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Proceedings—Future Forests of the Mountain West: A Stand Culture Symposium

Missoula, MT, September 29-October 3, 1986

Compiler:

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FOREWORD

"Future Forests of the Mountain West"—a catchy sounding title that was coined to attract natural resource people to "A Stand Culture Symposium" did just that. More than 300 people came to hear 57 papers and see 24 posters that presented the most current technical information about young forests of the Mountain West—mountain forests from the east slopes of the Cascades and Sierras to the high plains.

Old-growth forests, which provided many of the resources needed to settle the Western United States and Canada in the past century, are gradually being reduced by fire, insects, disease, and harvesting and are being replaced by young forests with potentials that are only now beginning to be realized. These young dynamic forests make up an increasingly more common scene on the slopes of the inland mountains of the Western United States and Canada, and they provide tremendous challenges and opportunities that were not feasible in the old-growth, virgin forests.

But let's back up a bit. Because of the predominance and attendant problems of old, mature forests, forest research and management in the first half of this century concentrated largely on developing the knowledge and techniques needed to properly harvest and regenerate forests of the West. These efforts were largely successful—they resulted in healthy, young replacement forests comprised of many species over vast areas of the West. These young forests presented a whole new set of knowledge gaps that resulted in the redirection and gradual shifting of research and management emphases into efforts that featured young forests. This knowledge about young forests has been accumulating in various publications and unpublished reports—most of it in the last 3 decades. However, much of this information has not been readily available to resource managers, and there were many uncertainties about knowledge gaps. Our European counterparts have been intensively researching and managing their forests for centuries, as opposed to our decades, and they still acknowledge the need for more information. We learned much from them, but the Mountain West of this continent has its own unique physical, biological, economic, and social conditions that present a whole new set of challenges and opportunities.

Thus, it was becoming increasingly apparent that we needed to ferret out, examine, and synthesize the best collective knowledge about stand culture and management of these young western forests. To help expedite the process of getting this information to the widest audience in the shortest time a symposium addressing this problem was organized. The goal of the symposium was to form "a legacy of quality forests for future generations." Specific objectives were "to present the best information available about these young, dynamic forests; to promote interaction among participants; to generate professional enthusiasm to chart the future of forestry in western North America; and to reinforce the commitment of forest managers and researchers to meet the needs and challenges of the Twenty-first Century."

The symposium program consisted of four major technical sessions: (1) The Opportunity, (2) The Analysis Tools, (3) The Practice, and (4) The Decision. The substance of each of these sections is described in the chapter introductions within this proceedings. These indoor sessions were followed by two field tours that emphasized immature stand management at: (1) Lubrecht Experimental Forest, and (2) the Swan, Flathead, and Glacier Areas of northern Montana and Coram Experimental Forest.

The symposium was sponsored by the USDA Forest Service, University of Montana School of Forestry and Center for Continuing Education, Canadian Institute of Forestry, Western Forestry and Conservation Association, and by the Society of American Foresters with designation as a SAF Regional Technical Conference.

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I want to acknowledge the planning group members, and the organizations that supported them, for their imaginative, enthusiastic, and dedicated efforts in the planning and conduct of this symposium. Also, I wish to acknowledge Dick Klade for the title suggestion and Kathy McDonald who processed all of the papers for this proceedings.

This symposium pointed out many knowledge gaps that need to be filled to manage young forests of the Mountain West most effectively. However, the depth, breadth, and quality of the papers in this proceedings demonstrates the tremendous strides that have been made in these few decades toward the development of knowledge and the management of these forests. The momentum is there. Our hope is that this symposium will help accelerate this quest for knowledge. If so, we have every reason to be totally optimistic about the Future Forests of the Mountain West.

—WYMAN C. SCHMIDT
Project Leader and Research Silviculturist
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A WELCOME TO THE FUTURE FORESTS SYMPOSIUM

Sidney Frissell

It is my pleasant responsibility to officially welcome you to the Future Forests Symposium. There are some 300 of you gathered here, to present and listen to papers and discuss the character and management of our future forests.

Throughout the Mountain West we are facing a challenge—the challenge of figuring out how to manage the young dynamic forests that are rapidly replacing old growth forests which are a gift to us from the past. These young stands have in many cases been created by us. They're the stands we will live in and derive resources from over the coming years.

A lot of people are interested in the forests that you're going to be dealing with this week: wildlife biologists, range managers, watershed managers, recreation planners, Federal, State and private foresters, rural land owners, ranchers, and land-use planners. All are, or will be, concerned with how these future forests develop. What will they look like? How should they be manipulated? How will their management affect scenery, wildlife habitat values, or water yield? Participants in this symposium will address many of those questions.

You'll be hearing about the resource opportunities these young stands offer, how stands can be measured, modeled, manipulated, and how they will respond to manipulation. Finally, you'll examine the management objectives that might be applied to these new forests.

Your presentations, the work they're based on, your discussions this week, and the new ideas you'll go home with will be critical in developing the knowledge we need to ensure a legacy of quality forests for future generations in the Mountain West.

We're extremely pleased that this symposium is being held in Missoula. The School of Forestry's Montana Forest and Conservation Experiment Station has an ongoing research effort called "The Mission-Oriented Research Program," which is focused on the management of second-growth forests. This Future Forests Symposium adds greatly to our enthusiasm and our momentum. It helps endorse our research program as meaningful—that we made a wise choice in concentrating on the development and management of young second-growth stands.

Thursday afternoon you'll have an opportunity to tour our Lubrecht Experimental Forest to see some of our young stand management research and demonstration areas. I urge you to take the tour—I hope that you'll offer us many suggestions on our current and future research opportunities there. On behalf of President James Koch, the faculty of the School of Forestry, and the City of Missoula, I welcome you to this noteworthy symposium. Listen well, have many active discussions, but also enjoy the campus and western Montana. Thank you for joining in this quest for knowledge about our forests of the Mountain West.

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THE ECONOMIC AND SOCIAL IMPORTANCE OF YOUNG FORESTS TO THE FUTURE OF THE WESTERN UNITED STATES AND THE NATION

Ted Schwinden

ABSTRACT

The economic importance of Montana's forests today goes far beyond the value attached to wood products. Tourism is the most rapidly growing segment of the State's economy, and recreation values essential to tourism are affected by forest management decisions. Clean water is essential to tourism and to the region's agricultural industry. Forests also are essential to our sense of well-being. Innovative management, with support from the public, is needed to provide the proper balance in forest use.

INTRODUCTION

This summer, National Public Radio commentator Daniel Schorr told a group of western governors that the "brash young West" is finally reaching middle age. With no new mountain ranges, no new water sources, no new frontiers waiting just over the horizon, we have come to recognize that we must live within the bounds of finite resources. And although I'm inclined to view the "foreseeable future" as a contradiction of terms, it is reasonable to assume that the 21st century will require a new and unfamiliar restraint. For a society that has long assumed that more is better, new limits will require a rethinking of our fundamental resource philosophies. Where we once assumed that we could "have it all," we will face increasingly difficult choices...something I'm sure the Nation's forest managers have thought long and hard about.

Today, a short drive through western Montana provides a graphic illustration of just how important our forests are to Montana's economy. Together, the ever-present logging trucks and the area's many wood processing facilities account for over 45 percent of western Montana's economic base. In the four northwestern States, over 120,000 workers are directly involved in the lumber and wood products industry. Even without adding in all those employed in the pulp and paper industries, our forests are very clearly a major component of the Northwest's economy. And since a 1977 report indicated that over one quarter of the raw materials driving our Nation's industries were timber products, the same can be said of timber's role in the national economy.

But the economic importance of our forests goes far beyond the dollar value attached to wood products. Montana's forest lands are also critically important to the production of associated resources that in themselves have significant and growing economic value. Those whose livelihoods depend on pursuits such as hunting, snowmobiling, river running, wilderness camping, and the most rapidly growing segment of Montana's economy, tourism, are all affected by the decisions made by forest managers.

For families and communities whose livelihoods are dependent on our forests, balanced forest management will, in the long term, smooth out some of the bumps in the economic roller-coaster so often associated with natural resources. For forest managers, that means finding a way to balance the needs of a stable timber industry with, for example, the need to maintain and improve our wildlife and fish populations. Perhaps an even tougher decision involves the tradeoff that must be made between motorized recreation and wilderness.

Through its impact on fish populations and the West's growing tourism industry, clean water is an essential element in the balance we seek. Responsible and intelligent forest management will make sure that short-sighted or ill-conceived activities do not increase the nonpoint pollutants coming from our forests. Forest managers must also consider the impact of forestry activities on the amount of water available in an area. The size and timing of a harvest, for example, can have a major impact on both when and how much water is available for use—something that is especially important to the region's agricultural industry.

INTRINSIC VALUES

But beyond their economic significance, forests have an intrinsic value that must be considered as part of the equation. Our forests are important to our sense of well-being—important even to those who live thousands of miles away and may never actually walk among its trees.

The importance of western forest management was stressed over and over again by the more than 1,000 Montanans who attended, or submitted testimony to, the Governor's Forum on Montanans Outdoors this January. The overwhelming consensus was that, in a country as rich and as varied as ours, every American—young, old, handicapped, poor, urban, rural—ought to have the opportunity to access their preferred form of recreation.

The message that came through loud and clear at Montana's hearing was that management of our current recreational resources simply isn't good enough. Despite funding cutbacks at all levels of government, Montanans place a high priority on continuing and improving the State's recreational opportunities. Many expressed a willingness to pay more for their outdoor recreation, with one important proviso—that they have a greater say in how and where such revenue is spent. Montanans want more local decision making—and they are fully prepared to accept the greater accountability and financial responsibility that go with it.

As both the east and west coasts become more intensely urbanized, our western forests will be burdened with a disproportionate share of the Nation's recreational demands. Already one of the top five basic industries in our State, how to better promote and accommodate increased tourism is of concern to both Montana's public and private sectors.

Without question, larger flocks of tourists will present new and difficult management challenges. There is growing concern that increasing demand for all types of recreation may diminish the quality of our outdoor experiences. Hiking along a beaten path, albeit in an officially designated wilderness area, is not the kind of wilderness experience Montanans value. Keeping pace with increased demand is viewed as critical in ensuring that we do not, by overuse, destroy that which we enjoy. Because fishing and hunting are a way of life for most of our citizens and a major attraction for a number of our nonresident visitors, we are extremely mindful of the need to strike that proper balance. In Montana, we have learned that the concept of "carrying capacity" is critical in decisions relating to fish and wildlife. For example, providing better access to streams or hunting areas that can't sustain increased fishing or hunting is a waste of time and money. All the additional facilities do is make it necessary to restrict the use they seek to accommodate.

The task facing forest managers is probably more like a Chinese puzzle than the neat equation I suggested earlier. How do all the pieces interlock? What kind of demands will be placed on our young forests as they mature? How should we plan today to meet tomorrow's demands?

Forest managers need to consider a complex web of demographic, economic, and industrial trends:

- How will an increasing population and the greying of the baby boom generation affect the demand for housing and for recreation?

- How will advances in telecommunications and the increased use of plastic and aluminum affect the demand for our wood products?

- To what new and innovative uses can our second-growth stands be put?

INNOVATIVE MANAGEMENT NEEDED

Change will require that field managers implement innovative management techniques, but they can't do it alone. They will need the support of supervisors who encourage their staff to take some calculated risks and of the researchers who develop better ways to manage our forest resources. They will need symposia like this one that allow the kind of information exchange that takes good ideas off the shelf and puts them to work in our forests. Most important, they will need the patience of a public that realizes that there are no good, short-term solutions to appropriate management for a given stand or forest.

Planning for the 21st century and beyond requires skilled professionals who are mindful of both the biological limits and the potential of our magnificent forest resource and of the expectations of a citizenry that is increasingly divided into vocal and well-organized interest groups. In recent years, the image of the forest ranger as a lovable, tree-planting, Smokey the Bear type has undergone considerable transformation in the public eye. Perhaps this was unavoidable given an increasingly polarized citizenry. Today, interest groups from the handicapped to backcountry horsemen question the effects of management decisions such as road closures or minimal trail maintenance.

If there is one voice that hasn't been heard often enough in the great political debate over the future management of western forests, it is that of the professional forest manager. As former state forester Gareth Moon urged in a recent Western Wildlands article, forest professionals have an obligation to speak up, not only in technical circles, but in the political arena. According to Moon, the Society of American Foresters' new willingness to take part in the political process is important because, in his words, "...today there is no way a professional land manager can obtain what is needed for quality resource management without help from the political process." Given your expertise, given your commitment, I share Moon's belief that forestry professionals would—and should—add a needed voice of moderation to the testimony heard in the halls of Congress and the committee rooms of Helena.

Ultimately, as Mary Austin wrote in "The Land of Little Rain," it is "not the law, but the land [that] sets the limits." If we are to successfully live within those limits, the existing cooperation between wildlife, recreation, and timber specialists working for different land owners must be strengthened and expanded. Balancing the competing demands on our forest resources will not be easy, but if future generations are to have the opportunity to enjoy the forests as we do today, we have no choice but to find that balance.

