre (54 m^2/ha) to about 100 ft^2/acre (22.5 m^2/ha). Trees were harvested in winter 1984-1985 leaving stumps no taller than 6 in (15 cm). Sprout growth was measured in August 1985 on 15 randomly selected stumps per plot. On each stump, we recorded the number of sprouts and measured the length and diameter of each sprout.

Sprout growth in clearcuts was vigorous compared with that in thinned plots. This difference was evident for both mean height and number of sprouts per stump:

	Height (cm)	Sprouts/stump
Treatment:	$x \pm$ S.E.	$x \pm$ S.E.
Clearcut (n=45)	24.5±1.8	41.9±6.3
Thinned (n=90)	14.6±1.0	17.8±2.1

Differences in average height between treatments resulted primarily from large proportions of very short sprouts in thinned plots (Figure 1). About 50 percent of the sprouts in thinned plots were under 10 cm in height, while only 30 percent of the sprouts in clearcut plots were that short. Although maximum sprout height differed little between treatments, 14 percent of the clearcut sprouts were over 50 cm tall compared with less than 4 percent of the sprouts in thinned plots.

Canyon live oak sprouted vigorously following thinning and clearcutting. The most vigorous growth--both in numbers of sprouts and in sprout height--was observed in clearcut plots. The clearcuts and three thinned plots were burned in November 1985. Sprout growth measurements are continuing on the burned and unburned thinned plots and the burned clearcut plots.

Acknowledgments: The results in this paper would not have been obtained without the dedication and hard work of Bob Tissell, Tom Keeney, Wende Rehlaender, and Melody Lardner.

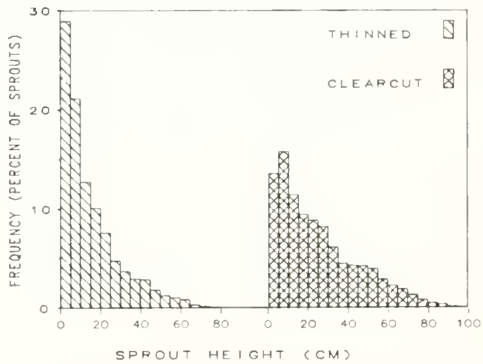

Figure 1—Frequency distribution of height growth for canyon live oak sprouts on thinned and clearcut plots.

[1] Poster presented at the Symposium on Multiple-Use Management of California's Hardwood Resources held at California Polytechnic State University, San Luis Obispo, November 12-14, 1986.

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Historical Review of *Quercus lobata* and *Quercus agrifolia* in Southern California[1]

Helen Treend[2]

Abstract: I will discuss the grass root community movement that led to the passage of the L.A. Citywide Oak Tree Ordinance, and the presentation of historical oaks. Quercus Agrifolia California Live Oak, and Quercus Lobata California White Oak were selected as trees to be preserved under the Los Angeles Citywide Oak Tree Ordinance. Historical oaks were included as part of an overlay zone. Historical trees must be 200-years-old, in good condition and have historical significance.

OPEN SEASON ON OAKS!!!!!!

In the early seventies bulldozers arrived in open pasture in Northridge, Woodland Hills, and Chatsworth in the city of Los Angeles and in Agoura, Saugus, and Newhall in Los Angeles County, and began uprooting oak trees. In the wake of this unprecedented move, the City of Los Angeles passed a policy instructing all departments to adopt policies to preserve oak trees. Such a condition would be an appropriate standard condition of all subdivision maps involving oak trees. The Street Tree maintenance joint report also envoked a statement that no trees be cut down between the hours of 6 a.m. and 7 p.m. on Saturday, Sunday, or legal holidays as one of the above cutting incidents had taken place on the fourth of July and began at 5:30 a.m. Prior to 1979, there was no legal method by which the City of Los Angeles could prevent a land developer from destroying oak trees before subdivision application.

Environmental Movement

The environmental movement of the seventies alerted private citizens that something had to be done. Massive destruction of oak savannahs by developers in Southern California gave rise to citizens groups amassing a petition drive to draw attention to the fact that a protective ordinance was urgently needed. Developers in their haste to clear their land before a protective measures were passed continued massive slaughter of oak trees. In Brown's Creek north of the projected Simi Valley Freeway at 6 a.m. on August, 1979, bulldozers arrived and within a few hours over 1,000 oaks were destroyed. Group sit-ins were conducted in Woodland Hills, Agoura, Chatsworth and other communities as the oak tree controversy escalated.

Citizens chained themselves to the oak trees and sat in the creek beds and the washes. Home videos were taken of contractors cutting and marketing oak for firewood. Injunctions were filed charging the City and County of L.A. with malfeasance for destroying visual entities, historical landmarks and ground water tables. A private war ensued. Over 7,000 signatures were gathered in preparation for battle at City Hall.

Injunction and Pending Litigation

One particular pending court case involved a prestigious area of land called Orcutt Ranch, a Cultural Heritage Monument and a Garden Center. Los Angeles City fathers had issued a contract for a 100 x 100 foot flood control box to replace Dayton Creek, a free flowing natural stream providing ground water table to 156 Eucalyptus trees and thirty-five oak trees. One particular tree was over 700-years-old and 34'11" in circumference. Local citizens held several meetings with city and county officials and decided to fight back when they learned that over one hundred and sixty trees were to be removed. Thirty-four trees were oak trees and all were historical. Since the contract had already been signed without the approval of the Environmental Impact Report the citizens demanded that one be filed. They were told that cutting was to begin at six a.m. the following day. At five thirty a.m. over one hundred residents stormed the area, tied themselves to the trees, and had a forty-eight hour sit-in at the creek. A human chain was formed around the windrow of Eucalyptus while the contractor cut down six trees. While television crews, police, and fire department were arriving, a stop order was being filed and citizens began collecting monies for the pending court case. Over $7,000 was raised in twenty-four hours. An injunction was filed by the newly formed citizen's group called Save Orcutt Community, Inc., suing the L.A. City Recreation and Parks Department, Los Angeles County Flood Control District and the City of Los Angeles. meanwhile, citizens continued to sleep in the creek and tied themselves to the trees to ward off the bulldozers.

Moratorium

City fathers passed a moratorium on May 9, 1979. Recommendations were:

[1]Presented at the Symposium on Multiple-Use Management of California Hardwood Resources. Nov. 12-14, 1986, California Polytechnic State University, San Luis Obispo.

[2]Central Michigan University. California State Northridge Environmental Quality Commissioner City of L.A. National Science Recipient. Bulletin-Orcutt Ranch.

a. To have developments compatible with limitations of the natural resources in conformance with existing Conservation and Open Space Plans, and community plans-restore the natural resources that were destroyed.

b. Protect private structures and private property downstream of owners.

c. Determine if imposition of Q conditions is warranted.

d. Red-flag undeveloped property so all agencies would be apprised of specific problems and long-term cumulative effects.

Advisory agency, by a matter of policy, require replacement of trees destroyed by the developer, prior to subdivision application (would discourage other subdividers from evading the E.I.R. and subdivision process by destroying trees prior to subdivision application).

Negotiations

With the moratorium in place and the injunction filed negotiations began. The following year citizens met regularly with the County Flood Control, L.A. City Recreation and Parks Department and City Hall to come to some reasonable conclusion on the Dayton Creek matter. The Flood Control District redesigned their channel allowing flood waters to be channelized under an existing street outside of the park and creek and a low bypass flow through the natural stream bed. This particular case called Treend vs. the City of Los Angeles was instrumental in pushing the City Fathers into passing the protective Oak Tree Ordinance for the City and County of Los Angeles.

Writing of the Ordinance

Local citizens, members of the Building and Trade Industry, and the Los Angeles City Planning Department met for over a year to write the protective oak tree ordinance. A collection of oak tree ordinances from other communities in California were researched. Under study were ordinances from San Bernardino who had adopted a preservation policy in 1973 in response to wholesale tree removal in Arrowhead and Big Bear; the 1970 ordinance of Carmel, and Thousand Oaks, Saratoga San Mateo-Heritage Tree ordinance of 1968. Most of these ordinances provided for a "meeting and conferring" period during which the "selling" of the good features of the tree were presented and an education program could be developed making the public aware of the assets of the tree. The City of San Mateo's Heritage Tree section was one which provided an extra feature that everyone approved. In their ordinance, language provided that:

Heritage Tree is defined as any of the following:

1. A tree which is of historical significance, specifically designated by official action; trees which have taken an aura of historical appeal.

2. A tree which is indigenous to this area or one which has adapted exceptionally well to the climatic conditions.

3. A stand of trees the nature of which makes each dependent upon the others for survival.

4. A tree which has a trunk with a circumference of fifty inches or more, measured at twenty-four inches above natural grade.

After a year and a half of negotiations, hearings, debate, and discussion the Los Angeles City Council passed the Oak Tree Ordinance in March, 1980. The Oak Tree Ordinance No. 153,478 protects Quercus Lobata's California White Oak, and California Live Oak. Quercus Agrifolia, eight inches in diameter, measured four and one-half feet above the ground. The Board of Public Works is the lead agency for oak tree permits.

Weakness of the Ordinance

Under Article 6 Sec. 46.00, many exemptions exist which act as loopholes. For example, a permit for relocation of an oak can be obtained because its continued existence at said property prevents the reasonable development of the property. The first test case on this matter took place in April 1981 in the community of Woodland Hills. After the Advisory Agency allowed transplanting to take place, all of the trees died. The developer blamed the City and the City blamed the developer. Ironically, the development was called The Oaks. The City, after the fact, asked the developer to replace the trees on a two to one basis. Transplanting and relocation is still in the experimental stage and only time will tell whether many of the methods now being used can be successful. Other problems in the ordinance involve Section 12.071 in which developers of large parcels of land can set aside open space areas for trees and reduce lot sizes overall by 50%. This practice changes the intent of good zoning practices as a ploy for saving the tree.

Testing the Ordinance

The first prosecution under the Los Angeles' oak-tree protection law involved the removal of four three-hundred-year-old Quercus Lobata trees located in the community of Chatsworth, by construction firm, Jason Company of Encino. The trees were marked and measured as historical trees by the Oak Tree Coalition and verified as historical by the Chatsworth Historical Society who stated that these trees were located at the site of the Southern Pacific Railway Station built in 1896 and the Chatsworth Inn built in 1897. Under the oak-tree ordinance, the misdemeanor called for a fine of $1,000 or six months in jail, for removal of the trees without a permit. On Jan. 30, 1986, the City of L.A. ordered the construction firm to pay $11,700. $10,000 of that must be earmarked for a trust fund to help defray the cost of trimming historical oaks throughout the city. In addition, the cost of purchasing and replanting eight fifteen foot tall oak trees is estimated to be $20,000. Still pending is the second phase of the case involving the grading contractor who bulldozed the trees.

Heritage Trees

The Heritage Section of the ordinance states that a tree 36" or greater in diameter can be designated as a Historical Monument or part of a Historical Preservation Zone.

An overlay zone pattern was adopted by the Oak Tree Coalition and measuring began. Most requests for an oak tree come from private citizens for trees on private property.

The following historical trees have been registerd and are a partial listing. Additional lists of trees are available upon request.

Robert W. Morgan Tree

On April 7, 1979 a group of concerned citizens appeared at the site of a large beautiful Quercus Lobata, (Coastal White Oak) near Marilla at 9700 north block near Topanga Canyon Boulevard in the community of Chatsworth. The citizens were concerned over the possible removal of this large and beautiful tree. Mr. Morgan had been doing a series of radio talk shows on the citywide proposed Oak Tree ordinance. In order for this tree to be historic or to be included in the Historical overlay for the City of Los Angeles, some historic event had to take place. This was our way to make a dedication. The Chatsworth Historical Society was there to present the historical background and make the official dedication. In 1890, this area was the center of Chatsworth and dedicated on maps as Chatsworth Park. The tree is near the location of the old Graves and Hill General Store, which also was the first Post Office in Chatsworth in 1910. (Chatsworth Historical Museum, Virginia Watson, Homestead Acre Museum, 10385 Shadow Oak Drive, Chatsworth, California) A plaque was presented to the Oak Tree Coalition, Mr. Morgan, and the Chatsworth Historical Society dedicating this tree. This plaque is located at the Homestead Acre Museum in Chatsworth Park South, 10385 Shadow Oak Drive, Chatsworth, California No. 1379-1. The tree is registered in the name of Mr. and Mrs. Gene and Arlene Vernetti and family. The tree is 9'2" in circumference and is over 300-years-old. No. 64-SAVE ORCUTT COMMUNITY NO.