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FUTURE FORESTS OF THE MOUNTAIN WEST: IMPORTANCE FOR THE CANADIAN WEST

Fred W. McDougall

ABSTRACT

The present importance of Canada's mountain forests is described and explained. There is a forecast of future demands on the mountain forests, which predicts increasing importance for "nontimber" uses, such as watershed, recreation, and wildlife. The implications of what these changes mean for forest management in the future are discussed. Finally, there is a brief sketch of what the public will see in the future forests of the Canadian West.

INTRODUCTION

In Canada, the Mountain West could be considered to include an area of approximately 90,000 mi^2. It would include the eastern slopes of the Rocky Mountains and Banff and Jasper National Parks in Alberta; most of the interior mainland of the Province of British Columbia; and parts of the Yukon Territory. It is roughly that area of Canada where lodgepole pine forms a significant part of the forest.

As a keynote speaker, I would ask you to place your deliberations here, over the next 4 days, within the context of three basic questions:

1. Why are the forests of the Mountain West important today?
2. For what will they be important in the future?
3. What does this mean for forest management in the future?

PRESENT IMPORTANCE

Why are the forests of the Mountain West important today?

Watershed

All of western Canada's great rivers originate in our Mountain West. Our prairies as far east as Winnipeg depend on mountain water to support life. Without it, Canada's prairies would be a true desert. The essential nature of our mountain watersheds has been recognized for decades. The Forest Reserves were created at the beginning of this century to protect them. The Eastern Rockies Forest Conservation Board, and more recently, the Alberta government's "Policy for Resource Management of the Eastern Slopes" have all recognized the essential importance of our mountain forests in maintaining regular flows of clean water throughout western Canada. Virtually the entire western Canadian population is dependent on this vital function.

Recreation

Canada's national park system started in the Mountain West, and the mountain parks are still, by far, the most important in our national park system. In addition, the Provinces of British Columbia and Alberta both maintain major recreational programs, including provincial parks and recreation areas, in the Mountain West. The recent addition of Kananaskis Country, a major recreational development in Alberta's Rocky Mountains, is evidence of the continued growth and importance of recreation in our mountain forests.

Our mountain scenery, clean mountain air, and water are major international attractions. Our mountain forests form an integral and essential part of these attractions.

Recreational, or sport fishing constitutes a major recreational activity in Canada, and our mountain streams are an important attraction for fishermen.

Camping, hiking, and mountain climbing are important recreational pursuits, and trail riding has become an increasingly important activity. There has been major growth in Alberta's commercial trail riding industry, much of it geared toward tourists from other parts of the world.

Many of Canada's finest ski resorts are, of course, located in Canada's mountain resort areas. The 1988 Winter Olympics will be held in Calgary, Alberta, with many events on sites in the mountain forests west of Calgary.

Wildlife

The wildlife in Canada's Mountain West is exceptional in its diversity and appeal. Unique species, like the grizzly bear, cougar, bighorn sheep, elk, marmot, and mountain goat combine with populations of more widespread species, like the moose, black bear, and white tail and mule deer to comprise an unparalleled opportunity for wildlife viewing and big game hunting.

Big game outfitting is an important and growing part of the tourist industry in both Alberta and British Columbia.

Timber

The forest industry in the Mountain West has grown remarkably in importance in recent years. The British Columbia interior experienced a timber harvest in 1983 of 44.6 million m^3, the equivalent of about 12 billion board feet. In 1983 approximately 50 percent of the total Alberta provincial harvest of 7.3 million m^3 came from our mountain forests. So the forests of the Mountain West in Canada produced the equivalent of 13 billion board feet of timber in 1983 and have the capacity to maintain, if not increase, this production in future years.

The Mountain West is Canada's greatest timber producing region, exceeding the total timber production in either of the provinces of Quebec or Ontario, and exceeding production from the British Columbia coast by more than 50 percent.

The main timber products in the Mountain West are dimension lumber and kraft wood pulp. The annual value of production from this major forest industry exceeds C$4 1/2 billion.

Other Uses

To conclude this discussion without extending it unduly, the following significant activities are simply listed:

1. The grazing of domestic livestock is a locally significant activity;
2. Oil and gas exploration and development are widespread in the region, which includes many of Canada's largest natural gas and sulfur extraction plants; and
3. Most of Canada's metallurgical and export coal mines and
4. Major limestone and cement production facilities are located in the Mountain West.

The above information, while not complete, is adequate to describe the factors that make Canada's mountain forests important today. But what of the future?

FUTURE DEMANDS ON OUR MOUNTAIN FORESTS

For what will our mountain forests be important in the future?

In Canada, it is clear that watershed, recreation, and wildlife interests will continue to grow in importance. In fact these will soon become the determining considerations in the management of our mountain forests. Alberta's integrated land management planning program has developed in direct response to the growing importance of these interests. What are the implications of this growing priority for "nontimber" values?

The first perception may be negative to the traditional forester. Certainly increased recognition of nontimber values will make timber management more complex and difficult, and increase forest management and logging costs. Commercial timber harvesting is excluded from about 25 percent of the land base under a typical integrated land management plan in Alberta's foothills and mountain areas.

But there are many positives. Those lands set aside from commercial harvest are often at very high elevations, and very steep. In fact, a good portion of them does not support merchantable timber stands. Furthermore, it is becoming increasingly evident that management for watershed, recreation, and wildlife **requires** the planned removal of overmature forest stands. It is becoming increasingly recognized that pure preservation doesn't work. A management philosophy of "no logging" is, by itself, not management at all. The mountain pine beetle and the spruce bark beetle have recently demonstrated remarkable effectiveness at killing timber stands that had been "saved" from the logger. Harvest by *Dendroctonus* and *Choristoneura* is not good for watershed, is terrible for recreation, creates scenic and access disaster areas for many years, and is far less desirable for wildlife than well planned logging and reforestation.

Finally, it should be noted that timber values are still important. Alberta's eastern slopes contain the best uncommitted timber areas in Canada. Increasing wood costs and allowable cut reductions, which are occurring as the industry in developed regions moves from old growth to second growth stands, will result in further forest industry expansion in the Canadian West. Also, the existing forest industry in the West is essential to the economic well-being of the region.

FOREST MANAGEMENT IN THE FUTURE

What does this mean for forest management in the future?

The increased importance of nontimber values does not reduce the importance of forest management. It does not even mean the demise of logging. It makes these activities more difficult, but also, in many ways, more important. The public is beginning to perceive that even watershed and recreation forests must be managed, and that intelligent logging can be much better for recreation, watershed, and wildlife than uncontrolled, indiscriminate natural catastrophes like wildfires, windthrow, or the mountain pine beetle. However, forest managers and loggers are going to have to accept the challenge of managing for much more diverse and complex objectives. A well-planned cut area, with well-planned access, good slash treatment, and successful reforestation is good for the watershed, good for recreation, and excellent for wildlife for 57 out of 60 years. That's a 95 percent rating on the nontimber scale, and it will pass the test of public scrutiny.

There are some essential elements, however, to achieving such a rating. First, the water management interests, the recreational users, and the wildlife managers must be fully involved in setting forest management objectives, and there must be a reasonable public consensus developed in support of them, before they are implemented. Increasingly, timber production will be an incidental benefit, derived from an integrated forest land use plan that is primarily driven by non-timber values. Various interest groups, and the public, will have to be encouraged to visit forest operations, to see, first hand, how the forest is being managed. What will they see in the future forests of the Mountain West?

They will see vistas of healthy green vigorous forests, in an aesthetically pleasing mosaic of different ages and heights. They will see stands that are more open, and more ground forage. There will be greater species diversity. The streams will continue to flow clean and cold. There will be more game animals and a greater diversity of wildlife. And down at the bottom of the valley, at the edge of settlement, there will still be a sawmill.

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THE FUTURE OF MOUNTAIN WEST FORESTS—WHO CARES?

Ross S. Whaley

ABSTRACT

Even with the faster growing species, or improved genetic stock, or fertilization, forestry is a long-term proposition compared to almost any other economic investment. The time from planting to thinning to harvesting usually spans decades. Yet, we as foresters rarely take that into consideration when planning our investment strategies. We may discount future revenues to compare them with current costs, but this is hardly considering the future. If social, technological, and economic change is occurring at even half the rate that many claim, what do we really know about the world in which our trees will be harvested six, or eight, or even 10 decades hence? It is important that we examine the problems of investments where an ability to forecast the future would be of inestimable value, but where we may have to settle for sharpening our skills in decision making under uncertainty. Unfortunately, managers abhor uncertainty and, therefore, often simply ignore it.

Although forecasting the future with any precision may be impossible, we can know enough about it to be useful. There are several trends that will have an impact on how we manage and use the forests of the Mountain West. These include: (1) increasing globalization of renewable resource issues; (2) changing age structure, geographic distribution, and nationality makeup of our domestic population; (3) a continuation of environmentalism; and (4) continuing decline in expenditure of Federal funds for many renewable resource programs.

INTRODUCTION

I want to talk about my favorite subject—the future. Like Charles Kettering, my interest is in the future because "I'm going to spend the rest of my life there." I also say it's a pleasure because of the whole focus of this conference that has already been pointed out by Wyman Schmidt—the title "Future Forests of the Mountain West," your goal of "a legacy of quality forests for future generations," and your task "to reinforce the commitment of forest managers and researchers to meet the needs and challenges of the 21st century."

My title, "The Future of the Mountain West—Who Cares?," will be largely unanswered by me. I do hope, however, that over this week it is answered by you, and I think that we've already had a good start. Mr. McDougall laid the framework of the importance of forests in the Province of Alberta. I think Governor Schwinden certainly did a good job of capturing the meaning of the forests for the State of Montana. So we're part way there in terms of who cares.

I'm going to focus my comments today on three propositions. I will treat the first one briefly, the third one briefly, and spend a little more time on the second one. I only mention that because as a youngster I remember sitting in church many times listening to the minister who always had three-point sermons. By the time he got through the second one I was all excited that it was about to end and then he spent a lot of time on the third one that was terribly boring. Let me warn you, my third one is going to be very brief, but watch out for the second one!

PROPOSITION 1

Although the United States historically has done an amazingly good job of rising to solve crises, we've done an atrocious job of long-range planning. I think back to successes in dealing with the Dust Bowl. Have you seen pictures of those years in the United States? Unbelievable! The essence of a desert was created in the prairie regions of the United States. There was an amazingly quick solution to that when thousands of miles of shelterbelts were planted and soils were quickly restored to productivity. I look at the Depression Era and the first 100 days after President Roosevelt took office. This was a prime example in the history of this country of a quick coming together to solve a crisis. And if you look at the way the United States rallied around World War I, and World War II, and again in a crisis, dealt with it very effectively. More recently, consider the roles of the United States and Canada in dealing with famine in Ethiopia. Again, a crisis, people rising to the occasion, and doing something about it very, very quickly.

On the other hand when I look at long-term planning, of which I mean vision, analysis, policy, and follow through, I don't see many examples in recent history where we do well with that. In fact if I look for some successes of what I call long-range planning, I go back to the change of the century and look at names like Theodore Roosevelt, Gifford Pinchot, Frederick Olmstead, and Benton MacKaye. Those are the names I come up with. These names are largely three-fourths of a century old in terms of the contributions that they made. In fact the only current example that I can think of, in the Federal level of government anyway, where I see a sense of long-term vision in analysis, followed by policy, followed by implementation, is perhaps the Star Wars Program. Now isn't it too bad that it is ill-conceived, has such a high probability of failure, and is so bloody expensive? But it's the one example that I can see in the current government of what I would say is long-range planning. Although the problems in taking the short-term view are deleterious to all aspects of our social, economic, and political welfare, they're particularly so for forestry. When you start measuring the time from planting to thinning to harvesting to replanting in terms of decades, long-term planning becomes crucial. I'm afraid so many of us, when we think of the future, remember those exercises at school where we did some discounting exercises. We discounted future values to the present, and assumed that was looking at the future. That exercise has little to do with the future. It seems to me that it's critically important to us that we think in terms of decades and what will be important at that time.

I'd like to take some time to talk about the dilemma and why it is that long-range planning is so difficult for us, but we don't have time here. The one thing I would say, however, is that I find it very glib that we tend to blame it on the politicians when we talk about their 2-year elections, 4-year elections, and 6-year elections. We talk about the time horizons for these people being only 2, 4, or 6 years and talk about how shortsighted that is. On the other hand, if you think about it, why do they take that short-term perspective? It's not something they invented, it's something we imposed upon them. Show me a politician who takes a long-term view, and I'll show you an expolitician. We simply won't reelect them. We want our views and our problems solved in the short-term. Well, as I think about it, why is it that we don't take a long-term view? The only reason that I can come to is we are all very uncomfortable with making decisions under uncertainty. That too was mentioned by Governor Schwinden. And that's what futuring is all about. It's not about forecasting. It's about making decisions under uncertainty. That leads me to Proposition 2.

PROPOSITION 2

The sophistication of forecasting isn't important. What is important is the ability to influence decisions. Now you just think about that a little bit. You have an airplane going west at 40,000 ft aiming at a particular latitude and longitude, and you have an airplane going east at 40,000 ft heading toward the same particular latitude and longitude—the success of the forecast of a crash is not critically important. What is important is the ability to make a decision that will prove the forecast wrong—that they will not intersect at a given longitude and latitude.

This became very clear to me in an activity that I was involved with in the Forest Service which was a tremendous learning experience for me. After the 1980 Resources Planning Act (RPA) process was finished, we were sitting in a group of people who were criticizing the RPA process. A group of industry people was there and the one I remember speaking up was a vice president of Champion International. He was saying, "The problem with you people in the Federal Government is you're always reinventing the wheel. There is all kinds of good planning going on in the private sector. Why don't you look at what they're doing and borrow some of their techniques?" I thought that was an interesting challenge. So I took it upon myself to visit industry planners, and what a fantastic exercise that was.

I visited Champion International, I visited Royal Dutch Shell, I visited McDonald's Hamburgers. The example that I remember best is the visit with McDonald's Hamburgers. The person in charge of long-range planning for McDonald's Hamburgers and I got together for lunch. I couldn't imagine what we possibly could have in common and what we were going to talk about. In a few minutes we started to talk about red meat consumption, and all of sudden I knew that we had something in common. In the Assessment portion of the RPA process, there's a whole chapter on domestic livestock grazing. I thought I knew a lot about red meat consumption. I could have told you that it peaked in 1978 at about 140 lb per capita per year, and that it declined between 1978 and 1982. But if it followed historical trends, with increased income, red meat consumption would go up to something like 150 lb per capita per year. I knew all of that stuff, so we really had something to talk about. But I found him fascinating. The McDonald's man's analysis did not come out of any computer. His analysis was on the back of an envelope and he simply did this—he said, "Ross, one of the concerns of McDonald's is the changing food habits of the American people. They are getting older, and as they get older, their average red meat consumption tends to go down. There's also a lot of concern about health in our life right now and people are concerned about cholesterol and nitrites in food. All of these things suggest a downward trend for red meat consumption." He in fact had some numbers he had calculated on the back of his envelope as to how low it might get. He took that information to the Board of Directors of McDonald's Hamburgers and they did something with it. They came up with a product called Chicken McNuggets. Now all of a sudden it struck me that he had done his future exercise on the back of an envelope, but it influenced a decision. Ross Whaley had reams of computer output stacked high, and I'm not sure he ever influenced a decision in his life. In fact it became very clear to me that we were so involved in the elegance of analyses that we may have developed something that was almost useless. Part of the problem is we are continually trying to do away with uncertainty. But that's not the critical aspect of thinking of the future.

Now what I'd like to do is make five back-of-the-envelope speculations about some trends, all of which will have a bearing, or at least an indirect bearing, on the forests of the Mountain West. They will bring considerable uncertainty to the decisions you people are going to face. The trends that I'm going to talk about are not those you are going to talk about this week. I'm not going to get into the technological changes that affect your harvesting or producing a better genetic stock through genetic engineering. Rather, I'd like to talk about the things that have little or nothing to do with the details of forestry, but which I think will have a tremendous impact on forestry in the Mountain West over the next decade or so.

First Trend

The first trend is that the movement of the population to the Sun Belt will begin to slow and may even reverse during the next several decades. I've not read that in any Bureau of Census reports, but I think it will happen. Why do I think it will happen? Well, let's speculate as to why people move from the north and east to the south and west.

When I mention this in New York, I really get into trouble, but nonetheless I still believe it. I think a lot of that movement occurred because New York City, Pittsburgh, Cleveland, Indianapolis, Detroit, Chicago, and Gary, Indiana, were crummy places to live. The crime rates were high. The cities were dirty. The labor unions had taken hold, and prices of labor were extremely high. And so if you are considering the location of a firm, where are you going to move? You move some place where it's clean, where the crime rates are low, and where the cost of labor is fairly low, such as Albuquerque, Salt Lake, and Denver.

How long is it going to take for Albuquerque, Salt Lake, and Denver to take on the very attributes of Chicago, New York, Cleveland, Pittsburgh, and Gary? The last time I visited those cities, I think they were well on their way. In addition to that, you have the interesting dilemma of water and the availability of water for industrial growth. I'm not sure but what we might see a bit of a change in that trend of population movement to the south and west.

Second Trend

As long as we are talking about some demographic characteristics, let's talk about another, which I think may have a striking impact on the forests of the Mountain West. That is, over the next few decades immigration will be responsible for an increasing share of our population growth. Simply, in this Country we have deferred marriages and deferred births, but there is an increase in immigration—that is an increase in legal immigration. In addition there is an increase in illegal immigration for which we do not even have very reliable estimates. But we do know from the numbers that we have, that immigration will make up a greater share of our population growth.

Immigration has always been a major share of the growth in our population, particularly in the early days of our Country. But, I think there's something different occurring. I don't mean this in the critical sense, nor do I mean it in the positive sense. I haven't thought that through in my own mind yet, but I do happen to think that something different is happening. The people coming to the Country now have a tendency to hold onto the language and the culture of the country from which they came. I think this is different than what occurred in the early days of our Country. When a family came from Italy, they settled in an Italian ghetto in New York City, but Rosa went to school and came back and she started to speak Italian around the house and Mama said, "No, we don't speak Italian now, we speak American." On the Fourth of July they put up the flag, and there was that sense of Americanization that I think is changing. There's an attempt to hold on in life, to hold on to the culture, to hold on to some of the mores of the country from which I came, and again I'm not sure that's bad.

I would argue that already, if they were organized, in New Mexico, Texas, Arizona, and southern California the Hispanic population would be the most powerful political block in those States. So there's the potential of a cultural enrichment coming from that kind of immigration or the potential that those States will become our Quebec. I think that's going to have a major influence on what happens in this Country in forestry in the next decade.

Third Trend

There are those who would lead you to believe that the environmental era is over; it's not. The only thing that has changed is that the environmental era has taken on a level of sophistication far greater than anything we saw at the end of the 1960's and early 1970's.

The thing that we don't recognize oftentimes is that those people who were carrying placards in the late 1960's and early 1970's are now wearing pinstriped suits and are located in your State Capitol or in Washington, DC. And so the name of the game is going to be a considerably more sophisticated name than that of the past. As soon as the economy gets going again, pressures will become greater for two reasons: obviously as the economy gets going it puts greater pressure on the land and environmental base, but the other thing is that the people get going. This Country's rich, well-fed people are getting excited about environmental concerns.

The fact that there was a decline in the environmental concerns over the early part of the 1980's was only partially because some needed legislation had been passed. A greater reason for the decline was the fact that there were a lot of unemployed people. When you have unemployed people concerned about where their next meal is going to come from, environmental concerns go by the wayside. As soon as the economy picks up again, the pressures will pick up, but also we have the luxury of being concerned about those things.

Fourth Trend

The fourth trend that I think will have a major impact on the forests of the Mountain West is this—the maldistribution of resources globally relative to the population will result in an increase in international interdependency. A lot of folks are talking about this becoming a global society. Yet as we look at the resource situation of the country, we really do not take an international perspective at all. Rather we take a domestic perspective. While the Forest Service Assessment has a chapter dealing with international trade, it still takes a U.S. perspective. I started doing a lot of reading about this business of global scarcity. I read the Global 2000 Report, and things of that kind, and as I read them I became more and more convinced that the fact of the potential of global scarcity was there and, if you listened to some of the more recent speeches by these folks, they were even saying that the decade of the 1980's would be a pivotal decade; that somehow in the 1980's we would go over the peak and worldwide we would start looking at concerns like we'd never seen before. A few were pointing to starvation in parts of Africa and saying "I told you so, the 1980's is going to be a pivotal decade."

The only problem with all that gloom-and-doom literature and coming to a conclusion from it was that for every book I read that said we are going to have global scarcity, I could find another one that said there was no problem. For every Dennis Meadows, I could find a Julian Simons; for every Chuck Barney, I could find a Herman Kahn. And these people had some substance in their argument, too. Don't discount them too quickly because what these people were saying was look at the historical statistics. Look at food consumption. Look at education levels. Look at health levels. Look at live births. Look at the developing nations of the world. And those statistics have gone up over time. Look at it from a statistics sense and they haven't peaked and they haven't turned down. Where's all the evidence of scarcity coming from? Statistically, it doesn't follow if you look at the historical well-being of the developing world. How do you wrestle with that? The one conclusion that I could come up with, the one point where both groups will agree, is the point of maldistribution. Whether you are the optimist or the pessimist, you have to conclude that the resources are not always located where the people are. And that's why there's going to be an impact on the western world because the United States happens to be one of those countries that's very well off and one of the rich nations with regard to resources. The only conclusion I can come to is that we will play a greater and greater role in the world resources situation.

There's another little side aspect to that I might mention. How does all of that track with people saying that this Country is going to be more and more of a service society and an information society, that we are going to be less and less involved with basic industry or manufacturing? I would make another forecast, and that is that in the future I see the United States being a bimodal economy; where in fact the manufacturing aspect of our economy as a proportion of the total economy may indeed go down, but the service and information side will go up and so will the primary industries. Agriculture will increase, forestry will increase, mining will increase. On the information side, we're going to find an increase there too and a good share of the manufacturing will be done across the border in Mexico, Korea, or Indonesia, or where it's growing at tremendous rates right now.

I also have to put my own little warning on those who will talk about us being totally an information society, and a tertiary service society. Although I believe the trend, I don't believe the ultimate conclusion. That is, if you look at the tremendous growth over the past several decades, a lot of that growth has been in the medical and legal services. Now it seems to me if you project that out too far that by the year 2020 we would spend all of our time getting sick and then suing doctors for malpractice. I might add in terms of us being a relatively rich Nation that not only will we be supplying international markets for timber, but we will be supplying international markets for recreation.

Fifth Trend

The fifth and last trend I'm going to mention I do with some hesitation, because I don't know if it has a direct implication for the Mountain West in terms of its forests. I only mention it because it might have an overwhelming toll on all of society. I would argue that the most serious problem facing our nation in the future is undereducation in a high-tech society. One of the things that most concerns us involved in higher education is the decline in the 18- to 24-year-old cohort in the population between 1985 and 1995. There's going to be about a 25 percent reduction in that cohort. In addition to that, I was looking at a map in the New York Times a couple of weeks ago which had those States in which 25 percent or more of the high school age kids were not graduating from high school. It was about 20 States in the Nation.

While there is a 25 percent drop in the population in the 18- to 24-year-old group between 1985 and 1995, the proportion of those people who are minorities is going up. This is the group with the highest high school dropout rate. Is there any possibility that as much as a third of our high school kids will not be graduating from high school by 1995? At a time when we are moving into a technologically oriented society, it scares me to think of the consequences of this trend.

PROPOSITION 3

Proposition 3 isn't a matter of predicting the future, it's structuring thoughts so we aren't caught by surprise. I mentioned those past five trends not in a sense of predictions, but rather for awareness building. They are things that I worry about, things that I think about in terms of putting together my plans so I'm not caught by surprise. This idea of not being caught by surprise was brought home to me best in conversation with a consultant colleague in Washington, DC, by the name of Joe Cotes. Joe Cotes categorized people into three kinds. The first kind is that group of people who are afraid of the future. They look in the mirror and they see themselves getting old. They don't like what they see. They long for the good old days; all they ever talk about are the good old days. You'd think that the future doesn't even exist in their minds because they are afraid to change. Now I would guess that there is probably nobody like that in this room.

On the other hand, Joe's second kind of person is the person who talks about change, but you have to assume that they believe it won't occur on their watch. They read Naisbitt's book, they read Toffler's book, they read other books, and they quote from them, but they make absolutely no change in the way they conduct their family life, or in the way they operate on the job, and they do the same old stuff they've always done. It seems to me that the only conclusion that you can come to from those people is yes, they believe that change is coming, but it's around the corner and certainly not on their watch—therefore they don't have to worry about it. I think there may be some of that kind of people in this audience.

Joe Cotes' third kind of person, however, is the kind of person who says: (1) The future is bright with opportunities; (2) I can't forecast it precisely, but I can know enough about it to be useful; and (3) I can influence it. So Joe Cotes' third kind of person knows the future is bright with opportunities, can't forecast it, but can know enough about it to be useful, and they can influence it. I guess my simple wish for this conference is that if you're not Joe Cotes' third kind of person at the beginning of this conference, that you will be by the end of the conference.

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SESSION 1.

The Opportunity

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Session Coordinator

We build our future on the resources of today. These resources—lands, forests, people, and knowledge—are the building blocks to construct the Future Forests. The papers in this section provide an overview of these resources with a focus on the potential for future production of multiple resources from our young forests.

The first papers inventory the magnitude and distribution of young forests in relation to total forest land area. They provide the source of information to define the young stand resource in terms of species, age, density, and productivity. These are the lands and stands where we have an opportunity to practice stand management. The next group of papers reviews basic tenets of wood production and the effects of management, including the basics of enhancing tree and stand growth, featuring a thorough look at utilization opportunities of a major species—lodgepole pine—and the opportunities for making major improvements in future wood quality and resulting value increases.

The last group of papers in this section addresses the opportunities to enhance resource values other than timber through management practices in young stands. Two perspectives are important as these experts review the effects of stand management on wildlife, forage, water, and recreation. First is the opportunity to enhance other resource values by giving them due consideration in the design and conduct of stand management practices for wood production objectives. The second perspective is to recognize the opportunity to employ silvicultural practices where the primary objective is to enhance nontimber values. These papers set the stage for other papers in this proceedings that deal with specific guidelines to enhance multiple resource values through management of immature stands.