Orcutt Ranch Horticulture Center

Rancho Sombra Del Roble, the oldest registered tree on this site is 700-years-old. The tree is a fine example of a Coastal Live Oak (Quercus Agrifolia). Each year it sheds massive amounts of acorns which are set aside, germinated, and grown in the greenhouse for new trees. The tree is 32'11" in circumference. Its root system lies beneath Dayton Creek, a natural stream bed that flows through the park. Large limbs were cut from this tree and others on the site to be used in the kiln manufacturing.

Bicentennial Oak

Orcutt Ranch Horticulture Center
23600 Roscoe Boulevard, Canoga Park, California
"Rancho Sombra Del Roble" "Ranch of the Shaded "Oak"

Orcutt Ranch Horticulture Center is Cultural Heritage Monument Number 31, and is owned and operated by the Los Angeles City Recreation and Parks Department. Oaks at this location are extremely large, varying in age from fifty to seven-hundred-years-old. It is known as "Rancho Sombra Del Roble (Ranch of the Shaded Oak). Many large beautiful Valley Oaks surround the estate and gardens. The Spanish mistook the magestic Valley Oak, with its broad, leafy crown and stout large limbs for the majestic well-known European Quercus Robur, and hence called it "roble." There are thirty-four oak trees at this site that are over two hundred years old and qualify for the Historical Overlay Zone, as well as Historical Monuments. One such tree is a large beautiful California Live Oak with the circumference of 32'11". Its root system lies in Dayton Creek. It is over 165' in height and had a magnificent span of 150' until the heavy rains of 1979. In February of that year a large limb split and fell to the ground, thus causing a weakening of one side of the tree. Severe pruning had to take place, thus altering its beautiful canopy. Remarkable history can actually be seen on this magnificent tree as the scars still remain today from the saws and makeshift tools where cuts were made to remove the limbs for wood in the nearby kiln manufacturing processes. Limbs were cut from this and many other trees at this site. Oak wood was chosen because of its longevity in burning and for its high temperature qualities.

This large and beautiful Coastal Live Oak from which the limbs were cut for kiln operations is known as the Bicentennial Oak. It was registered on July 4, 1976 by the Treend Family and is listed on the Binet Master File in Washington, D.C.

(Treend, Helen E. Research Orcutt Ranch Brochure) The plaque at this site states that William W. Orcutt, a renown geologist/paleontologist and early settler in the Canoga Park area known as Orcutt Ranch, wrote that the limestone outcroppings near his ranch, and at CAN 651 in the Chatsworth Reservoir are indeed Spanish period, and shows the ingenuity of the early colonizers of California and verifies the fact that intelligent natives were brought into the kiln operation. (Dentzel, Dr. Carl S. Los Angeles Municipal Art Department, City of Los Angeles, 1975) Kiln operations were located in this area because it was the most heavily wooded area in the San Fernando Valley and because lime, necessary in the manufacture of mortar, concrete, whitewash and bricks, was available. (University, Northridge. Dr. Roger Kelley field class, Spring, 1975)

Field Oak

J. A. Graves, author of "My 70 Years in California" wrote of a court case in which he was asked to remove squatters from a section of property owned by Mr. Van Nuys. (Graves, J.A. My 70 Years in California, 1927. L.A. Times Mirror Press) Mr. Van Nuys had been searching for documentation of boundaries and finally had hired Mr. Graves as his attorney, In preparation of his case, he contacted Mr. Romulo Pico, son of the famous Andres. Romulo took Mr. Graves to the Graves to the site and showed him the large cross marked in the trunk of the Quercus Lobata, (California White Oak). Also lodged in the bark was the number 39. Romulo said that he and his father marked the trees in this manner for the exterior lines of the track. This particular tree was the southwestern boundary. Each location was called a station. Mr. Graves won his case. This lovely tree is located at the private home of Mr. and Mrs. Skaral and family, 23263 Dolorasa, Woodland Hills. No. 65 Save Orcutt Community Inc.

Chatsworth Reservoir Oaks

Beautiful oak savannahs occur in the western portion of the reservoir facility, which is owned and operated by the Department of Water and Power. The area is fed by underground streams which flow from the Simi Hill watershed. This area supports both the Quercus Agrifolia (the California Live Oak) and the Quercus Lobata (the California White Oak). Trees are estimated to be from two to five hundred years old. They were all marked and measured in 1975 by Mrs. Treend and the biology class at Chatsworth High School.

Lassen and Topanga Canyon Trees (8 Quercus Lobata, Coastal Live Oak)

Mrs. Virginia Watson of the Chatsworth Historical Society stated that these trees are at the location of the southern Pacific Railway Station, built in 1896 and the Chatsworth Inn built in 1897.

Bell Oak--located in 280 acre plot of land in the west end of the San Fernando Valley, which contains cultural remains representing the entire span of history ranging from 2000 years ago to the present, where the Chumash Tongva village of huwam or jucjauyvit once flourished.

CA LAN - 783
CA LAN - 784

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Photographic Points for Monitoring Vegetation Dynamics in Oak Woodlands[1]

Jeffrey S. White and Wendell C. Gilgert[2]

A vital component of any resource management plan is the monitoring system. In ecosystems where domestic livestock grazing is a resource value (use) monitoring systems can measure and evaluate actual animal use, vegetation change, forage utilization, soil surface conditions, weather, and in forest and woodland situations, tree canopy cover. In both grazed and ungrazed oak woodlands an assessment of changes and trends in these characteristics gives the resource manager feedback on the response of the ecosystem to management activities.

Photographic points and plots can provide information about vegetation dynamics, forage utilization, tree canopy cover, and tree regeneration. Photographic points have been used to follow vegetational change (Mark 1978), biomass dynamics (Noble 1977), and range trend (Hall 1976). Additionally, photographs serve as effective integrators of information not readily indicated by quantitative or other descriptive means (Benson 1983). A monitoring system based on photographic points and plots can be used for assessing management on hardwood rangelands. Such a monitoring system is not complex and is easily implemented on privately owned land.

The monitoring scheme suggested consists of a series of photographic points located in key areas throughout a management unit. Depending upon the level of monitoring intensity and information desired, photo-point photographs (general landscape views)(Figure 1) may be sufficient. If detailed ground surface information is required, then photo-plot photographs (vertical photos of the ground) (Figure 2) are also used.

Photo-point photographs should be of a representative portion of the key area and include some sort of fixed landmark in the background - the horizon, a ridgeline, a peak or the like. The area photographed can also include specific management targets such as a gully or landslip.

The exact point from which photographs are taken can be marked with a fencepost, rock cairn, or as a point a fixed distance and direction from an existing tree or rock outcrop.

Photo-plots are 2 feet by 2 feet (0.61 meter by 0.61 meter) square quadrats photographed vertically from a standard height, usually about 4.5 feet (1.5 meters). These plots are located in clusters in the vicinity of a photo-point and have their corners permanently marked with short reinforcing steel stakes so that they may be easily relocated. The above-ground portion of the stake should be short so as not to attract stock. If possible, photo-plots should be photographed with the photographer standing on the north side of the plot to prevent his or her shadow from falling across the plot. It is often helpful to make a simple diagram of the plot and show the location and identity of perennial species.

Figure 1. Landscape photograph from a photo-point.

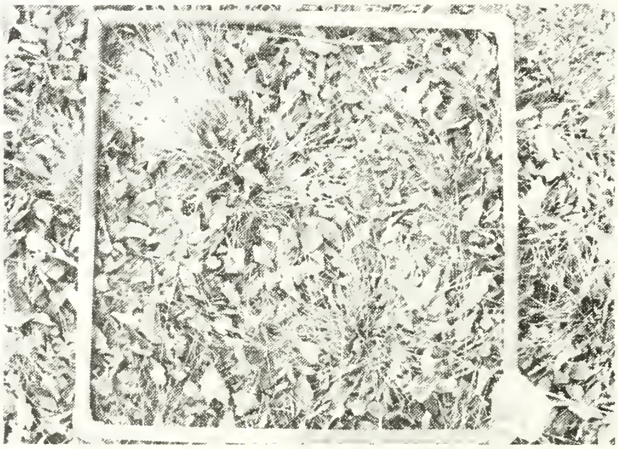

Figure 2. Photo-plot photograph.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, San Luis Obispo, California, November 12-14, 1986.

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The photo-points and plots are re-photographed at intervals determined by monitoring needs. As a minimum, photographs should be taken once a year during mid-spring. More information concerning response to management may be determined from several photographs per year. Timing of the photographs should coincide with important management related events such as peak standing crop, end of grazing period, and just before acorn drop.

If possible, camera and film size and type should be the same throughout the life of a monitoring station. A 35mm camera with a standard (50-55mm) or somewhat wide-angle lends is preferable. 35mm film is readily available and the standard or slight wide-angle lens gives a field of view similar to that of the human field of vision. There are many small, easily portable, and inexpensive 35mm cameras on the market. Some have 'data-backs' which automatically record the date on the film. Ease of use and portability are important considerations when selecting a camera for use at remote monitoring stations.

Choice of film is determined by the use of the photographs. Black and white prints are perhaps the best choice for long term records. They retain their sharpness and clarity over time while color prints will fade and undergo color shifts after several years. However, color prints or slides are often desirable for documenting changes in fall and spring vegetation color, soil color, and similar characters whose interpretation is dependent upon color. Color slides lend themselves to greater flexibility in evaluation such as enlargement and projection of photo-plot photos on dot-grid screens for cover determination. Perhaps the best approach is black and white prints with supplemental color prints or slides taken as needed.

Interpretation of data from the photographs is dependent upon the needs of the user and the information required. General changes can be assessed through the comparison of pairs of photographs from consecutive years (e.g. 1986 compared with 1987).

A technique developed by Noble (1977) can be used to evaluate changes between and among years. In this approach, pairs of photographs from consecutive years are compared to determine if the character in question increased, decreased, or remained the same. These year-to-year changes are then plotted in relation to each other on a graph. From the resultant plotted line, general trends can be detected and assessed. Figure 3 is an example of the trend in residual dry matter (RDM) remaining on the ground at the beginning of the rainy season. No tangible units are indicated on the RDM axis as changes are presented relative to each other as an index of change. Comparison between non-consecutive years (e.g. 1986 compared with 1990) can also aid in detecting long term trends.

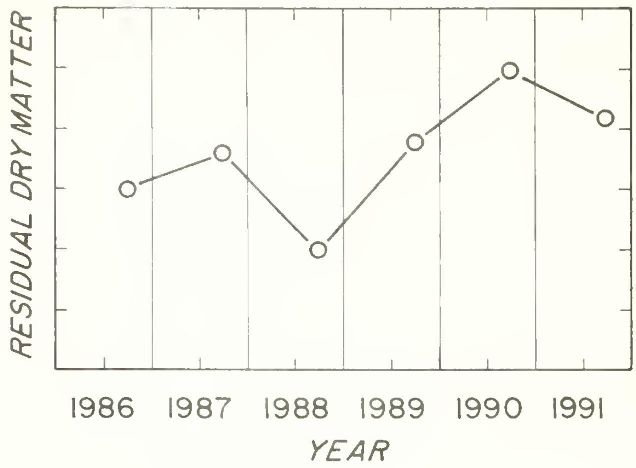

Figure 3. Example graph of changes over time in the amount of residual dry matter (RDM) remaining on the ground in the fall at a given photo-point.

Additional characteristics which can be easily evaluated by comparison of photographs include biomass production, forage and browse utilization, recovery of grazed or browsed plants, changes in plant density, understory composition changes, acorn production, and tree and shrub regeneration.

References

Benson, R.E. Using photos to extend resource inventory data. In: Bell, J.F. and Atterbury, T., editors. Renewable resource inventories for monitoring changes and trends: proceedings of an international conference, August 15-19, 1983. Oregon State University, Corvallis, OR. 1983; 349-352.

Hall, F.C. Range trend sampling by photographs. R-6 Regional Guide 2-1. USDA Forest Service, Pacific Northwest Region, Portland, OR. 1976. 50p.

Mark, A.F. Permanent photographic points for following vegetation changes. J. Tussock Grassland and Mountain Lands Institute 37:38-45; 1978.