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IMMATURE FOREST STANDS IN THE ROCKY MOUNTAIN WEST

Dwane D. Van Hooser
Sharon W. Woudenberg

ABSTRACT

Of the 57 million acres of timberland in the Rocky Mountains more than 33 percent could be considered stocked with immature trees. The characteristics of these acres are discussed, including their geographic and ownership distribution. The methodology used to allocate these acres is examined, and an alternative approach which is database oriented is presented.

INTRODUCTION

The forests of the Rocky Mountain West have been undergoing change. The majestic old-growth stands that once covered the mountainsides have slowly been removed or set aside, and today they represent less than 10 percent of the total timberland area. While stands in which large trees are the major component still predominate, many forested acres are stocked with young and hopefully dynamic stands that represent the future of forestry in the region. The first section of this paper deals with the general characteristics of these immature stands and then compares these characteristics based on standard Forest Survey definitions and an alternative definition that may be more meaningful. The next section compares the current and past stocking situations in western Montana. The final section discusses data sources and describes briefly a new resource database currently under development.

THE TIMBER BASE

Before discussing the immature stands in detail, we first need to define and generally describe the forest resources of the Rocky Mountain West. The States included in the region are shown in figure 1. The timberland area in the region amounts to some 57 million acres and represents 14 percent of the Nation's total. The forests in the region are second only to the Pacific Coast in the amount of softwood sawtimber they support. And, like its western neighbor, the majority of the forests are administered by the National Forest System. Twenty-five percent of the area, though, is under the direct control of private citizens or corporations.

Ponderosa pine, Douglas-fir, fir-spruce, and lodgepole pine types occupy more than 80 percent of the forests in the Rocky Mountain West. The most dominant single species are Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), and ponderosa pine (*Pinus ponderosa*), which combined account for nearly 60 percent of the softwood growing stock in the region.

While some of the Nation's most productive sites (those capable of producing 225 cubic ft/acre/yr) are found in the Rocky Mountain West, the potential productivity for the average forested acre is just over 60 cubic feet per acre per year. More than half of the forests have the inherent capability to produce 50 cubic feet per acre per year annually.

As shown in the following tabulation, more than two-thirds of the timberland in the Rocky Mountain West occurs in stands classified as sawtimber size. Twenty percent is in stands that are predominantly poletimber; nonstocked and seedling/sapling stands combined account for about 13 percent of the area.

Stand size	Thousand acres	Percent
Sawtimber	37,700.4	67
Poletimber	11,403.3	20
Seedling/sapling	4,869.3	9
Nonstocked	2,547.9	4
Total	56,520.9	100

(Source: USDA 1982)

On a State-by-State basis the distribution of timberland is greatest for Montana and Idaho; 20 percent or more of their total land area is timberland. Colorado is next with 17 percent. The remaining States are less than 10 percent forested.

Figure 1—Rocky Mountain States.

DEFINING IMMATURE STANDS

The Traditional Approach

To describe the immature resource in terms that are consistent with recent national, regional, and State reports the traditional stand-size classifications will be used in defining immature stands. By Forest Survey standards:

- A sawtimber-size stand is at least 10 percent stocked with growing-stock trees, with half or more of total stocking in poletimber and sawtimber trees, and with sawtimber trees at least equal to poletimber stocking.

- A poletimber-size stand is the same as a sawtimber stand except that poletimber stocking exceeds that of sawtimber-size trees.

- Seedling/sapling stands are defined as those stands that are at least 10 percent stocked with growing-stock trees of which more than half are below 5.0 inches diameter at breast height (d.b.h.).

- Nonstocked areas are those forests that are less than 10 percent stocked with growing-stock trees.

For purposes of discussion all stands **except** those of sawtimber size will be considered immature.

Using this definition we find that the characteristics of the immature resource are quite similar to those of the total resource. Nearly three-fourths is on lands administered by public agencies, and more than one-fifth is in nonindustrial private ownership.

Nearly two-thirds of the immature stands are stocked with poletimber-sized trees. One-fourth are in seedling/sapling stands, and the remainder are nonstocked.

In terms of productivity potential the immature stands are distributed as follows:

Productivity class	Percent
Ft³/acre/yr	
20-50	63
50-85	21
85-120	11
120+	5
Total	100

Differences in characteristics occur in distribution by forest type and by State. The forest type with the largest proportion of immature stands is lodgepole pine. Thirty-four percent of the immature stands in the Rocky Mountains occur in this type. And 60 percent of the type is classed as immature. Nearly one-fifth of the immature stands are contained in a rather minor forest-type group—western hardwoods.

On a State-by-State basis we find an almost inverse relationship (table 1). That is, for those States containing a substantial acreage of timberland, the proportion in immature stands is low. For example, one State with a high proportion of timberland—Idaho—has only 29 percent in immature stands. Two States with a relatively low proportion of timberland—Utah and Wyoming—each contain a significant component of immature—between 30 and 35 percent. Overall, the State with the largest component of immature is Colorado; nearly half of its timberland acreage is in immature stands.

Table 1—Timberland area in the Rocky Mountains by State and proportion in immature stands

State	Total timberland	Immature stands: Area	Immature stands: Percent of total
	Thousand acres		
Arizona	3,895.6	492.2	13
Colorado	11,314.7	5,503.6	49
Idaho	13,540.6	3,922.0	29
Montana	14,359.4	5,346.3	37
Nevada	134.3	17.8	13
New Mexico	5,537.5	915.3	17
Utah	3,404.6	1,095.3	32
Wyoming	4,334.2	1,528.0	35
Total	56,520.9	18,820.5	33

(Source: USDA 1982)

All of the preceding data have been based on national and regional statistics (Green and Van Hooser 1983; USDA 1982) compiled using standard Forest Service definitions. The value of having these standards is that consistency is maintained over time and data are comparable, so that trends can be analyzed. Designating stands as immature using the traditional stand-size definition, however, may cause some difficulties because of the wide range of sawtimber stocking allowable for a stand to be in the sawtimber-size class. For example, figure 2 shows the potential distribution that can occur for a stand to be classed as sawtimber. Quite clearly, sawtimber stocking less than 40 to 50 percent would indicate a stand in a developmental state, especially if this represented total stocking of that stand. Thus, using this definition alone

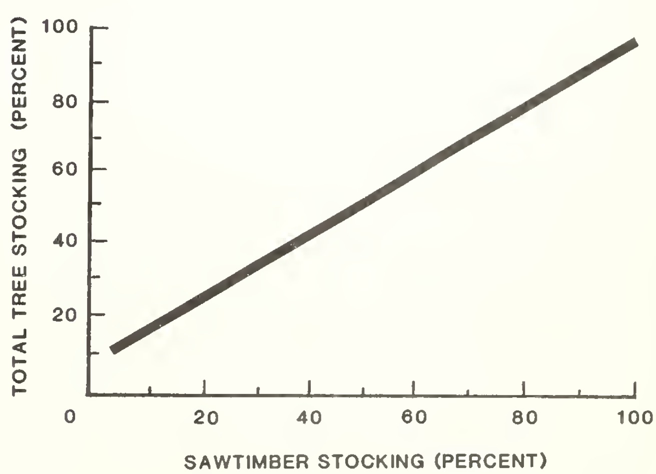

Figure 2—Range of stocking percentage for sawtimber stands.

may be misleading when trying to determine the amount of immature area.

An Alternative Approach

Perhaps, a more useful approach for the purpose of examining immature or future forests would be to define those stands with the potential for treatment. For purpose of discussion these will be defined as stands that are 60 percent or less stocked with trees and less than 80 years old. The 80-year age is simply an arbitrary break, since some stands could not be treated economically after 35 years of age.

To compare the difference between the traditional approach and the one outlined above, the recently completed inventory of western Montana will be used (Brown and Van Hooser 1980). The data are for State and private timberlands only. Resource statistics do not include estimates for lands administered by National Forest System, U.S. Department of the Interior, Bureau of Land Management, or other public agencies. The area contains approximately 3.6 million acres of State and private timberland. Sixty percent is classified as sawtimber size, using the traditional definition. The predominant forest type is Douglas-fir, accounting for nearly half the area. The State administers slightly over one-half million acres—the remaining area is about equally split between forest industry and nonindustrial private.

After screening the data for western Montana using the two definitions outlined above, several interesting comparisons were developed.

First, the distribution of immature stands by ownership using the new definition indicated an increase in the nonindustrial private portion; the area by forest type showed a minor increase in Douglas-fir and a significant decline in the lodgepole pine type. It decreases from 29 to 12 percent of the area of immature stands. And since the number of acres increased under the new definition, the areal decline would be even larger. Moreover, this decline also reflects the age distribution of the lodgepole types. Many of these stands tend to be overstocked and stagnated with little development beyond the poletimber stage.

The most significant change occurs in the distribution of immature stands by stand-size class (fig. 3). Under the traditional definition the proportion of immature stands was about equally distributed between seedling/sapling and poletimber stands with each accounting for about half the area. Nonstocked stands accounted for 3 percent and by definition there were no sawtimber stands classed as immature. Under the new definition there is a significant shift in the distribution. The contribution of seedling/sapling and poletimber stands decreases noticeably, and the proportion of immature stands that are sawtimber-size increases to nearly two-fifths of the area. This is a direct reflection of the number of stands classified as sawtimber size that are really grossly understocked and in need of treatment.

When comparing the shift in distribution of immature stands by productivity class, we find that under the new definition more than two-thirds of these stands are in the 20-50 class. The next class, 50-85 ft³/acre/yr, also shows a slight increase. The higher productivity classes show significant declines in area under the new definition. Since much of the area change can be attributed to the increased contribution of sawtimber stands, the shift in productivity class distribution could be attributed to the characteristics of these larger stands. While the inventory data do not permit actual descriptions, we assume that many of these sawtimber stands are those growing on the more severe sites and in fact may not be part of the forest that would be treated to increase future yields.

The assumption that many of the sawtimber stands considered immature under the alternative approach are not "fodder" for treatment is further reinforced, when actual annual growth per acre is compared to potential growth of these immature forests. Since productivity class definition is based on potential cubic foot growth at culmination of mean annual increment, one would expect that truly immature stands would be on the increasing segment of the growth curve and would actually be exceeding the annual rate reflected at culmination. Under the standard definition this is true. In all cases these immature stands have a component where current growth exceeds the potential. The new approach also contains stands where current growth exceeds potential but in every case the number of stands is fewer for the new compared to the standard (fig. 4).

The distribution of stands at or above annual potential indicates that either definition of immature could be used.

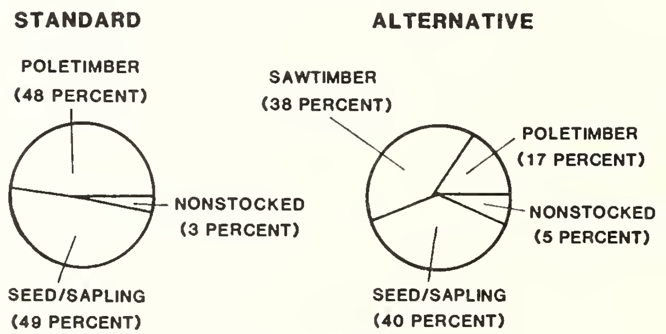

Figure 3—Distribution of immature stands by stand size class in western Montana using standard and alternative definitions of immature.

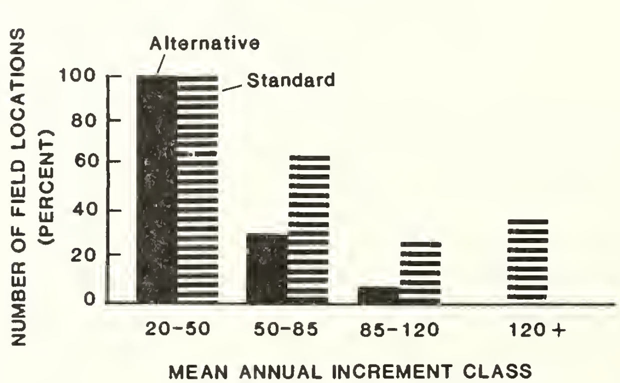

Figure 4—Comparison of stands at or above potential mean annual increment using standard and alternative definitions of immature.

Apparently many of the stands are growing quite vigorously and may not need additional treatment to enhance future yields. There is, however, much to be considered when making decisions about future actions. These decisions are usually made on a stand-by-stand basis which goes far beyond the scope of the information presented here. The information presented above does give an indication of the magnitude of the immature condition in western Montana and the Rocky Mountain States. And there are several conclusions that can be drawn. First, the area in immature stands is about the same regardless of how we define it. Under the scenarios presented here for western Montana the area of immature stands amounted to 40 percent under the standard definition and 30 percent under the new. The regional summaries indicate that for the Rocky Mountain States in total about 35 percent of the area is in immature stands. Second, like children and parents the characteristics of the immature stands resemble those of the mature or total forest resource. Third, a significant number of the immature stands in western Montana, using the standard definition, are presently exceeding their potential at culmination of mean annual increment which indicates that they are indeed young and vigorous. The new definition indicates that there may be stands of sawtimber size that are either grossly understocked or growing under adverse conditions that may preclude any kind of economically feasible treatment opportunity.

PAST VERSUS PRESENT

The above analysis is based on the latest available resource statistics for the Rocky Mountain States and western Montana. How does today's resource situation compare to the past with regard to the stocking levels within the major forest types and their implications for treatment?

In the early 1960's Wikstrom and Wellner (1961) did an analysis of the pruning and thinning opportunities in the Rocky Mountain West. That analysis included a profile of timber stocking in western Montana by forest type, using the 1958 reinventory as a source of data. They found that with the exception of ponderosa pine and alpine fir types well-stocked stands predominated, and medium- to well-stocked stands occupied "the lion's share" of the area. They also found that the Rocky Mountain West had relatively few poorly stocked stands. By their definitions, a well-stocked stand was 70 percent or more stocked with trees, medium-stocked stands were 40-70 percent stocked, and poorly stocked stands were less than 40 percent stocked.

Using these criteria the current data for western Montana were summarized and compared to the summaries generated from the 1958 inventory data. Because of data limitations our comparisons were limited to those forest types displayed in figure 5. With the exception of the lodgepole pine type, the proportion of the stands that are well stocked has declined. The most notable shifts occurred in the spruce and Douglas-fir types. The well-stocked component declined by 50 percent in the spruce type, going from 70 percent in 1958 to 36 percent in 1978.

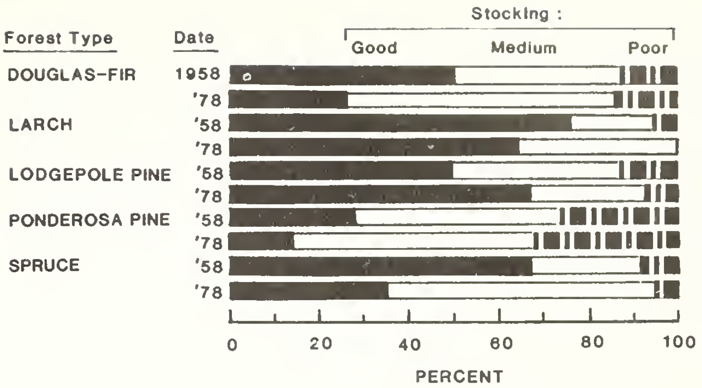

Figure 5—Comparison of timber stocking by forest type in western Montana, 1958 and 1978.

Douglas-fir showed similar but smaller declines in well-stocked stands. The area in poorly stocked condition remained about static overall with minor shifting occurring within types. Ponderosa pine and Douglas-fir, for example, had slight increases in the area of nonstocked stands. Larch, lodgepole pine, and spruce types all had declines. Larch currently has no area in a nonstocked condition.

Overall, the forest condition has remained about the same since the 1958 inventory. Full- to medium-stocked stands still account for "the lion's share" of the area, and many of the treatment opportunities that existed in the early 1960's still exist today.

DATA SOURCES

The organizers of this symposium asked that we also present an "inventory" of data sources that could be useful in making further analyses of the forest resource situation in the Rocky Mountain West. Several have been cited in the preceding sections. There are, however, additional sources to be considered.

Published

Within Forest Survey our policy is to publish resource bulletins for county groups as the field work progresses. An example is the bulletin for the headwater counties of Montana (Sterrett and Felt 1983). Once we have completed an inventory in a State we produce a report covering the ownerships included in the field sample (Van Hooser and Green 1985). We also publish State analytical reports that include the total forest resource base within a State (Green and others 1985). These are incorporated into the regional and national reports cited earlier.

When the inventories are conducted as a joint venture, the cooperator may do a more detailed analysis on a substate basis. This was done in Montana. Each working circle, or working circle group, was thoroughly analyzed and a report such as that for Working Circle 2 (Montana Department of State Lands 1983) published.

Others such as Naugle and McQuillan (1985) have researched data sources within a State and summarized their availability.

Computer Oriented

The Forest Survey Research Work Unit is generally the repository for forest resource information for all lands except those administered by the National Forest System. We are currently developing a PC-compatible database that will be available to outside users for a small fee. This database, which is plot oriented, will include area and volume data as well as information on growth and mortality. The plots will be self-weighting; thus any user will be able to define which county groups are of interest and develop tailormade resource data retrievable in "the comfort of their home."

When using published information or computer databases it is important to exercise care. Many data elements are rigidly defined and can lead to erroneous conclusions if misapplied—our sawtimber-size stand classification, for example. Moreover, most of this information is statistically based and requires county aggregations before the totals can be judged statistically reliable. Forest Survey statistical requirements, for example, are that the estimates of timberland be within ± 3 percent at 1 million acres at the 67 percent probability level.

And, finally, no matter how complete the sources of data may be it is important to remember that the answers you seek may not be in the information you possess.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Susan Stout)—What definition of stocking was used in your paper and the Forest Survey associated publications (both stand stocking and sawtimber stocking)?

A.—Stocking is a nebulous concept at best. Our procedures, however, use the basal area standard approach to determine stocking potential and to assign stocking to individual trees. Essentially the basal area standard is determined for each field location based on dominant species, age, and site index and is an expression of the stocking the location could support to produce optimum or maximum yield. Another approach utilizes number of trees per acre by diameter to determine stocking rates or levels.

The bottom line, though, is to develop a measure that reflects the degree to which the site is occupied by the various stand components and that can provide input into the decision-making process.

FOREST LAND INFORMATION SYSTEM: INVENTORYING IMMATURE STANDS IN THE CANADIAN INLAND MOUNTAIN WEST

Frank Hegyi
J. F. McLellan

ABSTRACT

The attainment of maximum productivity of forest resources for present and future generations depends to a large extent on our knowledge of the state and condition of the resource and our ability to identify, locate, and delineate those forest types that will maximize productivity returns. The Inventory Branch of the British Columbia Ministry of Forests and Lands has developed and implemented a fully geocoded Forest Land Information System integrating computer-assisted mapping, satellite image analysis, digital terrain modeling, growth and yield projection, and inventory processing and reporting capabilities. Uses of the Forest Land Information System are presented and discussed, with particular reference to the selection of candidate areas for intensive forest management.

INTRODUCTION

The Canadian Inland Mountain West has three broad physiographic units: the Southern Canadian Rocky Mountains, the Purcell Mountains, and the Rocky Mountain Trench. The area covers approximately 3.1 million ha (7.66 million acres) of which 75 percent lies in British Columbia (BC Department of Lands, Forests and Water Resources 1970) and 25 percent in Alberta (Alberta Department of Forestry, Lands and Wildlife 1985)(fig. 1).

The Canadian Inland Mountain West has high vertical relief with strong climatic gradients. The mountains run in a northwest to southeast direction rising above 3,000 m (9,840 ft). They form barriers to the eastward flow of moist Pacific air, forcing air to rise, which causes increased precipitation of 1,500 to 2,000 cm (59 to 79 inches) per annum on the western slopes and drier climates in the rain shadow of the mountains. The major valleys, including the Rocky Mountain Trench and east-facing slopes, are relatively dry to semiarid with an annual precipitation of 450 to 750 mm (18 to 30 inches).

The combination of high vertical relief, complex geology, and rugged topography has had a major effect on soil formation (BC Ministry of the Environment 1978). Common parent materials include colluvium, glacial till, and fluvial deposits. The common occurrence of sedimentary limestones results in extensive areas of soils developed on calcareous parent materials.

Most forest land of the Inland Mountain West is managed by the Provincial governments of British Columbia and Alberta. Approximately 2.33 million ha (5.75 million acres) lie in British Columbia and 0.77 million ha (1.90 million acres) in Alberta (Morgan 1986). There are three management units, two in British Columbia (Cranbrook and Invermere), and a portion of one in Alberta (the Bow/Crow). All units have been recently inventoried or updated. Statistical summaries are not always comparable between the two Provinces, but area statistics have been aggregated and shown for the whole area, where possible.

A summary of the major land classes for the Canadian Inland Mountain West is shown in table 1.

The major tree species found in the area are: lodgepole pine (*Pinus contorta* var. *latifolia*), white and Engelmann spruce (*Picea glauca, P. engelmannii*), Douglas-fir (*Pseudotsuga mensiesii*), western larch (*Larix occidentalis*), and

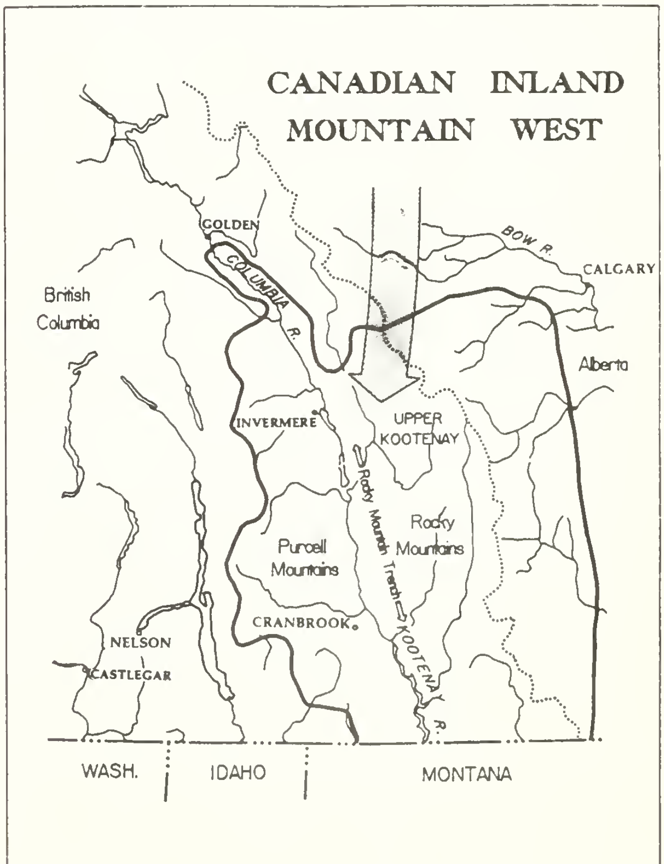

Figure 1—The Canadian Inland Mountain West.

Table 1—Land area summary by major cover classes

Cover Class	British Columbia	Alberta	Total	Percent
	Millions of hectares			
Immature[1]	0.83	0.38	1.21	39
Mature	.50	.10	.60	19
Not satisfactorily stocked	.05	.02	.07	2
Noncommercial[2]	.03	—	.03	1
Nonforest[3]	.92	.27	1.19	39
Total	2.33	.77	3.10	100

[1]Includes all satisfactorily stocked forest stands up to 120 years of age.
[2]Includes productive forest land covered by brush.
[3]Includes unproductive forest and nonforest land.

Table 2—Area summary by major growth types for immature stands

Major growth type	British Columbia	Alberta	Total	Percent
	Thousands of hectares			
Deciduous	18	45	63	5
Lodgepole pine mixtures	392	263	655	54
Spruce mixtures	111	65	176	15
Western redcedar, hemlock	2		2	
Western larch, Douglas-fir	104		104	9
Ponderosa pine, Douglas-fir	51		51	4
Douglas-fir	148	8	156	13
Total	826	381	1,207	100

alpine fir (*Abies lasiocarpa*). Inventory growth types are grouped and summarized in table 2.

The productive zone ranges from 900 m (2,953 ft) to 1,900 m (6,232 ft). Productivity varies widely as a function of moisture, soil, and topographic location: from 0.5 m^3/ha (7 ft^3/acre) to 3.9 m^3/ha (56 ft^3/acre) (Jungen and others 1968). Summaries of area and average mean annual increment by site class are given in table 3.

Approximately 55 percent of the productive land base is occupied by young forests of less than 80 years. The high proportion of young stands and the age pattern reflects a history of uncontrollable wildfires, particularly in the 1920's and 1930's. Fire has created suitable conditions for the establishment of extensive natural stands of the seral species, lodgepole pine and western larch. The age distribution pattern is summarized in table 4.

Effective forest management is a major challenge in this area. Not only is management made difficult by extremes in topography, but also by the inherent problems of obtaining satisfactory regeneration on the drier sites, and at higher elevations that are subject to invasion by brush. Other challenges to managers include extensive areas of overstocked lodgepole pine, a major infestation of mountain pine beetle (*Dendroctonus ponderosae*), and uneven-aged mixtures of ponderosa pine and Douglas-fir in the Rocky Mountain Trench. Finally, the forest manager must also be concerned with other resource values that are particularly important to this area, such as a major cattle industry, recreation, wildlife, and water.

For the forest manager to meet the current and future needs of society for goods and services, information is required on the forest resource. The basis for most of this information is a forest inventory data base that is current, comprehensive, able to be updated, and designed to provide a wide range of data for resource allocation, stand management, and future projections. This paper will focus on the procedures currently in place and used by the British Columbia Inventory Branch to ensure the availability of forest stand data required by both local and regional forest managers.

Table 3—Productivity data for stands up to120 years

British Columbia			Alberta		
Site class	Area	Mean annual increment[1]	Site class	Area	Mean annual increment[2]
	Thousand ha	m^3/ha		Thousand ha	m^3/ha
Good	59	3.8	Good	177	3.9
Medium	333	2.5	Medium	88	2.4
Poor	371	1.1	Fair	116	1.3
Low	63	0.5			
Total	826			381	

[1]17.5 cm (6.9 inches) d.b.h.+, 30 cm (11.8 inches) stump height, 10 cm (3.9 inches) d.i.b. top, less decay.
[2]30 cm (11.8 inches) stump height, 13.0 cm (5.1 inches) d.o.b.+ at stump height, 7 cm (2.8 inches) d.i.b. top, less decay.