Noble, I.R. Long term biomass dynamics in an arid chenopod shrub community at Koonamore, South Australia. Aust. J. Bot. 639-653; 1977.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Prescribed Fire for Restoration and Maintenance of Bald Hills Oak Woodlands[1]

Neil G. Sugihara and Lois J. Reed[2]

Abstract: Redwood National Park has initiated a program of prescribed burning in an effort to maintain it's oak woodland resource. Re-introducing periodic fire in conjunction with manual conifer removal can successfully restore the threatened Oregon white oak (*Quercus garryana*) ecosystem. Following fire, all tree and shrub species native to the woodlands die back and all except Douglas-fir (*Pseudotsuga menziesii*) vigorously resprout. Herbs responded with a flush of growth and the presence of native species not common to the unburned woodland. Most importantly, the integrity of the oak woodland can be maintained by controlling conifer forest encroachment. Periodic low intensity burning can result in long-term preservation of one of California's threatened oak woodland types.

Fire is a primary environmental factor influencing the development and maintenance of Oregon white oak woodland and grassland communities within the coast redwood (*Sequoia sempervirens*) forest. Prior to the arrival of man, naturally occurring fires originating primarily in the hot, dry interior would have periodically burned into the narrow, coastal redwood belt. For approximately 6,000 years prior to European settlement, Native Americans regularly burned the bald hills, profoundly affecting the vegetation of the area (Thompson 1916, King and Bickel 1980,Lewis 1973). The resulting vegetation was a mosaic of oak woodland and grassland referred to as bald hills. Bald hills oak woodland ecosystems occur from Humboldt and Trinity Counties south to Napa County (Griffin 1977).

At the time of European settlement in the 1850's, extensive areas of north coastal California supported bald hills vegetation (Wistar 1937). In 1948, 19 percent of the region supported oak/grass communities (Wieslander and Jensen 1948, Storie and Wieslander 1952). Redwood National Park (RNP) is located near the northern end of the bald hills oak woodland geographical range. In what is now the park, pre-settlement bald hills occurred in equilibrium with adjacent coast redwood forests. Centuries old redwoods stood immediately adjacent to open woodlands and grasslands (Sugihara and Reed 1987). The fires which once excluded conifers from the oak/grass community have become less frequent with changes in land management and effective fire suppression.

Presently, one-third of this vegetation is converted to coniferous forest. Half of the remaining woodlands are threatened by the presence of sufficient Douglas-fir to potentially dominate the canopy. Succession is eventually to *Sequoia/Pseudotsuga* forest (Sawyer et al. 1977). Conifer forest encroachment is region wide and loss of the only oak woodland type in north coastal California is possible if this pattern is allowed to continue (Reed and Sugihara 1987).

Maintaining natural ecosystem diversity is one of the primary objectives in management of the park's resources (U.S.D.I. 1982). The National Park Service recognizes the importance of fire in stimulating, retarding or eliminating various components of ecosystems. In ecosystems modified by the prolonged exclusion of fire, prescribed fire is used to restore vegetation composition to a pre-settlement state. Prescribed fire is required in park areas because most natural fires originated outside park boundaries and these are now suppressed (Kilgore 1984).

This study was initiated to determine the feasibility of using fire to restore and preserve the oak woodland component of RNP's vegetation. This paper discusses the ecological role which fire plays in the bald hills and the potential effects of reintroducing fire by management prescription.

FIRE HISTORY

Evidence of past fire occurrence was obtained from basal cross-sections collected from Oregon white oak trees within the park. Composite fire histories for the three locations studied are diagrammed in figure 1. Although trees rarely showed external evidence of scarring, records of multiple fires were found in each of the three areas studied. Fires have become less frequent in the past four decades. Excluding prescribed fires, evidence was found for only two small, scarring fires occurring since 1948. Reduced fire occurrence is primarily due to increased efficiency of fire suppression efforts in recent years.

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[1]Poster presented at the Symposium on Multiple-use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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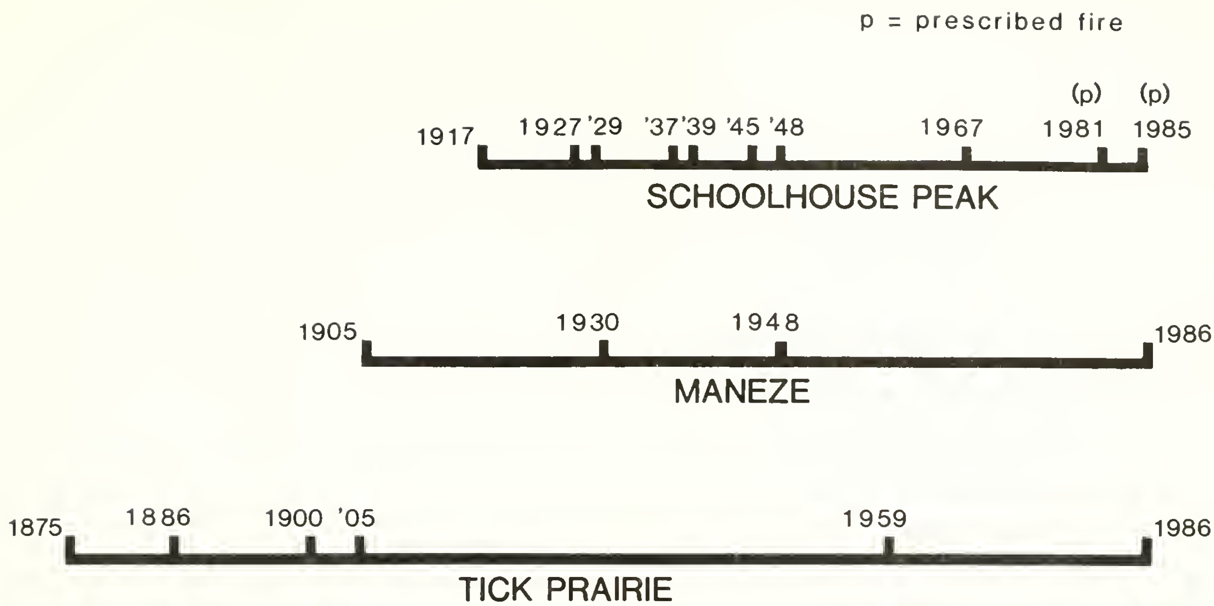

Figure 1--Composite fire histories for three oak woodland locations within RNP. Years at the ends of lines indicate the period of record. The left end represents the date of stand establishment and the right end is the date sampled. Numbers along lines date fire scars.

The Schoolhouse Peak site is located at 750 meters elevation near the ridgetop in the part of the park with the least coastal influence. This site had evidence of more fires than any other studied with six fire occurrences in the period between 1927 and 1948. Distinct even-aged stands of oaks originated following each pair of fires (1927/1929, 1937/1939, 1945/1948). The 1948 fire was described by a local resident as very intense and having a significant impact on the vegetation (Severtson 1986). The only scarring fires found which ocurred since 1948 were in 1967 and prescribed burns in 1981 and 1985.

Maneze is a mid-slope site at 500 meters elevation. The only fire scar records are for 1930 and 1948. The oak stand is even-aged and originated between 1905 and 1910. Douglas-fir has heavily encroached here since 1948 and is presently co-dominating the canopy.

Tick Prairie is an isolated, lower slope prairie located at 150 meters elevation which is well within the summer coastal fog zone. The scar record shows that fires occurred here fairly frequently until 1905. The only record of fire since 1905 is in 1959. The oak canopy trees originated following fires in the late 1800's and early 1900's.

In 1981 a three acre prescribed burn was conducted in the oak woodlands to determine the influence of burning on vegetation. In 1985, an eighty acre prescribed burn was conducted. Both were low intensity surface fires located in areas near Schoolhouse Peak. The following summarizes the vegetation response to fire based on fire history and interpretation of the prescribed burns.

THE INFLUENCE OF FIRE ON OAK REPRODUCTION

Sugihara et al. (1983) describe three kinds of oak stands in RNP. Characteristics of these stands are listed in Table 1. Young, dense stands are composed of even-aged stems which originated following fires in 1945 and 1948. Clustered oak stands are composed of even-aged trees 70 to 100 years old. All-aged stands have their oldest individuals exceeding 300 years of age.

Very few canopy but many, small subcanopy oaks are killed by low intensity surface fire. Following burns, basal sprouting is widespread. Sprouts form dense clusters from the bases of both live and top killed trees. Sprouting is more intense from 40 year old than 70 year old trees. Large, older trees sprout even less vigorously. Sprouts grow rapidly, attaining as much as a meter of height during the first season. By contrast, seedlings initially grow more slowly, requiring a decade or more to obtain the meter of height.

Comparing fire history with oak age structure reveals reproductive flushes follow scarring fires. Oak stems are often clustered and grow together at their bases, suggestive of sprout origin from a single parent. Trees aged at both the base and breast height show small age differential, indicative of rapid initial growth, and suggesting sprout origin. Some stands contain multiple age classes, but each class is distinct and originated following a scarring fire. Stand establishment dates on figure 1 probably correspond to fire stimulated sprouting which originated the stand. Trees of sprout origin are typically clustered. In 70-100 year old stands, the trees are clustered. However,

Table 1. Characteristics of Oak Stand Types

STAND TYPE	STEMS /HA (#)	DBH (cm)	AVERAGE CANOPY COVER (pct)	AGE CLASS (years)
YOUNG-DENSE	4,500-12,000	<12	90	34-37
CLUSTERED	740-2,550	10-30	86	70-100
ALL-AGED	60-530	all-size	76	all-aged

young, dense stands which are the result of repeated sprouting of young oaks following fires are uniformly distributed, not clustered. A previously unreported type of oak sprouting was found which explains this uniform spatial distribution. Top killed trees sometimes form underground runners extending as much as 2 to 3 meters from the base before emerging. Resulting sprout clusters are wider than the original individuals and develop into stands of clustered trees (Sugihara and Reed 1987). Repeated high resprouting, eventually leading to evenly spaced, dense oak stands.

Five important silvicultural characteristics of Oregon white oak have been observed at RNP:

1) Fire stimulated basal sprouting of oaks whether the individual tree is killed or not.
2) Young sprout and seedling mortality is very high in any occurrence of fire.
3) Because Oregon white oak is intolerant of shade (Miller and Lamb 1985, Silen 1958), sprouts and seedlings require canopy gaps to receive sufficient light to develop into trees.

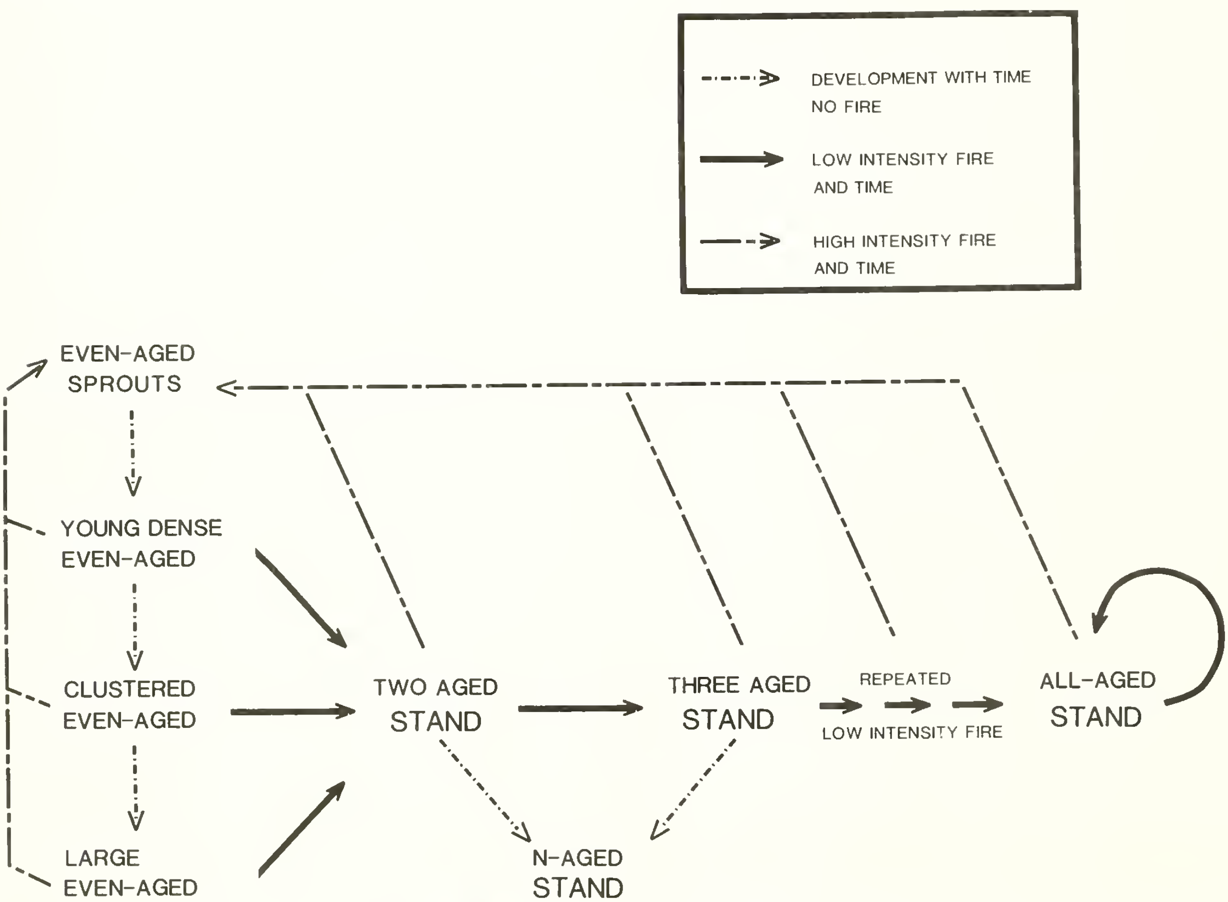

Figure 2--Flow chart projecting the development of oak stand structure in relation to occurrence of no fire, or high and low intensity fire.

4) Low intensity fire creates a few gaps but generally leaves the canopy intact. Low intensity describes any fire that remains in the understory and does not result in the significant mortality to the overstory trees.
5) During long intervals without fire, any sprouts and seedlings that are present in openings can develop into a well defined age class of canopy trees.

Regeneration patterns for *Q. garryana* in this habitat may be deduced by utilizing this information. Fire frequency controls stand structure by influencing the oak reproductive cycle as follows:

1) Long intervals between fires allow sprouts or seedlings which receive sufficient light to develop into individuals too large to be eliminated by a subsequent surface fire.
2) Long fire free intervals following high intensity, canopy killing fire result in much sprouting, leading to even-aged stands.
3) Regular occurrence of low intensity fire results in low turnover in the canopy and constant regeneration. Typical of pre-settlement times, this regime results in all-aged stands.

A flow chart relating stand development and fire occurrence is diagrammed in figure 2. The long term response of a stand to various fire regimes is projected.

Low intensity fire probably occurred annually or every few years before settlement. Sprouting stimulated by each fire was followed by high sprout mortality in subsequent fires. The long term result was a small amount of successful regeneration distributed throughout many years producing stands without dominant age classes. This all-aged stand structure corresponds with the descriptions of the early settlers (Wistar 1937).

During the post-settlement years, infrequent high intensity, canopy killing fire occurred in some stands. Many years followed without subsequent fire to thin sprouts, stimulate additional sprouting and open the canopy. Sprouts developed into small, densely spaced trees and eventually to stands of even-aged larger trees. Within RNP, these event originated, even-aged stands are the most common. Older individuals exceeding 300 years of age are found scattered in the young stands or in the all aged stands which have escaped catastrophic fire and other canopy removing events.

Future management will determine the future structure of the oak stands. Regular occurrence of low intensity fire can result in more all-aged stands dominated by large, old individuals. Effective fire control with no prescribed burning will allow existing even-aged stands to develop dominated by distinct age classes. Restoration of pre-settlement, all-aged stand structure will require the reintroduction of a near pre-settlement fire regime.

THE INFLUENCE OF FIRE ON PLANT SPECIES COMPOSITION

Though represented by just 600 acres, oak woodlands are the most species rich plant community in RNP. Over three hundred species have been identified, of which 74 percent are native and 26 percent introduced (Sugihara and Reed 1987).

Following the prescribed fires in 1981 and 1985 there was a strong flush of herbaceous growth. Oregon geranium (*Geranium oreganum*), Blue field gilia (*Gilia capitata*), California tea (*Psoralea physodes*) and Scouler's St. John's wort (*Hypericum formosum*) are species found in oak woodlands only following burns. Several other species are only abundant following fire. In general, fire was observed to favor forb cover domination over grass cover. Within five fire-free years after fire the herbaceous layer cover was observed to shift back toward grass domination.

All of the tree and shrub species common to the park's oak woodlands are native. With the exception of Douglas-fir, all are also well adapted to surviving fires by sprouting after being burned. Shrubs which were top killed by the prescribed fire grew back vigorously the following season. Although fire likely influences reproduction in several woody species, only Douglas-fir was severely reduced in occurrence by low intensity fire.

THE INFLUENCE OF FIRE ON DOUGLAS-FIR ENCROACHMENT

The most immediate threat to the oak woodland ecosystem is encroachment of the conifer forest. Before settlement, young Douglas-fir trees colonizing the bald hills would have been killed by the frequent fires. With introduction of fire suppression and the subsequent reduction of fire frequency, Douglas-fir establishment has proceeded without control. Douglas-fir stands that have become established under the oak canopy are often dense and originated during a fire-free period. Long fire free periods allow the seedlings, which are continuously being established, to survive and attain a fire resistant size. Once Douglas-fir is well established, fire can no longer control it effectively. The rapidly growing, dense canopy of conifers soon shade out the herbaceous layer. Within 3 to 4 decades conifers overtop the oak canopy, shading out the oaks.

If the bald hills oak woodlands are to be maintained, Douglas-fir forest encroachment must be controlled. Douglas-fir trees less than 3 meters tall suffered very high mortality in the

1981 prescribed fire. However, few trees taller than 3 meters were killed (Sugihara et al. 1982). Thus, for low intensity fire to effectively control the continuous establishment of Douglas-fir, fires must be frequent enough to prevent Douglas-fir from reaching 3 meters in height. Within the park's oak woodlands, approximately 10 years are required for a Douglas-fir seedling to grow to 3 meters height (fig. 3).

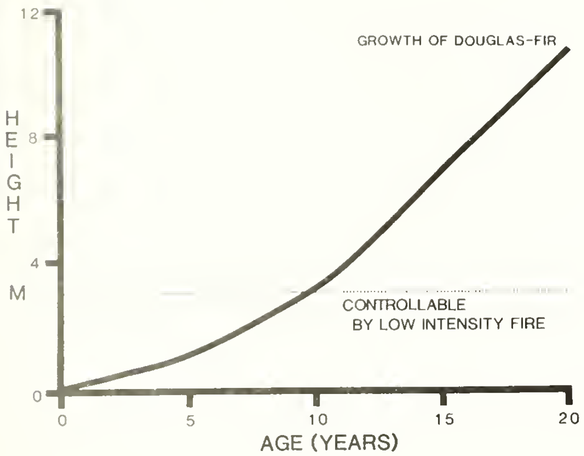

Figure 3--Growth of Douglas-fir during the first 20 years. Trees effectively controlled by fire are under 3 meters in height.

DISCUSSION: THE ROLE OF FIRE IN NATIONAL PARK MANAGEMENT

Fire must play an important role in the maintenance of a natural bald hills oak woodland community within RNP. Prescribed fire has the potential to restore stability to the oak woodland community. Exclusion of fire has allowed successional replacement of oak woodlands and prairies by conifer forest. The result is an overall reduction in both ecosystem diversity and plant species richness. Without reintroduction of fire, loss of bald hills oak woodlands will continue (Reed and Sugihara 1987). Several factors other than fire undoubtedly have an influence on the establishment and growth of Douglas-fir in bald hills oak woodlands. Soil patterns, possible climate changes and the impacts of humans, wildlife and livestock are potentially important influences on forest/woodland dynamics. These other factors, while potentially important, do not exclude Douglas-fir. Present conditions, including these influences, allow the easy establishment and rapid growth of Douglas-fir. Fire remains as the dominant controlling factor which prevented the conversion of bald hills oak woodlands to conifer forest. Re-establishment of frequent fire will prevent development of the conifer forest and maintain oak dominance.

Use of fire to maintain natural ecosystem diversity contributes directly to the achievement of RNP's primary resource management goal: to restore and maintain the natural ecosystems of the park as they would have evolved without disturbance by human technology. In the bald hills, the Park Service has the opportunity maintain a seriously threatened ecosystem by the reintroduction of a pre-European-settlement environmental factor. Prescribed fire returns one of the key environmental factors under which the ecosystem developed and was sustained. Regular occurrence of fire will gradually return the oak stands to an all-aged structure, dominated by large old trees, from the present young, even-aged, event originated stands. Stable boundaries between coniferous forest and the oak/grass communities of the bald hills can be restored with a consistent program of prescribed burning.

Prescribed fire frequency is premised on halting Douglas-fir establishment and controlling oak regeneration. Annual or nearly annual burning would most accurately simulate pre-settlement conditions. A minimum frequency of 5 years appears necessary to effectively maintain the oak woodlands as a distinct community. Stable vegetation patterns might be obtainable by burning every 10 years, but it is impractical to expect complete coverage in any burn. Therefore, regular occurrence of low intensity, prescribed fire on a 5 year interval is probably sufficient to sustain the bald hills oak woodlands.

There are two management options for owners of intact oak woodlands with abundant Douglas-fir which are already established, more than 3 meters tall and fire resistant. Restoration of the oak woodland can be accomplished by manually removing Douglas-fir by cutting or girdling. A program of prescribed burning is then necessary for long-term maintenance. The second option is to allow conifers grow and manage the area permanently as conifer forest. Specific management objectives will dictate the direction is which is appropriate for individual landowners.

REFERENCES

Griffin, J. R. Oak Woodland. In: Barbour, M. G.; Major, J., eds. Terrestrial vegetation of California. New York, NY: Wiley Interscience.; 1977:384-415.

Kilgore, B. M. Restoring fire's natural role in America's wilderness. Western Wildlands. 10(3):2-8; 1984.

King, A. G.; Bickel P. McW. Resource evaluation at nine archaeological sites, Redwood Creek basin, Redwood National Park, California. Arcata, CA: National Park Service, Redwood National Park.; 1980.

Lewis H. T. Patterns of Indian burning in California: ecology and ethnohistory. Ramona, CA: Ballena Press.; 1973. 101 p.

Miller, H. A.; Lamb S. H. Oaks of North America. Happy Camp, CA: Naturegraph Publishers, Inc.; 1985. 317 p.

Reed, L. J.; Sugihara N.G. Northern oak woodlands - Resource in jeopardy, or is it already too late? 1987 (These proceedings).

Sawyer, J. O.; Thornburgh, D. A.; Griffin, J. R. Mixed evergreen forest. In: Barbour M. G.; Major,J., eds., Terrestrial vegetation of California. New York, NY: Wiley Interscience.; 1977:359-381.

Severtson, A. Former Bald Hills area resident. Personal communication. 1986.

Silen, R. R. Silvical characteristics of Oregon white oak. U.S.D.A. For. Serv. PNW Silvical Series No. 10; 1958. 13 p. Portland, OR.

Storie, R. E.; Wieslander, A. E. Dominant soils of the redwood-Douglas-fir region of California. Soil Sci. Soc. Amer. Proc. 16:163-167; 1952.

Sugihara, N. G.; Hektner, M. M.; Reed L. J.; Lenihan J. M. Oregon white oak woodlands of Redwood National Park: description and management considerations. In: Van Riper, C. III; Whittig L. D.; Murphy, M. L., eds., Proceedings of the first biennial conference of research in California's National Parks; 1982 September 9-19; Davis, CA. Coop. Park Studies Unit, Univ. of California, Davis; 1983:177-182.

Sugihara, N. G.; Reed L. J. Ecology and management of bald hills oak woodlands in Redwood National Park. Redwood National Park Technical Report; 1987. In press.

Thompson L. To the American Indian. Eureka, CA: Cummins Print Shop.; 1916. 214 p.

U.S.D.I.-National Park Service. Redwood National Park Resource Management Plan; 1982.

Wieslander, A. F.; Jensen H. A. Forest areas, timber volumes and vegetation types in California. Forest survey release no. 1, California Forest and Range Experiment Station; 1948 March 1. Berkeley, CA.

Wistar, I. J. Autobiography of Issac Jones Wistar, 1827-1905, half a century in war and peace. Philadelphia, PA: Wistar Institute of Anatomy and Biology.; 1937.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Eucalyptus Trials at Fiddletown, Amador County, California[1]

David W. Raney[2]

With the renewed interest in growing eucalyptus for fuel and fiber, the Bureau of Land Management is cooperating with the USDA Forest Service in the seed source variation studies being conducted by Ledig (1985) at the Institute of Forest Genetics, Pacific Southwest Forest and Range Experiment Station. The program depends upon the cooperator to cultivate and irrigate the eucalyptus during the first year of seedling establishment.