Table 4—Area summary by age for stands up to120 years

Age	British Columbia	Alberta	Total	Percent
	Thousands of hectares			
1-20	39	2	41	3
21-40	108	41	149	12
41-60	346	109	456	38
61-80	202	127	329	28
81-100	76	61	136	11
101-120	55	41	96	8
Total	826	381	1,207	100

INVENTORY PROCEDURES

The major activities of the inventory process are forest stratification and description, production of maps, collection of field data to determine stand volumes, preparation of growth estimates, and maintenance of inventory data base.

Forest Classification

Initially, the land is stratified into homogeneous strata based on a set of well-defined criteria using mid-scale aerial photography of 1:15,000, although 1:20,000 and 1:10,000 scales are also used. Forest and nonforest land are identified. Forest land is further subdivided and described in considerable detail by continuous variables for such criteria as species composition, age, height, crown closure, stand density, and stand structure. In addition, stand history is recorded for disturbances and silvicultural activities. Each forest type is also rated for environmental sensitivity where harvesting constraints need to be applied. Finally, nonforest land is recognized as barren, rock, high-elevation nonproductive burn, swamp, nonproductive brush, cultivated, or urban area.

Forest Sampling

Forest land is sampled with the objective of estimating timber volumes by aggregated types to a statistical accuracy of ±10 percent at the 95 percent probability level. The sampling technique applied is a multiphase stratified random sampling system, using large-scale aerial photo plots and ground samples within the context of double sampling. This approach facilitates the inclusion of existing ground samples from different surveys, and at the same time provides the opportunity of sampling with aerial photo plots populations not previously sampled owing to inaccessibility and high cost.

The two main components of the multiphase sampling system are phase 1 and phase 2 samples. The phase 1 samples are large-scale (1:200 to 1:1,000) aerial photo plots distributed randomly or in a restricted random manner. Stereo pairs of aerial photographs are obtained using twin Hasselblad 70-mm cameras mounted a fixed distance apart on an aerial platform attached to a helicopter. Phase 2 samples are ground samples selected in a restricted random manner from the photo samples with the purpose of covering the range of variation encountered.

Phase 3 samples are growth and depletion samples selected in a restricted random manner from phase 2 samples.

Final Classification and Data Transfer

Based on data obtained from ground and photo samples and other field surveys, aerial photographs are interpreted in terms of the classification system. A separate description is given for each layer (maximum two) in a multilayer stand. Forest cover type boundaries are transferred to a forest cover base map; each forest cover map type is assigned a unique reference number and the associated descriptive details recorded onto a data transfer sheet. The final step is the loading of forest cover attribute information and the digitizing of map details using a computer-assisted mapping system.

Statistical Summary and Update

Volumes per hectare, as well as other descriptive statistics, are obtained for each major stratum (defined by growth type or species composition, age class, and site type) from ground and photo samples. Aerial photo volumes are adjusted, when applicable, through double sampling using regression equations. The last step in the inventory process is the preparation of inventory statistics by merging the map-related data with sample data. The system provides area summaries by forest cover type as well as volume summaries by strata. The history of each stand is maintained as well as its present status.

On a regular basis, the present status is updated to reflect changes that are predictable, such as growth. Files are also updated for disturbances and silvicultural activities. Sources for this update information include local monitoring and satellite imagery.

DATA BASE DESIGN

The data base has been created primarily for planning and management applications. An integral part of the forest management planning system is the establishment of broad management strategies, including the allowable annual cut and the location of operating areas. These analyses involve the use of inventory allocation models and other techniques.

Since the planning system requires land information for both detailed local areas and timber supply management unit planning, the data base has been designed to be flexible in terms of resolution and time, especially to accommodate the planning and selecting of management strategies for silvicultural treatments, fire and pest protection, planning cutting priorities, regular updating, and the projections of future growth and changes.

Geographic Information System

The map data are digitized in vector format. Files are of variable length and sequential; they are scanned in a manner that permits query on geographic and other criteria. The various maps, such as forest cover and administrative boundaries, are stored as separate levels for display or analysis. The polygons are linked to nongraphic attribute data by text node, which is the position within the polygon where the label appears.

Attribute data files are regularly updated, queried, subsetted, aggregated, reported, and used for projection functions. The data required for specific functions may be accessed through key-maps that indicate which files contain data relating to each area.

Vector files are not easily manipulated. For this reason vector files are converted to grid (raster) files that have a resolution of 25 by 25 m. These files lend themselves to determining the extent of each polygon, overlaying different levels, aggregating polygons with similar attributes, calculating areas, and producing color maps based on selected criteria.

During the past few years the Inventory Branch, in cooperation with the Canada Center for Remote Sensing and private consultants, has tested satellite image analysis for forest classification, sampling, insect damage detection, and disturbance update (Hegyi 1985). Results indicate that satellite image analysis has particularly good potential for upgrading areas disturbed by logging, windthrow, insect attack, and fire. LANDSAT multi-spectral scanner (MSS) is now used on an operational basis for disturbance update.

The parallel development of CAM systems and the digital image analysis system (IAS) has now reached a point where they can be integrated to provide a CAM/IAS interface. This integration has provided the capability to link LANDSAT MSS data with conventional inventories. A more recent development is the capability to overlay integrated digital terrain models (D.T.M.) on the data base; this provides the opportunity to examine forest and the related resource land data in three dimensional space.

OPPORTUNITIES FOR MAKING STAND CULTURE DECISIONS FOR IMMATURE STANDS

The introduction of computer-assisted mapping and satellite image analysis systems provides a wide range of new opportunities for forest management: the information contained in the digitized maps can be summarized in a flexible manner; a variety of resource folios can be viewed simultaneously through overlay procedures; and single- or multiple-level information can be highlighted in color for planning purposes. In addition, multiresource land information can be combined with digital terrain models, providing the capability of examining the forest and related resource land base in three dimensions.

Relevant Information Available for Stand Culture Decisions

A major objective of forest management is to increase the yield and values of future forests through silvicultural treatments. The objective can be achieved by the forest manager in two ways: (1) by evaluating stands in need of treatment, the level of treatment required, cost of treatment, and expected increase in value added from the treatment, and (2) by allocating available silvicultural funds to those stands that will yield the highest return for the resources invested. A current, well-ordered data base can provide much of the information required for initial selection and prioritization of opportunity classes for treatment.

Basic forest cover type details are organized by forest cover map. Each forest cover type (polygon) is assigned a unique reference number that links the polygon to associated files that carry descriptive details. Attributes are summarized by polygon on a map attribute file. The map attribute file includes the following information:

1. Polygon reference number.
2. Forest cover attributes, such as:
   - Species composition to the nearest 10 percent.
   - Stand age to the nearest year (updated annually).
   - Stand height to the nearest decimeter (updated annually).
   - Site index.
   - Stand density per hectare (when available).
   - Crown closure to the nearest 10 percent.
   - Stand structure: Each layer of a multilayer stand is fully described for species composition, age, height, and crown closure to a maximum of two layers. Uneven-aged stands are given a special code, plus an age range, in addition to species composition, age, height, and crown closure.
   - History attributes: Disturbances are described as to kind, degree, and year of disturbance; silvicultural activities are described as to the kind(s) and year(s) of activities.
   - Environmentally sensitive areas, particularly those areas where there will be constraints against harvesting, are identified as to the reason for the constraint, and degree of sensitivity.
   - Regenerating stands, generally those less than 20 years, are described for the number of acceptable, well-spaced stems per hectare, and for the presence of an unacceptable amount of brush.
   - Data source: Describes the source of the data on which the label is based.
3. Derived attributes that are linked to the map attribute file such as area and growth projection data.

The map attribute file is currently being expanded to capture additional descriptive details such as elevation, slope, aspect, ecological association, and other information from compatible data bases of other resource agencies.

From the data base there is a wide range of information that can be extracted and presented, from details associated with a specific polygon to more generalized or thematic summaries that can be used for integrated resource management, and for identifying stands that would benefit from a silvicultural action. Several examples are shown to illustrate how the data base can be used to identify opportunity classes for possible silvicultural treatments, without and with topographic attributes.

Identifying Cultural Opportunity Classes Without Topographic Attributes—Example 1. Identify opportunity classes for juvenile spacing in cover types leading in lodgepole pine, age 21-40 years for the Upper Kootenay subunit with a gross area of 552,000 ha (1,363,440 acres). Types are summarized by area, site class, and crown closure class (table 5).

Example 2. Identify opportunity classes for conifer release in cover types with Douglas-fir deciduous mixtures, age 1-60 years. Types are summarized by area, age class, and site class (table 6).

Identifying Cultural Opportunity Classes With Topographic Attributes—As noted earlier, D.T.M.'s can be overlayed onto forest cover base maps to generate elevation, slope, and aspect by forest cover polygon. This capability adds a useful dimension for helping managers to identify potential opportunity classes for silvicultural treatments. Several examples are shown, based on a single forest cover map sheet that covers approximately 15,000 ha (37,500 acres).

Example 1. Identify stock type requirements and plantation priorities for cover types classified as not satisfactorily restocked (NSR). Types are summarized by area, site class, and elevation class (table 7).

Example 2. Identify opportunity classes for precommercial thinning in cover types with mixtures of Douglas-fir and western larch, 21-40 years. Types are summarized by area, site class, elevation class, slope class, and crown closure class (table 8).

Table 5—Area summary for cover types with leading species lodgepole pine, 21-40 years, by crown closure class and site class

Crown closure class	Site class				
	Good	Medium	Poor	Low	Total
Percent	- - - - - - - - - - - -	*Hectares*	- - - - - - - - - - - -		
10	87	595	686		1,368
20	139	215	192	18	564
30	6	363	58		427
40	139	351	49		539
50	83	195	525		803
60	166	20	161	4	351
70			60		60
80					
90					
Total	620	1,739	1,731	22	4,112

Table 6—Area summary of cover types with Douglas-fir deciduous mixtures, 1-60 years, by site class (British Columbia only, total area)

Age class	Site class				
	Good	Medium	Poor	Low	Total
Percent	- - - - - - - - - - - -	*Hectares*	- - - - - - - - - - - -		
1-20		34	55		89
21-40	23	630	308	11	972
41-60	71	449	1,599	84	2,203
Total	94	1,113	1,962	95	3,264

Table 7—Area summary of cover types not satisfactorily restocked (NSR) by site class and elevation class

Elevation class	Site class				
	Good	Medium	Poor	Low	Total
Meters	- - - - - - - - - - - -	*Hectares*	- - - - - - - - - - - -		
800-900	8.6	2.1	10.9	0.9	22.5
901-1,000	7.1	22.6	5.4	6.1	41.2
1,001-1,100		27.2		.1	27.3
1,600-1,700		14.7			14.7
1,701-1,800		3.4	3.1		6.5
1,801-1,900		6.3	12.0		18.3
1,901-2,000		11.2	21.6		32.8
Total	15.7	87.5	53.0	7.1	163.3

Table 8—Area summary of cover type with mixtures of Douglas-fir and western larch, 21-40 years, by site class, crown closure class, elevation class, and slope class

Crown closure class	Elevation class	Site Class/Slope Class						Total
		Slope percent		Slope percent		Slope percent		
		0-60	61+	0-60	61+	0-60	61+	
Percent	*Meters*	- - - - - - - - - -		*Hectares*		- - - - - - - - - -		
6-55	701-800			2.7		12.6	8.4	23.7
	801-900			19.9	0.2	14.0	1.9	36.0
	901-1,000			.2	1.1	3.5		4.8
	1,001-1,100			1.2	.2	.2		1.6
	1,101-1,200			2.9				2.9
56+	701-800	5.4						5.4
	801-900	7.5	2.1					9.6
Total		12.9	2.1	26.9	1.5	30.3	10.3	84.0

CONCLUSIONS

Our ability to maximize productivity of forest resources for present and future generations depends largely on our knowledge of the resource and our ability to identify those forest types that will yield the highest return for the resources invested. The Inventory Branch of the British Columbia Ministry of Forests and Lands has developed and implemented a fully geocoded Forest Land Information System that integrates computer-assisted mapping, satellite image analysis, digital terrain modeling, growth and yield projection, and inventory processing and reporting capabilities. Potential applications and products have been presented and illustrated for the immature stands of the Canadian Inland Mountain West. Particular emphasis was given to the identification and selection of candidate areas for intensive forest management.

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ENHANCING FOREST GROWTH: THE ROLE OF CULTURAL PRACTICES

Richard F. Fisher

ABSTRACT

Silviculture operates at many levels of abstraction. In the truly domesticated forest, silviculture alters both biological and physical reality to produce wood in the most desirable form at the most desirable rate. Can we ever have this level of silviculture in the Mountain West? Of course we can; we even may. Cultural practices, properly applied, can produce dramatic increases in the quantity and quality of wood produced per unit area and dramatic reductions in the time necessary to produce that wood. But forestry is a bioeconomic endeavor. We must know how to do silviculture, and we must be able to afford to do it.

INTRODUCTION

Silviculture is the care and tending of the forest for the production of all the goods and services derived therefrom. Consequently, particularly in diverse areas such as the Mountain West, much silviculture will be carried out to promote values other than timber production. The classical German injunction "good forestry is hard to see" applies to these areas where silvicultural practice seeks to maximize recreational opportunity and wildlife habitat.

In this paper we will be concerned solely with timber production on highly productive sites and with the cultural practices that increase growth and wood production. Forestry operates at many levels. To help us see where we have been, where we are, and where we hope to go along the continuum of forest practice, let us consider Stone's (1975) depiction of the stages in forestry development (fig. 1).

Remote wildlands are protected from human impact simply by their remoteness. Few such areas still exist in North America. Protected forest is guarded by man. Indiscriminate cutting and fire are controlled, but no additional efforts at management are made. Exploited forest, which occupies much of the Mountain West, is protected and harvested but little or no effort is made to regenerate it or to control the composition of future stands. Regulated forest, as the name implies, is managed to produce a regular timber yield over a protracted period. Many acres of Mountain West forest are regulated, some more successfully than others.

In the regulated forest the silviculturist operates within the bounds of natural site conditions and plant materials. In the domesticated forest natural conditions are altered through technology. Tree improvement is used to produce superior genotypes; site preparation, drainage, fertilization, even irrigation may be used to alter normal site conditions. Weed control, insecticides, fungicides, and soil fumigants are used to change competitive relationships. In this paper we will be concerned with the regulated forest and the beginnings of domesticated forestry in the Mountain West.

SPECIES SELECTION

One of the easiest ways to increase productivity is to choose the correct species. Often species grow best on sites they might not normally occupy. Ponderosa pine often grows best on Douglas-fir sites (Lynch 1953). Douglas-fir grows considerably better on seral sites than on sites where it is climax (Pfister and others 1977). Often both lodgepole and ponderosa pine can be grown on the same site. Well-managed lodgepole may produce more fiber than ponderosa pine on these sites; however, the large individual tree sizes achieved by ponderosa may be more valuable.

As management intensifies, greater gains can be made by matching specific genotypes to specific sites. Species such as ponderosa pine and Douglas-fir contain significant genetic variability, and the prospect of finding superior genotypes is great. In the truly domesticated forest, selected genotypes would be used to increase productivity and reduce rotation length.

Obviously we need a thorough understanding of the silvics of the species with which we hope to work and of the sites available to us. We must always keep in mind that the level of knowledge sufficient to carry out regulated forestry may be less than adequate for domesticated forestry. A more exact knowledge of the silvics of specific genotypes and a more precise system of site classification and mapping undoubtedly will be necessary if we are to achieve maximum productivity.

STOCKING CONTROL

A significant proportion of the forest acres in the Mountain West is either over- or understocked. Hutchison and Roe (1962) estimated that 15 to 20 percent of the stands in the Clark Fork Unit in Montana were understocked; 30 to 40 percent were overstocked. Such conditions are not unique to the Clark Fork Unit. It is probably safe to say that in the Mountain West as a whole nearly half of all the forest stands are not properly stocked for maximum timber production.

Control of the amount of regeneration is essential if we are to correct our stocking problems. Since investment in a stand at the time of its establishment is the most expensive type of investment in forestry, it may be some time before this problem is properly addressed.

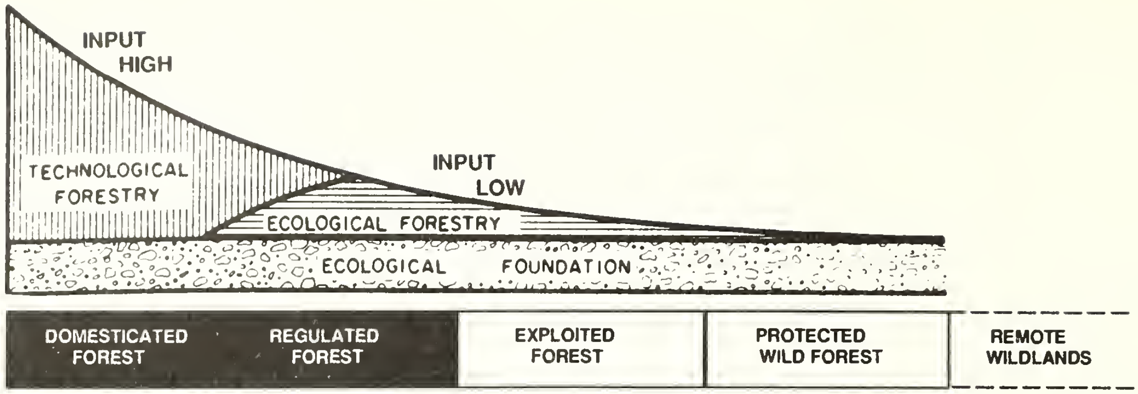

Figure 1—Schematic spectrum of the levels of forest management and degree of cultural control of the forest. (Adapted from Stone 1975.)

With the development of effective stocking guides we now can determine how many trees need to be established to achieve any combination of total volume and individual tree size. We also have available the techniques necessary to achieve those stocking levels, but costs are still a major problem. How can we afford to make a large investment at the beginning of the rotation?

We could count on inflation or a sharply rising price for lumber to reduce the carrying cost of this investment. A more appropriate method of reducing these costs is to reduce rotation length. Tree growth curves are of two general types (fig. 2). Lodgepole, ponderosa, and western white pine, and Douglas-fir exhibit type I growth, while spruce and the true firs exhibit type II growth. Because type I growth reaches maximum current annual and mean annual increments much sooner than type II growth, type I species commonly have shorter rotation lengths. Type I rotation lengths can also be significantly shortened by removing the first decade of the growth curve (fig. 3). This is often accomplished in the Southeast by proper site preparation, planting, and competition control techniques (Pritchett and Fisher 1987). It clearly is possible to achieve similar reductions in the Mountain West. By reducing the rotation length 10 to 20 percent we may reduce carrying costs sufficiently to make early cultural treatments affordable.

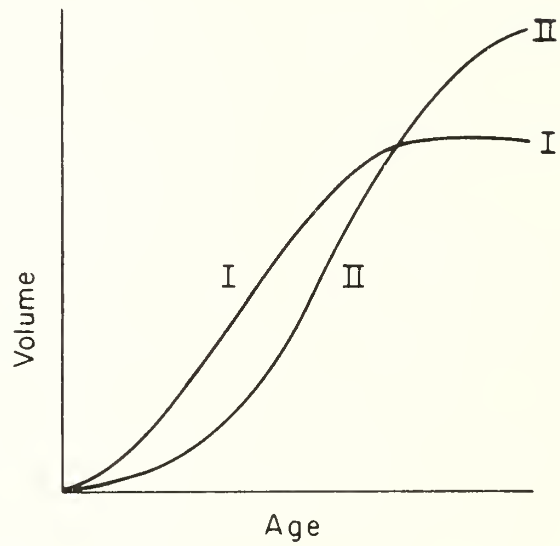

Figure 2—Two generalized types of tree volume growth curve.

THINNING AND PRUNING

Many older stands in the Mountain West contain too many trees for optimum growth (Wikstrom and Wellner 1961). Thinning these stands can promote more rapid growth of individuals, thus reducing rotation length and often creating a more valuable product. Carefully planned thinning can produce dramatic results in individual tree growth (fig. 4). With modern density management guides, the silviculturist can choose a desired final stand diameter and manage density to minimize rotation length or vice versa. Of course, thinnings capture more volume from the site; that is, they increase the cumulative net yield (fig. 5). Sufficient markets for the trees taken in thinnings may pay for the cost of thinning. The reduced rotation length then creates considerable profit.

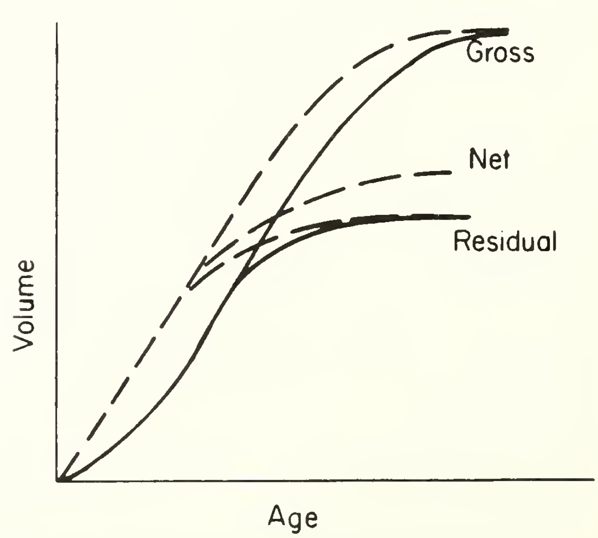

Figure 3—The effect of shortening the time required for stand establishment on a generalized growth curve.

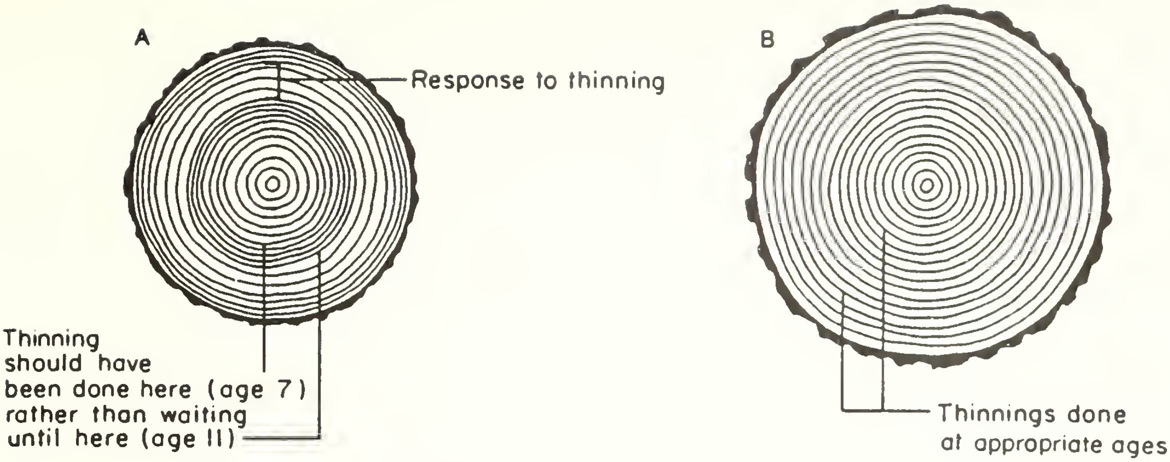

Figure 4—Schematic representation of the effect of thinning on individual tree diameter growth.

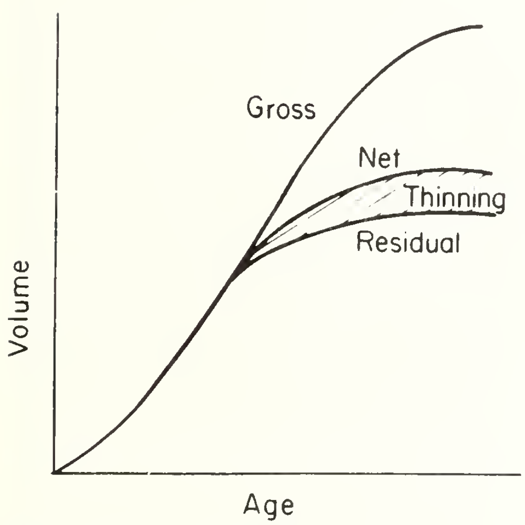

Figure 5—Thinning increase yield by capturing potential mortality.

Pruning, especially when combined with thinning, can also lead to a considerable increase in the profitability of growing timber (Assmann 1970). The percentage of clear lumber yield from a given tree is markedly influenced by pruning (fig. 6). Although the value of clear lumber varies widely by species, the increase in value over common lumber grades is always significant (fig. 7). As markets change these value differences also change, so we must gamble to some degree on future returns when we prune. It seems clear, however, that the value of pruning, much like the value of thinning, has long been underestimated.

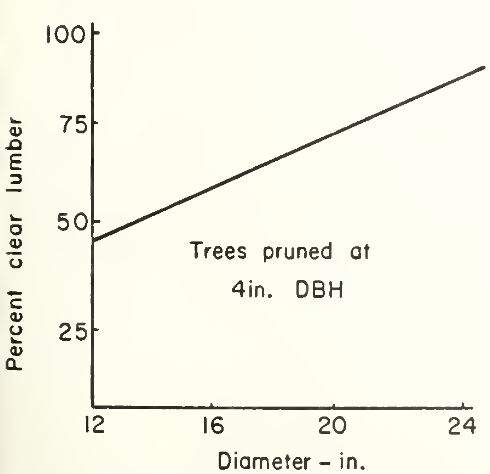

Figure 6—Percentage of clear lumber in pruned logs of various diameters.