FIDDLETOWN SEED SOURCE VARIATION TESTS

Status

At Fiddletown, BLM used a small tractor (John Deere 450-C) with a dozer blade and rear-mounted ripper teeth to clear all the chaparral brush and scarify the soil to a 12 inch depth. The slopes were terraced to control erosion. The USFS planted containerized stock using augers. BLM pumped water from an intermittent stream with a water powered "High Lifter" pump. A 40 foot fall of water in 1800 feet of one inch pipe powers the pump raising water 260 feet at the rate of 400 gallons per day via 2600 feet of ½ inch pipe to storage tanks for summer irrigation.

In May 1985, 2160 blue gum (Eucalyptus globulus) from 29 seed sources were planted with 2.25m by 2.25m (7.5' by 7.5') square spacing. In 1986, 320 shining gum (E. nitens) from 12 seed sources and 1312 Mysore gum (40 half-sib families of an as yet undetermined species of eucalyptus from the Mysore region of India) were planted at the same spacing. All test trees were planted with two border rows as buffers. A drip irrigation system was used to water each tree with 1 to 1½ gallons of water every two to three weeks during the summer. The blue gum was watered only during the first summer. The shining gum and the Mysore gum will be watered for the first two summers.

Preliminary Observations

One and a half years after planting, 37 percent of the blue gum survived. Death is attributed to frost and drought or lack of soil. Soil was deeper on the fills of the terraces than on the cuts and slopes between the terraces. Tree height growth and survival is markedly greater on the fills of the terraces. More available water and nutrients may account for this increased growth and survival. Some tree heights were in excess of 4 meters and the average of all survivors was 1½ meters. As of December 15, 1986, the shining gum had 75 percent survival and the Mysore gum had over 99 percent survival. The Mysore gum height growth was less than the blue gum during the same length of time.

Problems and Suggested Solutions

Gullying was noted on the first plantation. Erosion may be reduced by closer spacing of the terraces and waterbars along the terraces.

Differences in site quality on and between the terraces results in great differences in the tree growth. It is too early for definite conclusions, but this environmental influence may mask the expression of growth variation attributable to genetic differences among seed sources. In future tests the environmental variation may be reduced by planting all test trees spaced along the fills rather than on a square grid.

The impacts of frost and drought vary yearly. The use of recording thermographs and rain gauges may help to correlate the weather patterns with the tree's tolerance to frost and drought.

Plans and Expectations

In 1988 we plan to test 16 sources of manna gum (E. viminalis) and 7 sources of mountain gum (E. dalrympleana). In 1989 plans are for tests of 10 sources of forest red gum (E. tereticornis), 3 sources of flat-topped yate (E. occidentalis), and 2 sources of cabbage gum (E. amplifolia) as well as growth and yield studies using the best seed sources from earlier trials.

The best seed sources identified can be used for tree breeding efforts by the Eucalyptus Improvement Association.

Growth and yield data for eucalyptus plantations will aid in the economic evaluation of aforestation in the Sierra Nevada foothills.

REFERENCE

Ledig, F. Thomas. Problem Analysis: RWU 1401 Problem 3: There is almost no directly applicable information on the amount or distribution of variation among seed sources of eucalypt species known to be adapted to California, such as blue gum, shining gum, river red gum, manna gum, or mountain gum. Berkeley CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture: 1985. Unpublished report supplied by author.

[1] Presented at the Symposium on Multple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo. California.

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

The Use of Acorns for Food in California: Past, Present, Future[1]

David A. Bainbridge[2]

Abstract: Acorns are a neglected food for people, livestock, domestic fowl, and wildlife in California. Acorns are easy to collect, store, and process. In addition to the nutritious nut and meal, acorns yield an oil comparable in quality and flavor with olive oil. The existing acorn market could be greatly expanded and provide new income for rural people. A serious effort to identify and propagate the best oak acorn cultivars for these products is long overdue. It is particularly appropriate for this research to be done in California, which once had an acorn based economy.

Acorns have been used as food by Homo sapiens for thousands of years virtually everywhere oaks are found. The worldwide destruction of the acorn resource by mismanagement may well have led to the development of annual plant based agriculture and to civilization as we know it today (Bohrer, 1972; Bainbridge, 1985b). In Europe, Asia, North Africa, the Mid-East, and North America, acorns were once a staple food, (Hedrick, 1919; Loudon, 1844; Brandis, 1972; Lefvebre, 1900; and Bishop, 1891). The Ch'i Min Yao Shu, a Chinese agricultural text from the sixth century recommends Quercus mongolica as a nut tree (Shen Han, 1982). In Spain and Italy acorns provided 20 percent of the diet of many people just before the turn of the Century (Memmo, 1894).

Acorns were perhaps nowhere more important than in California. For many of the native Californians acorns made up half of the diet (Heizer and Elsasser, 1980) and the annual harvest probably exceeded the current California sweet corn harvest, of 60,000 tons. Acorn foods remain on the market not only in Korea, China, and North Africa, but in most major American cities, at Korean food stores (Wolfert, 1973; Bainbridge, 1985a).

A reevaluation of acorns and their uses is long overdue. The acorns of all 500 species should be tested. Although the acorns of some oaks are probably too small or too hard to open for widespread use many species that can and should be planted for use as food. They are also valuable feed for domestic animals and birds, and wildlife.

The factors that made acorns a major food source in California in the past make them attractive candidates for greater use in the future. They often ripen all at once and are easy to collect. They store well and were kept by the native Californians for several years in simple storage bins (Merriam, 1918). They are simple to prepare, even for the varieties that need to be leached. Although most species are bland, as are corn and wheat; some have good flavor and could be used in place of other nuts.

[1]Presented at the Symposium on Multiple-use Management of California's Hardwoods, November 12-14, 1986, San Luis Obispo, California.

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The yield of acorns per acre compares well with grains. When the long-lived, deep-rooted oaks can reach sufficient water; acorn production can be very high, with yields of more than 5,280 kg/ha (6,000 pounds/ acre) (Bainbridge, 1986). High acorn yields can be maintained on hilly lands where annual grain crops cause severe soil erosion (Bainbridge, 1987a).

ACORN HARVESTING

Harvesting acorns should be very similar to the harvesting of other commercial nuts such as almonds or filberts. Wolf (1945) found that it was possible to collect from 110-660 kg (50-300 lbs) of acorns per hour with very simple hand tools. My own experience has confirmed these numbers. However, when harvesting small acorns, like Q. gambelii, in an off year it may be possible to collect only a few pounds per hour.

ACORN NUTRITION

The nutritional qualities of 18 species of acorns are described in Table 1. California's acorns are described in Table 2.

TABLE 1--ACORN COMPOSITION, 18 SPECIES

	Percent
Water	8.7 - 44.6
Protein	2.3 - 8.6
Fat	1.1 - 31.3
Carbohydrate*	32.7 - 89.7
Tannin	0.1 - 8.8
KCAL/100 gms	265 - 577
KCAL/lb	1200 - 2600

* or N free extract

(Bainbridge, 1985a)

X-ray diffraction showed that the structure of acorn starch from Q. mongolica and Q. crispula fell between that of corn and potatoes. Acorn starch had limited gelatinization at 61-68°C, with gelatinization of Q. crispula lowest and Q. mongolica highest (Kim and Lee, 1976). The amylose content of acorn starch was 27.1 percent, blue value 0.43 and Aldehyde number 1103 (Chung et al., 1975).

TABLE 2-- ACORN COMPOSITION

Species	Water	Protein	Fat	Carbohydrate	Tannin
Q. agrifolia[1]	9.0	6.26	16.75	54.57	--
Q. chrysolepis[1]	9.0	4.13	8.65	63.52	--
Q. douglasii[1]	9.0	5.48	8.09	65.50	--
Q. douglasii[2]	40.75	3.03	4.77	43.39	3.61
Q. dumosa[2]	44.58	2.29	3.42	40.65	5.15
Q. kellogii[1]	9.0	4.56	17.97	55.48	--
Q. kellogii[2]	37.6	3.43	11.05	32.71	1.81
Q. garryanna[1]	9.0	3.94	4.47	68.87	--
Q. lobata[1]	9.0	4.90	5.54	69.02	--
Q. lobata[2]	40.57	2.82	4.25	43.44	3.85
Q. wislizneii[2]	29.80	3.08	14.47	40.40	4.60
Lithocarpus densiflora[3]	36.00	2.06	8.50	38.29	--
Indian Corn[3]	12.5	9.2	1.9	74.4	--
Wheat[3]	11.5	11.4	1.0	75.4	--

[1] Wolf (1945), [2] Wagnon(1946), [3] Heizer and Elsasser (1980)

Acorns are also good sources of some vitamins, with 5 - 54.8 mg of Vitamin C per 100 gm of raw acorn (Djordjevic, 1954; Minieri, 1954). This compares favorably with the Negev lemon, with 58.1 mg per 100 g. Acorns are also an excellent source of Vitamin A, with 180 IU per gm in Q. phellos (King and Titus, 1943). Twenty-seven grams, or less than tenth of pound of acorns, would meet the suggested daily requirement of 5,000 IU for vitamin A. This may prove of great benefit in areas of the world where vitamin A deficiency is common among the poor. Thorough testing of a full range of oak species and oak processing methods may well discover other species with even higher levels of these and other vitamins and trace elements.

Acorns include many essential amino acids, Table 3. (Luk'yanets, 1978; Videl and Varela, 1969). Testing is needed to establish the amino acid content of the

TABLE 3: AMINO ACID CONTENT OF ACORNS

	milligrams/gram
Glycine	0.98 - 1.37
Alanine	1.02 - 1.57
Valine	0.97 - 1.22
Leucine	1.69 - 2.08
Isoleucine	0.63 - 0.72
Serine	0.94 - 1.23
Threonine	0.87 - 1.13
Methionine	0.26 - 0.31
Phenylalanine	0.90 - 1.09
Tyrosine	0.68 - 0.99
Lysine	1.19 - 1.51
Arginine	1.48 - 2.25
Histidine	0.71 - 1.05
Proline	1.41 - 1.58
Aspartic acid	2.75 - 3.66
Glutamic acid	3.10 - 4.33

(Luk'yanets, 1978).

California species. Minor deficiencies can probably be rectified with complementary legumes, fish, or meats. When acorns are cooked with ash, to neutralize bitterness, the acorn foods should also be a good source of calcium. Cooking with ash may also make more niacin available if the tests Ruttle (1976), conducted on corn are replicable for acorns. Acorns also supply many trace elements. It is not at all surprising that acorn-based cultures prospered for thousands of years with this excellent food base.

EDIBILITY OF ACORNS

The acorns from many species of oaks are edible raw, just as they are harvested. Sweet acorns have been reported for Quercus gambelii, Q. mongolica., Q. emoryi, Q. dumosa, Q. vaccinifolia, Q. stellata, Q. virginiana, Q. garryana, Q agrifolia Q. macrocarpa, Q. lobata, Q. pumila, Q. muehlenbergii, Q. alba, Q. michauxii, Q. brandeegei, Q. gramuntia, Q. E'sculus, Q. aegilops, and Q. ilex var ballota (Bainbridge and Asmus, 1986; Bainbridge, 1984; Coyle and Roberts, 1975; Loudon, 1844; Bohrer, 1972; Chestnut, 1974; Brandis, 1972; Hedrick, 1919; Michaux, 1810; Ofcarcik et al., 1971; Smith, 1950; Fray, 1986). Undoubtedly, other species and varieties are equally sweet and more flavorful.

A careful worldwide search for good cultivars is long overdue because there is hope of finding sweet acorns even in those species normally considered bitter. Some of these include the best tasting acorns, with cashew and chocolate overtones.

ACORN LEACHING

It is also practical to harvest and use the bitter varieties. The tannins which cause the bitterness can be leached from acorns or acorn meal with water. Using hot water hastens the process. Studies at Dong-guk University in Seoul, South Korea showed the tannin level was reduced from 9 percent to 0.18 percent by leaching, without loss of essential amino acids, (Kim and Shin, 1975). Virtually all of the acorns the native Californians used were bitter and were leached with water to remove the bitterness. They apparently based their acorn preference on oil content, storability, and flavor rather than sweetness. However, the Cahuilla people in Southern California remember sweeter acorns from their past (in the south-Central U.S.) and consider their loss as a fall from grace, like Adam and Eve's expulsion from the garden (Bainbridge, 1987a).

Native Americans also sweetened bitter acorns with iron-rich red earth, wood ashes, and other ingredients to neutralize the acids. Steaming or baking were sufficient for some acorns (Chestnut, 1974; Kavasch, 1979; and Gifford, 1936).

COOKING WITH ACORNS

Acorn meal can be substituted for corn meal in most recipes (Bainbridge, 1986b). Acorns can also be used in place of chickpeas, nuts, peanuts, and olives in a variety of dishes. Acorn meal and acorn pieces are excellent in soups and stews and were often used that way by native Californians. Acorns can also be treated with pickle brines or the lye treatment used for olives (Wolf, 1945; Bainbridge, 1986b).

Acorns have also been used to make coffee-like drinks (Kavasch, 1979). The success of the venture depends on the particular acorn and technique used. Q. muehlenbergii was especially favored for this purpose in the Midwest, (Ofcarcik et al., 1971). Q. robur and Q. frainetto have been used in Europe where the resulting drink is referred to as "Eichel kaffee", or acorn coffee (Sholto Douglas, 1978; Readers Digest, 1984). A similar acorn coffee has been used in Mexico, (Usher, 1974). Raccahout, a spicy Turkish acorn drink more like hot chocolate, was included in the Larousse Gastronomique until recently.

ACORN OIL

Acorns can also be used to make acorn oil by boiling, crushing, or pressing. Acorn oil has been used as a cooking oil in Algeria and Morocco (Loudon, 1844; Hedrick, 1919; Smith, 1950). It was used by the Indians of the eastern U.S. for cooking and as a salve for burns and injuries (Michaux, 1810; Smith, 1950). Some varieties contain more than 30 percent oil, equal or greater than the best oil olives (Wolf, 1945; Ofcarcik et al., 1971). The quality and flavor of the oil is comparable to olive oil (Wolf, 1945; Smith, 1950; Bainbridge, 1985a). Table 4 presents further information on acorn oil.

ACORNS AS FODDER

The meal left after pressing oil can be used for animal feed, but the whole acorns are better. They have been used for feeding livestock for many thousands of years. Most acorns, even without leaching, can be fed up to 20 percent of the ration of chickens (Weingarten, 1958; Boza et al., 1966; Varela et al., 1965; Medina Blanco and Aparico Macarro, 1965). Acorn fed bear and hog meat were highly valued in the early days of California settlement. Acorn-fed hogs were especially favored in Italy (Maymone and Durante, 1943). Leached acorns can be used for 50 percent or more of the diet, as part of a balanced diet, and may make up 90 percent of the diet of some California deer herds in the Fall and Winter.

In addition, many oak leaves can be fed to livestock and some were eaten by people (Bainbridge, 1985a). Oaks have been grown and maintained primarily for fodder in a number of countries. Q. infectoria for example, was favored in Iraq where it was pollarded for better fodder production (Blakelock, 1950).

The tannin in bitter acorns and leaves of some oaks can cause poisoning in livestock if fed in high percentage. Range poisoning sometimes occurs when other forage is limited. For further information on acorn poisoning see (Fowler et al., 1965; Duncan, 1961; Clarke and Cotchin, 1956; McGowan, 1970; Stober et al., 1976).

TABLE 4--ACORN OIL COMPOSITION

Species	Q. agrifolia	Quercus ilex	5 other species[a]	Olive	Corn
Specific gravity[b]	0.9170 (17°C)	0.9086	0.9100	0.914-0.919	0.916-0.9121(15°C)
Refractive index[b]	1.4709	1.4701	1.4627	1.466-1.468	1.470-1.474
Saponification value	192.3	189.05	191.45	187-196	187-196
Olieic acid%	--	57.05	58.31	83.5-84.4	19-49
Palmitic acid%	--	12.40	11.43	6.9-9.4	8-12
Linoleic acid%	--	30.50	37.50	4.0-4.6	34-62
Flash point	--	--	320° C	225° C	321° C
Flash point	--	--	360° C	343° C	393° C

[a]average of available data [b]at 25°C unless otherwise noted.
Acorn data: Jameison (1943), Wolf (1945), Hopkins et al. (1953), Khan (1977), Marwat et al. (1978).
Olive and corn oil: Weast (1979) and Windholz (1976).

ACORN USE IN THE FUTURE

With a serious oak selection and breeding effort there is little doubt that oaks that bear early and have large, sweet acorns could be developed for use in most areas of California. Most of the oaks hybridize well, so much could be done by careful breeding. Studies at the University of Utah have demonstrated that the subgeneras will cross, (Cottam et al., 1982), and successful crossing of good flavor and sweetness should be feasible. This type of hybridization work is slow, however, so the rapid development of acorns as a commercial crop will be more dependent on the selection of the best individuals now growing around the world. Good flavor and large sizes can probably be combined. I have found acorns weighing more than 19gms (Q. chrysolepis) and have been told of even larger acorns. The recent advances in plant breeding and genetics should reduce the time required to develop a plum sized, tasty acorn. Plant breeding might also develop a high yielding, sweet acorn and cork producing tree.

Selection for high productivity may be important for the development of commercial acorn orchards. Single trees have been found producing: more than 908 kg (2,000 lbs.) of acorns, Q. lobata; and consistently several hundred kg (pounds) per year, Q. garryana, Q. agrifolia, Q. ilex, and mixed stands (Wolf, 1945; Smith, 1950; Beck, 1977). Smith (1950) estimated that commercial oak orchards would produce 1250 kg of acorns per hectare (1,400 pounds/acre) annually with selected cultivars. I suspect this is a conservative estimate as natural forest yields of 1,300 - 4,400kg per hectare (1,450 - 5,000 lbs/acre) have been recorded for a good acorn crop, (Koenig 1979; Wolf, 1945). I have found up to 5,200 kg/ha (6,000 lb/acre) in a good crop year for Q. kellogii in the Sierra Nevada and similar yields in the forests of Q. chrysolepis in Southern California..

The challenge is first to alert farmers, foresters, and the food industry in California to the potential use of acorns. The second task is to establish a larger market for wild acorns (similar to the black walnut business) and acorn products. At the same time there is a critical need to identify and develop oak cultivars for acorn meal, nut, and oil production. Equipment for harvesting, hulling, and grinding must also be evaluated. It is likely that filbert harvesters and hullers will work but only field trials will confirm this.

Detailed economic analysis of acorn harvesting and processing in California is also needed. Wolf (1945) has done the only study of the California acorn business I am aware of and his results were encouraging. The only modern economic evaluation of acorn harvesting was done in Spain by de Ursinos et al (1969). They determined that the acorn harvest for industrial production of meal and oil had been economically viable when they began their study but was no longer profitable at the end, because of labor cost increases and the release of wild hogs in the study forest.

With current California prices for acorn meal running about $ 0.90/lb wholesale and to more than $30 per gallon for specialty nut oils it seems likely that an entrepreneur could establish a profitable acorn business. This enterprise will be easier to establish if processing and palatability tests are conducted by University researchers. These studies could also refine acorn oil processing techniques and help develop specialty products that can compete in the marketplace.

From my own experience I would think a talented cook/marketeer could make an entrance into the market with acorn chips and crackers or acorn breads and muffins. On a larger scale the market for acorn flour could be much increased and a market for acorn oil could be established. An acorn beer or acorn alcohol could also be prepared.

SUMMARY

The acorn was once the staff of life in most of California and many areas of the world (Bainbridge, 1984; Bainbridge, 1985b; Bainbridge, 1986a). It may become a more common food in California again. It is a perennial "grain" that can be grown on arid and semi-arid lands and steep slopes where annual grains would cause severe environmental degradation.

Further research on acorn composition (particularly vitamins) and flavor, recipes, processing, and oak tree management is needed. The hardwoods program undertaken in 1986 (Passof and Bartolome, 1985) is an excellent beginning but the resource commitment is small and includes no directives for acorn research.

Material on acorns, acorn recipes, and oaks would be appreciated.

ACKNOWLEDGEMENTS

My special thanks to my parents, who have helped collect and test acorns; to Norma Kobzina for her help in the libraries of UC Berkeley; and to Joan Fray and Peg Carkeet for their support and encouragement in collecting and tasting acorns. The help of Dana Sowers, John Gibson, and Catherine Gring is also appreciated. And to Stanley Scher for his review.

REFERENCES

Bainbridge, D. and Asmus, K. Acorn Testers News, 1(1). Riverside, CA, 1986. 8p.

Bainbridge, D. The Grain that Grows on Trees. Mother Earth News, 80-84. 1984, September/October,

Bainbridge, D.Acorns as Food: Oak Bibliography #1. Sierra Nature Prints, Twain Harte, CA. 1985a. 23 p.

Bainbridge, D. The Rise of Agriculture: A New Perspective. Ambio.14(3)148-151; 1985b.

Bainbridge, D. Quercus: A Multi-purpose Tree for Temperate Climates, Int'l Tree Crops Journal. 4(3)291-289; 1986a

Bainbridge, D. Cooking With Acorns, Draft.Dry Lands Research Institute,U.C. Riverside. 22p.1986b

Bainbridge, D. The Oaks. In: The International Permaculture Species Yearbook, Ed. Dan Hemenway, TIPSY, Orange, MA. (in press).1987a.

Bainbridge, D.Acorns and the Native Californians: A Mutual Harmony (book draft); 1987b.

Beck, D.E. Twelve-Year Acorn Yield in Southern Appalachian Oaks, USDA Forest Service Research Note: SE 244; 1977.

Bishop, I. Journeys in Persia and Kurdistan. John Murray, London; 1891.

Blakelock, R.A. The Rustram Herbarium, Iraq Part IV. Kew Bulletin. Number 3:375-444; 1950.

Bohrer, V.L.On the Relation of Harvest Methods to Early Agriculture in the Near East. Economic Botany. 16:145-155; 1972.

Boza, F., Fonolla, J., and Varela, G. *Digestibilidad y valor nutritivo de la harina de bellota des ecada y entera en ovidos.* Avances Mejora Animal. 7:515-518, 521-523; 1966.

Brandis, D. Forest Flora of NW and Central India, Bishen Singh, Dehra Dun,India; 1972 [1874].

Chestnut, V.K. Plants used by the Indians of Mendocino County, California, Contribution for the U.S. National Herbarium v7, repr. by Mendocino County Historical Society; 1974. [1904].

Chung, D.H., Yu, T.J., and Choi, B.K. Studies of the Utility of Acorn Starch, Journal of the Korean Chemical Society. 18(2): 102-108; 1975.

Clarke, E.G.C. and Cotchin, E. A Note on the Toxicity of the Acorn, Brit. Vet. Journal. 112:135-139; 1956.

Cottam, W.P., Ticler, J.M., and Santamour, F.S. Oak Hybridization at the University of Utah. State Arboretum of Utah, Publication #1. Salt Lake City, Utah. 1962.

Coyle, J. and Roberts, N.C. A Field Guide to the Common Edible Plants of Baja California. Natural History Publishing Co. 1975.

de Rafols, W. *Aprovechamiento Industrial de Dos Productos Agricolas.* Salvat Editores, Barcelona. 1964.

de Ursinos, J.A.F.R., Ayerbe, F.R., and Vela, F.M. *Obtencion industrial de la harina de bellota y extraccion de aciete.* Grasas y Acietes, 20(5)227-230; 1969.

Djordjevic, N. Vitamin C *u ziru* (semen Quercus) Acta vet, Belgrade, Inst. Pharmacol. 4(2)59-51; 1954.

Duncan, C.S. Oak Leaf Poisoning in Two Horses. Cornell Vet 51:159-162; 1961.

Fowler, M.E. and Richards, W.P.C. Acorn Poisoning in a Cow and a Sheep. J. Am. Vet. Med. Assoc. 147:1215-1220; 1965.

Fray, J.J. [Personal conversation] 1986.

Gifford, E.W. California Balanophagy. 1936, In: Heizer, R.F. and Whipple, M.A. The California Indians. U.C. Press, Berkeley. 1971.

Hedrick, U.P. Sturtevant's Notes on Edible Plants. Report of the New York Agric. Exp. Station, 20. Albany, NY; 1919.

Heizer, R.F. and Elasser, A.B. The Natural World of the California Indians. U.C. Press, Berkeley, CA; 1980.

Jameison, G. Vegetable Fats and Oils, Reinhold Publ., NY; 1943.

Kavasch, B. Native Harvest.Vintage Books; 1979.

Khan, F.W., Gul, P., and Marwat, A.G. Chemical evaluation of *Q. ilex* seed and oil, Pakistan J'rnl Forestry 27:98-100; 1977.

Kim, Jung-Ok and Lee, Mahn-Tun. Chemical Evaluation of Acorn Starch from Three Species of *Quercus*. Korean Journal of Food Science and Technology. 8(4)230-235; 1976.

Kim, C.S. and Shin, E.T. Studies on the utilization of Several Varieties of Acorns in Korea. Korean J. Appl. Microbiology and Bio-Engineering.3(1)17-22; 1975.

King, T.R. and Titus, H.W.Acorns of the Willow Oak (*Q. phellos*), a Source of Vitamin A Activity. Poultry Science. 22:56-60; 1943.

Koenig, W.D. Acorn Storage by Woodpeckers in an Oak Woodland.In: Ecology, Management, and Utilization of California Oaks. U.S.Department of Agriculture, Forest Service; 1979.

Lefevbre, H. Les Forets de L'Algerie. Alger-Mustapha; 1900.

Leung, W.-T. Food Composition Table for Use in East Asia: Part I. FAO, Rome; 1972.

Loudon, J.C. Arboretum et Fruticetum Vol:III. Longman, Brown, Green and Longman, London; 1844.

Luk'yanets, V.B. Content of Amino Acids in Acorns of Various Species and Climatypes of Oak, Leznoi Zhurnal, Lesotech Inst. Bosonezh., 4:29-32, 1978.

Marwat, A.G., Gul, P. and Khan, F.W. Chemical evaluation of *Quercus glauca* Seeds and its Oil. Pakistan J'rnl Forestry 28:116-119; 1978.

Maymone, B. and Durante, S. Use of Acorns in Pig Fattening with Special Reference to the Chemical Constitution of the Depot. Fat. Ann. Quad. Nutrizons. 9:162-177; 1943.

McGowan, B.A. Acorn Poisoning in Bovine. Southwest Vet. 24:68; 1970.

Medina Blanco M., and Aparico Macarro, J.B. *Utilizacion de Harina de Bellota en la Vacion de Pollos Para Carne.* Rev. Nutricion Animal, Madrid. 3:258-264; 1965..

Memmo, G. The Alimentation of Individuals of Different Social Conditions. Annid. Ist. d'ig sper d. Univ. di Roma,n. ser. 4. 1894.

Merriam, C.H. The Acorn, A Possibly Neglected Source of Food. National Geographic. 34(2)129-137; 1918.

Michaux, A. Quercus, or Oaks. Trans. by W. Wade. Graisberry and Campbell, Dublin; 1810.

Minieri, L. *Acido ascorbico totale in alcune ghiandi della Campania.* Zootec. Vet. 9:104-106; 1954.
Ofcarcik, R.P., Burns, E.E., and Teer, J.G. Acorns for Human Food. Food Ind. Journal 4(8)18; 1971.
Passof, P.C. and Bartolome, J.W. An Integrated Hardwood Range Management Program, Wildland Resource Center, U.C. Berkeley, 1985.
Pellet, P.L. and Shadarevian, S. Food Composition Tables for Use in the Middle East, American Univ., Beirut, 1970.
Readers Digest. Field. Guide to the Trees and Shrubs of England, Readers Digest Association, London, 1984.
Ruttle, E.J. Cooking with ash. Organic Gardening. 23(12)87-89; 1976.
Shen Han, S. Ch'i Min Yao Shu, Science Press, Beijing, 1982, 107p.
Sholto Douglas, J. Alternative Foods. Pelham Books, London, 1978.
Smith, J.R. Tree Crops. Devin-Adair, CT, 1950.
Stobler, M., Zeigler, H.P., and von Benton, K. Acorn Poisoning in Cattle. Bovine Practitioner, 11:36-41; 1976.
Subcommittee on Feed Composition, National Academy of Science. Atlas of Nutritional Data on United States and Canadian Feeds, Nat'l Academy of Sciences, Washington, D.C.1971.
Usher, G. A Dictionary of Plants Used by Man. Constable and Co., London. 492-494, 1974.
Varela, G., Fonolla, J., and Ruano, F. *Influencia del Maiz Sobre le Digistibilidad y Valor Nutritivo de la Bellota en Cerdos.* Avances Aliment. Mejora Animal. 6:221-235; 1965.
Videl, C. and Varela, C. Aminograms of Prickly Pear and Acorn -Possibilities of Improving the Nutritive Value of their Proteins. Rev. Nutricion Animal. Madrid. 7:53-66; 1969.
Wagnon, K.A. Acorns as Feed for Range Cattle. Western Livestock Journal. 25(6):92-94; 1945.
Weast, R.C. ed. CRC Handbook of Chemistry and Physics, CRC Press, Baton Rouge,1979.
Weingarten, A. The Use of Acorns as Feedstuffs for Chickens. M.S.Thesis, U.C. Davis, CA, 1958. 43p.
Windholz, M. ed. The Merck Index, Merck and Co., NY; 1976.
Wolf, C. B. California Wild Tree Crops, Rancho Santa Ana Botanical Gardens, Orange County, 1945.
Wolfert, P. Couscous and Other Good Food from Morocco. Harper and Row, New York, 1973.

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Enemies of White Oak Regeneration in California[1]

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Abstract: Blue oak (Quercus douglasii) and valley oak (Q. lobata) acorns and nursery stock (2-month-old and 1-year-old) were planted in six counties during the 1985-1986 growing season (October 1 to September 30), but each plant material was not planted at all sites. Results suggest weed competition was a major cause of poor emergence and survival of seedlings developing from field-planted acorns and survival of transplanted nursery stock. These problems were aggravated by use of a slow release fertilizer placed beneath acorns and transplants. Small mammals and insects were responsible for additional mortality at all locations.

In 1985-86, a series of artificial oak regenerations studies, using blue oak (Quercus douglasii) and valley oak (Q. lobata), was started in six counties: Yuba, Mendocino, Contra Costa, San Benito, Madera, and San Luis Obispo (fig. 1). Acorns planted directly in field plots and nursery transplants, 2-month-old and 1-year-old stock, were used, but each plant material was not planted at all sites. Acorns were planted in November and transplants in winter. Each site was as flat as the terrain permitted to minimize the influence of slope exposure. All work was conducted inside deer-proof exclosures and away from canopy effects on oak-grassland range supporting mature stands of the trees. These studies are supported by a 3-year grant from the Environmental License Plate Fund.

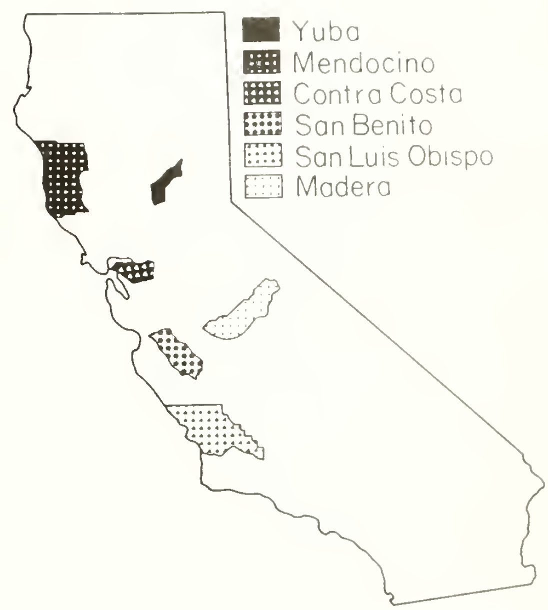

Figure 1--Counties in which regional artificial oak generation is being studied.

PROCEDURES

Acorns

Treatments used were: acorns planted with and without winter weed control, obtained with a systemic herbicide applied after planting but before emergence; and these treatments combined with and without fertilizer, slow release Osmocote® 18-6-12 (8-9 month release) buried beneath individual acorns. Treatments were organized in a randomized complete block design.

At one location, the Yuba County site, damage from grasshoppers became severe in June. To prevent complete loss, protection, in the form of hair nets used in the food processing industry, was applied to half the surviving plants, which were found only in fertilized and unfertilized treatments where herbicide was sprayed. This application created a split-plot design with respect to treatments with weed control.

Transplants

Winter planting of both age classes was accomplished after application of a systemic herbicide to reduce weed competition. Planting was done with and without Osmocote® buried beneath individual plants and with and without rodent protection, Foregon® rigid plastic protectors. These treatments were combined in a split-plot design with fertilizer treatment assigned to main plots

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, California Polytechnic State University, San Luis Obispo, California.

[2]Extension Wildlands Specialist and Staff Research Associate, respectively, University of California, Davis, California; Farm Advisors, University of California Cooperative Extension, San Luis Obispo and Madera, California, respectively; Associate Professor of Forestry, University of California, Berkeley, California.

and rodent protection assigned to subplots. Insect protection, hair nets, also was included at one location in July.

RESULTS

Oak Seedling Emergence

Adequate weed control in spring and summer was a problem in nearly all seeded plots treated with a systemic herbicide in winter. Winter weed control did not prevent spring emergence of weed competition in most sprayed plots. As a result, the effect of weed control on emergence could not always be measured. However, in Yuba County, the beneficial effect of weed control was easily seen (fig. 2).

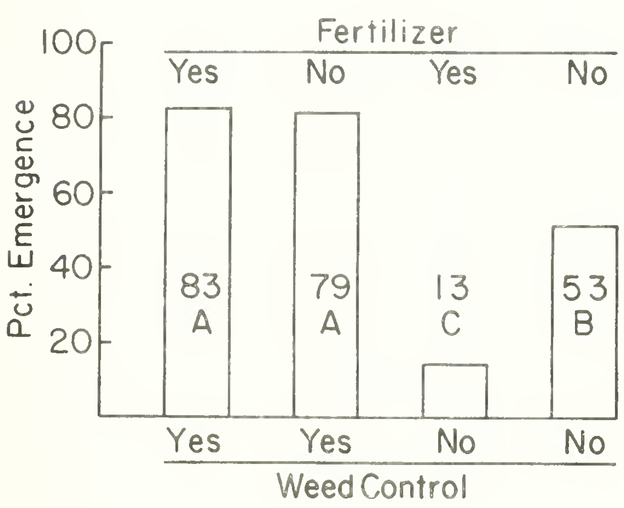

Figure 2--Percent emergence of blue oak seedlings in response to the combined efforts of weed control and fertilizer (Yuba County).[3]

On the basis of seedling emergence, valley oak is a stronger competitor than blue oak. In San Benito County, where both were growing in the same plot, valley oak produced 7 times as many seedlings as blue oak.

Fertilizer aggravated the problem of competition by stimulating weeds and reducing oak seedling emergence (figs. 2 and 3). The effect was particularly evident where weed control was not used.

Small mammals were a problem at all sites. At the Madera County site, more than 5,000 acorns were

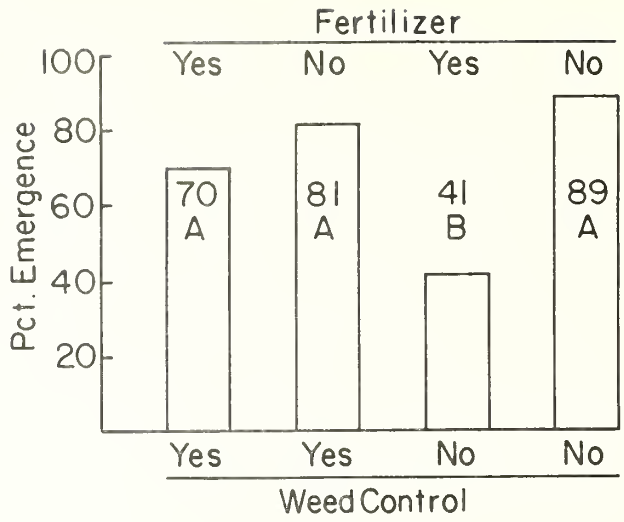

Figure 3--Percent emergence of valley oak seedlings in response to the combined effects of weed control and fertilizer (San Benito County).[3]

dug up. We assume that ground squirrels were responsible for most of this depredation. Also, pocket gophers contributed an unmeasured amount to mortality of all seedings.

Oak Seedling Survival

Incomplete control of late spring and summer weeds in many sprayed plots masked the possible value of weed control on survival. However, in Yuba County, no blue oak seedlings survived beyond the middle of June without weed control. At another site, the presence of weeds, stimulated by fertilizer in unsprayed plots, reduced survival by half compared with plots both sprayed and fertilized (fig. 4).

Due to stimulated weed competition, fertilizer had a negative effect on survival at all sites. At three sites, survival was 2 to 10 times greater without fertilizer (figs. 4 and 5).

Grasshopper depredation was severe in Yuba County. Protection applied in June to plants in sprayed plots insured 10 times the survival compared with unprotected plants (fig. 6).

Oak Transplant Survival

Survival of transplants was adversely affected by fertilizer wherever used. For 2-month-old blue oak transplants, survival without fertilizer ranged from about 15 percent more to 6 times more than with fertilizer (fig. 7). Without fertilizer, survival of 2-month-old valley oak ranged from 2.5 times more to nearly 30 times more (figs. 8 and 9). Where both age classes of valley oak were planted together and no difference in survival

[3]Values with the same letter are not different ($P \leq 0.05$) by LSD Separation. Where necessary, the arcsine transformation was used in the analysis to insure homogeneity of variances.

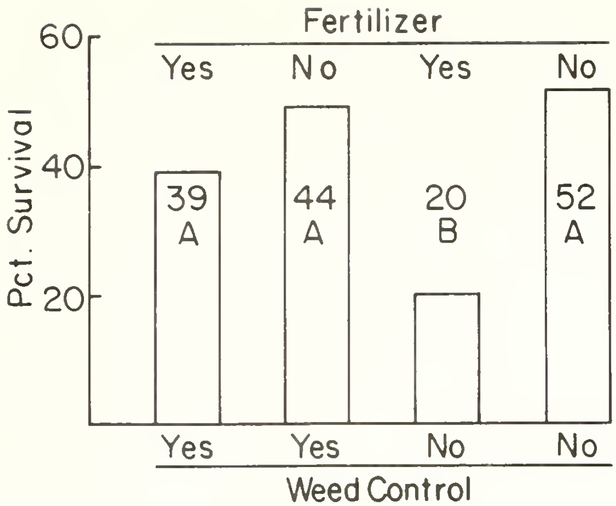

Figure 4--Survival of valley oak seedlings as a percent of emergence (74 pct. without fertilizer and 56 pct. with fertilizer[4]) in response to the combined effects of weed control and fertilizer (San Luis Obispo County).[3]

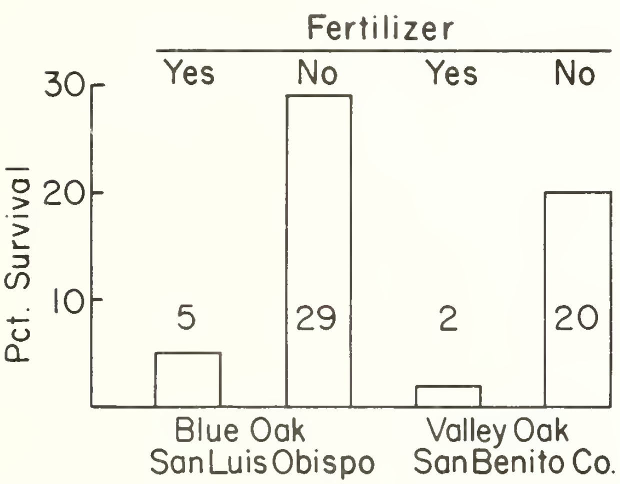

Figure5--Survival of blue oak seedlings as a percent of emergence (65 pct. in San Luis Obispo County and 72 pct. in San Benito County) with and without fertilizer.[4]

between the two existed, absence of fertilizer increased survival by nearly half (fig. 10).

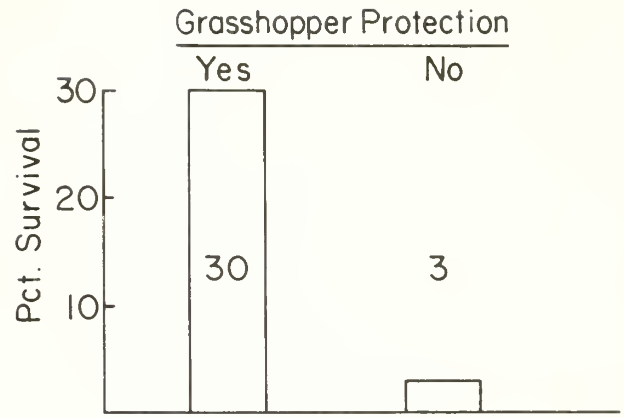

Figure 6--Survival of blue oak seedlings as a percent of emergence (81 pct.) with and without grasshopper protection in the weed control treatment (Yuba County).[4]

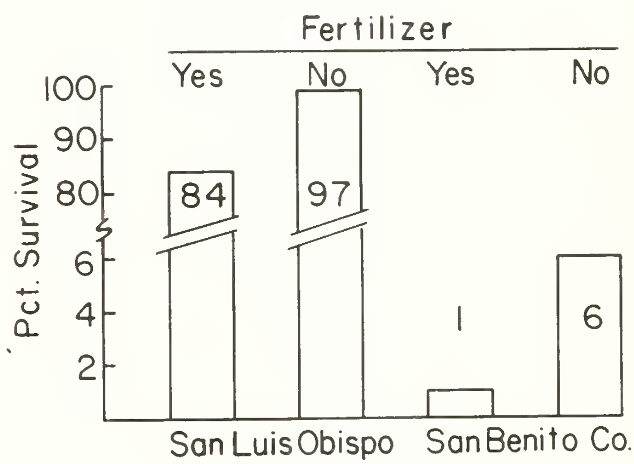

Figure 7--Percent survival of 2-month-old blue oak transplants with and without fertilizer.[4]

Moisture stress from weed competition in spring and summer was a problem despite use of a systemic herbicide to control winter growth. Weed regrowth after planting and the compeition for moisture it represented is assumed to have played a role in eliminating all blue oaks of both age classes in Mendocino County and Yuba County and all 1-year-old valley oak stock, the only plant material used, in Contra Costa County.

Protection against small mammals proved valuable at nearly all sites. Survival with protection ranged from about one-third more to 13 times more than without protection (figs. 8 and 11). Problem animals included jackrabbits, cottontail rabbits, squirrels, and pocket gophers. However, the Foregon® rigid plastic protectors provided no protection against pocket gophers that attacked seedlings from below the soil surface.

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[4]Values different at $P \leq 0.05$. Where necessary, the arcsine transformation was used in the analysis to insure homogeneity of variances.

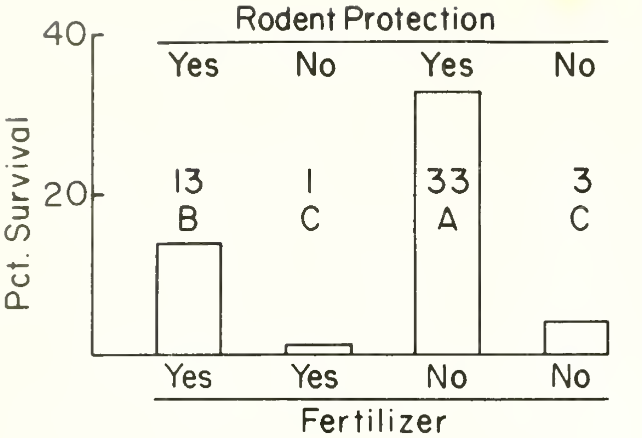

Figure 8--Percent survival of 2-month-old valley oak transplants in response to the combined effects of rodent protection and fertilizer (San Benito County).[3]

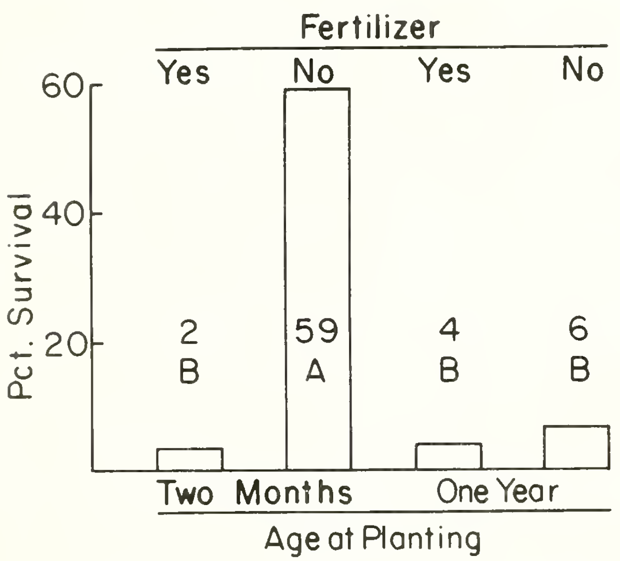

Figure 9--Percent survival of valley oak transplants in response to the combined effects of age class, and fertilizer (San Luis Obispo County).[3]

Protection from grasshoppers was necessary at the Mendocino County site. Here, protection of valley oak transplants increased survival by more than one half (fig. 10).

The effect of age class on survival was most obvious at the San Luis Obispo County site. Valley oaks of both age classes were planted together. Survival of unfertilized 2-month-old stock was nearly 12 times more than 1-year-old stock (fig. 9).

SUMMARY

Oak regeneration from acorns and nursery transplants faces many obstacles. Included are competition from spring and summer weeds, small mammals, and insects. Competition from weeds (moisture stress) may be the most important factor, but small mammals and insects can be major local problems. Weed control in late spring and summer will not only reduce competition, but will also discourage pocket gophers, a universal problem, by removing an attractive food source. In some areas, regeneration from seeded oaks and nursery transplants is unlikely without protection from all described enemies.

For field transplants, 2-month-old nursery stock appears superior to 1 year-old stock. Ignoring survival, the younger material is cheaper to grow and easier to transport and plant.

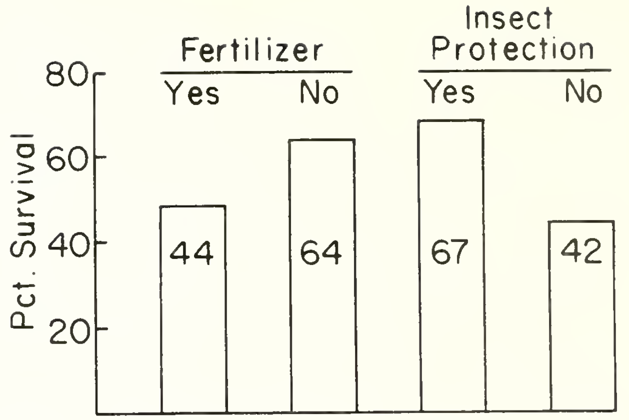

Figure 10--Percent survival of valley oak transplants with and without fertilizer; and with and without insect protection (Mendocino County).[4]

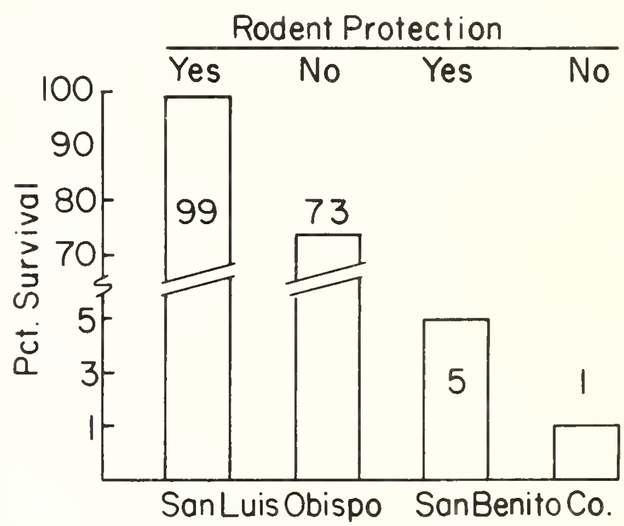

Figure 11--Percent survival of 2-month old blue oak transplants with and without rodent protection.[4]

GPO-789-253-955

The Forest Service, U.S. Department of Agriculture, is responsible for Federal leadership in forestry. It carries out this role through four main activities:

- Protection and management of resources on 191 million acres of National Forest System lands.
- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands.
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas.
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

The Pacific Southwest Forest and Range Experiment Station

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Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. **Proceedings of the Symposium on Multiple-Use Management of California's Hardwood Resources; November 12-14, 1986, San Luis Obispo, California.** Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987. 462 p.

Interest and concern about hardwoods in California has been increasing dramatically. This symposium addressed the State's hardwood resources and included sessions on silviculture, protection and damage factors, urban forestry-recreation, wildlife, wood products-utilization, inventory-measurements, range, and policy and regulation. Use and value of the hardwood resource will continue to grow as the population increases, the resource diminishes, and new uses for hardwoods develop.

Retrieval Terms: damage factors, inventory, measurements, policy, protection, range, recreation, regulation, silviculture, urban forestry, utilization, wildlife, wood products