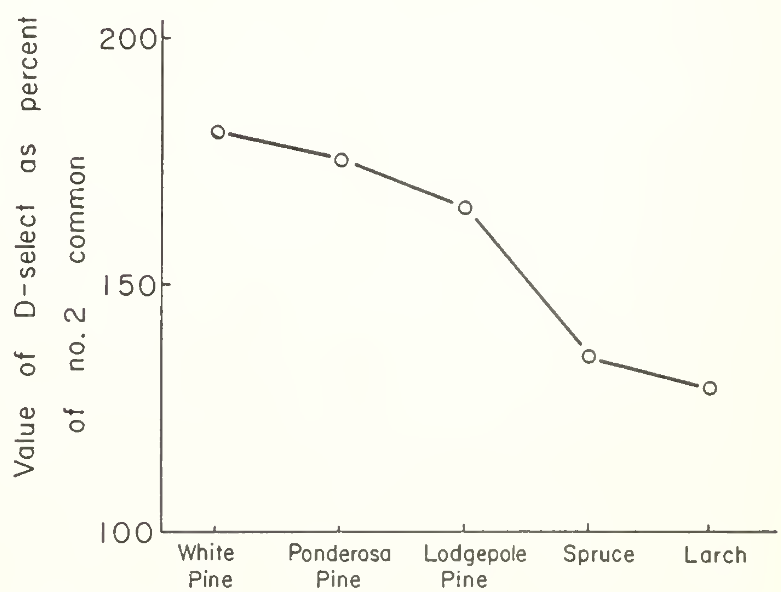

Figure 7—Relative value of clear lumber. (Adapted from Wikstrom and Wellner 1961.)

FERTILIZATION

Forest fertilization has produced large increases in productivity in many parts of the world. Since moisture or some factor other than nutrition generally appears to limit growth on most sites in the Mountain West, little attention has been paid to fertilization as a potential cultural practice.

Fertilization can occasionally make a good site of a poor one. The most dramatic results have been obtained using phosphorus, but other long-term increases in site quality have been brought about by fertilization (Pritchett and Fisher 1987). The return on investment in fertilization is indeed favorable on these sites. Greater efforts should be made to determine whether or not such sites occupy any significant land area in the Mountain West.

Growth response to nitrogen fertilization is common but short lived. Nitrogen fertilization seldom produces long-term increases in site quality; however, in properly stocked stands, fertilization 5 to 10 years prior to harvest can often pay large dividends.

The most promising feature of fertilization is the synergism that often occurs between thinning and fertilization (Scanlin and others 1976). Thinning generally causes a decrease in total or gross growth while increasing net yield through the harvest of potential mortality. Thinning and fertilization can be combined to actually increase both total growth and net yield (fig. 8). That is, the growth normally lost to thinning because of a reduction in growing stock can be compensated for by a much increased growth rate (Ballard 1981). This phenomenon can be used to increase total yield or shorten the rotation length.

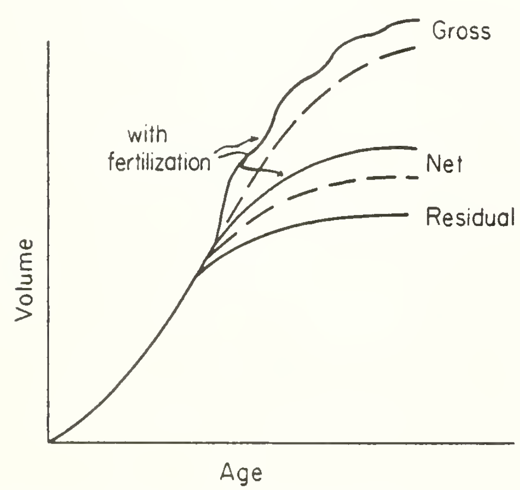

Figure 8—The influence of thinning and fertilization on volume production and yield.

CONCLUSIONS

Forestry is a bioeconomic endeavor. We need to know how to use cultural practices to control wood production. We also need to be able to afford to produce wood. At present the economics of wood production are unfavorable. But if and when that changes, it would be to our advantage to have the necessary cultural practices in hand rather than just in mind. Experience elsewhere in the world indicates that the level of knowledge adequate for regulated forestry is inadequate for domesticated forestry. There are many good prospects for domesticated forestry in the Mountain West. To fulfill these prospects we must improve our understanding of the application of cultural practices.

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UTILIZATION OF LODGEPOLE PINE—IDENTIFICATION OF THE PROBLEM AND A PROPOSED PARTIAL SOLUTION

Peter Koch

ABSTRACT

Lodgepole pine is dominant on about 13 million acres of commercial forest land in the United States; most of these acres are in the Rocky Mountains, and nearly half the volume in the Rockies is in Montana. Because of small diameters most lodgepole pines offer little opportunity for profitable processing through conventional sawmills. The public land manager faces the problem of how to clearcut and regenerate large acreages of stagnated or otherwise unproductive stands of lodgepole pine without expending public funds to cover the direct costs, and to accomplish this stand replacement according to a management plan without jeopardizing the other values of the forest. Such stand replacement with vigorous new stands is done in contemplation of precommercial thinning to a prescribed stocking density when the new trees reach a height of about 15 to 20 ft. To partially solve the problem, an operation is proposed that would harvest (clearcut) 2,400 to 3,600 acres per year from stagnated lodgepole pine stands for delivery to a major center for segmenting whole trees into components to maximize tree value. Products would include conventional roundwood items (cabin logs, tree stakes, posts and poles), 2 by 4 studs, structural flakeboard, and fabricated joists employing flakeboard webs and minimally machined lodgepole pine stems as flanges.

INTRODUCTION

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) is the fourth most extensive timber type west of the Mississippi River and is dominant on about 13 million acres of commercial forest land in the United States. Most of these acres are in the Rocky Mountains, and nearly half the volume in the Rockies is in Montana.

In an attempt to improve utilization of lodgepole pine a several-stage research effort was initiated in 1983. In the first stage, now completed, the world literature on the species was accumulated, keyworded, and appropriate data were entered to permit ready computer retrieval. Almost all the publications deal with forestry aspects—regeneration, protection, and growth and yield—only a miniscule fraction of the literature is concerned with utilization of lodgepole pine.

Next, the North American population of lodgepole pine (variety *latifolia,* and less intensively, *murrayana*) was systematically sampled at 2.5° latitudinal intervals throughout the range of the species from 40 to 60° north latitude (fig. 1). Results showed (Koch 1987) that properties of lodgepole pine vary significantly with latitude, elevation, and diameter class. For example, trees in Canadian latitudes have fewer open (nonserotinous) cones, higher specific gravity, more heartwood, less taper, and much lower moisture content than those in the United States. Trees from higher elevations within a latitudinal zone have more within-crown taper and thinner sapwood than those from lower elevations within the zone. Tree diameter class has a strong inverse correlation with stemwood specific gravity. Entire stemwood of trees 3 inches in diameter at breast height (d.b.h.) had average specific gravity (based on ovendry weight and green volume) of 0.43, 6-inch trees averaged 0.42, and 9-inch

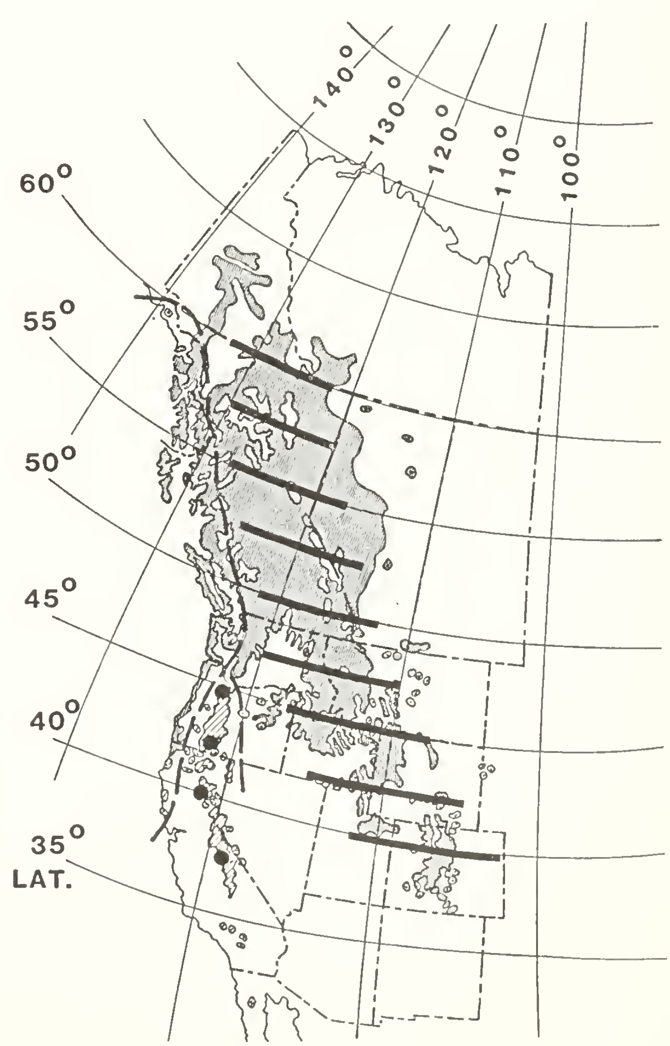

Figure 1—Sampling zones superimposed on Little's range map of lodgepole pine in North America. Variety *latifolia* is mapped to the right of the dashed lines, *murrayana* between them, and *contorta* to the left of them. Variety *contorta* was not studied because of its small potential for commercial use.

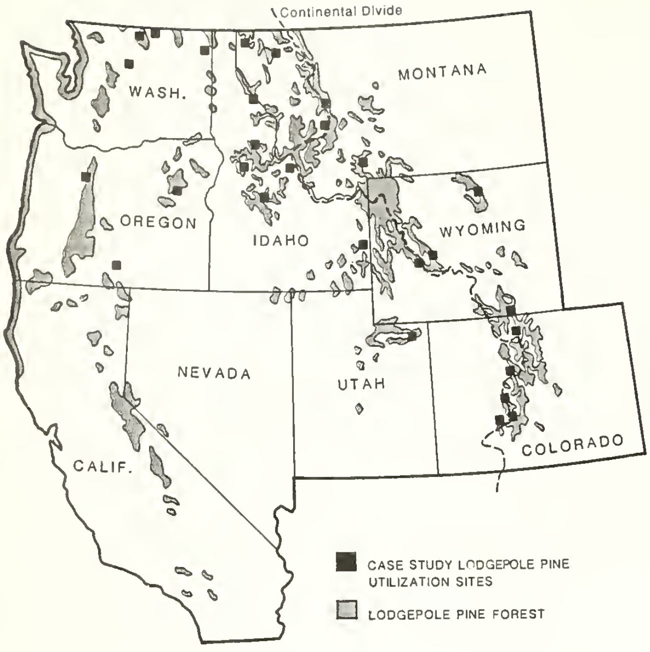

Figure 2—Locations (marked by black squares) of 28 representative acreages on public land in the United States for which the responsible land managers seek intensified utilization of lodgepole pine. The shaded area indicates extent of lodgepole pine forest type.

trees averaged 0.41. At stump height, trees 3, 6, and 9 inches in d.b.h. averaged 71, 91, and 107 years old, respectively.

In the third step, 28 representative public land acreages in the United States were identified (fig. 2) for which the responsible land managers seek intensified utilization. They range in size from 2,000 to 75,000 acres. During the summer of 1986, I visited each of these acreages to study the problem and to accumulate data preparatory to publication of an atlas (Koch and Barger in preparation) describing the areas. This 1986 work was done under a contract with the University of Montana; major funding was provided by the Intermountain Research Station, Forest Service, U.S. Department of Agriculture.

From these sequential operations, I have defined the problem as it appears to me, and arrived at a possible partial solution.

PROBLEM DEFINITION

The 28 acreages visited differ greatly. For example, although most are solidly forested in lodgepole pine, some contain significant amounts of larch, Douglas-fir, subalpine fir, spruce, or aspen. Meadows and grassy openings are common in the lodgepole pine acreages of Colorado, southern Idaho, and Wyoming. Growth potential varies from only slightly more than 20 cubic feet per acre per year to more than 100 cubic feet per acre per year. Annual precipitation varies from a low of slightly less than 20 inches to a maximum of near 40 inches. Terrain varies from nearly level to mostly steep; in aggregate, perhaps two-thirds of the lodgepole pine acreage delineated is on slopes of less than 45 percent. A few of the acreages are stony and strewn with boulders but most are not excessively rocky. Mortality—primarily from mountain pine beetle attacks—varies from most to virtually none of the stems. Defects in live trees that adversely affect utilization in solid wood products include porcupine scars (in some areas occurring on three-quarters of the stems and at several heights on each stem), stem crook, stem sweep, stem fork, cankers, fire scars, frost cracks, pith eccentricity, and excessive compression wood content, spiral grain, taper, and limbiness. Degree of defect varies greatly among and within acreages.

Accessibility of the acreages also varies significantly. Almost all have roads to their perimeters, and most have some interior roads; but a few can be reached only on foot. Most are within 50 miles of a railhead, but a few are more distant.

In virtually all of the acreages, stand type varies in a continuum. Classes of stands include "dog-hair" stands of trees less than 3 inches in d.b.h., pole stands with all trees live, pole stands with many dead trees, pole stands with dense understories of smaller trees, stands of sparsely stocked small sawtimber—usually over 200 years old, vigorous stands of large pole timber (6 or 7 inches in d.b.h.), stands of dead trees killed by bark beetles—many of suitable size for cabin logs—and stands of a variety of ages and generally low stocking containing relicts of past insect attacks as well as a range of smaller trees—usually suffering from mistletoe attack and cankers of various descriptions.

Most of the lodgepole cubic volume on the acreages visited is found in trees 3 to perhaps 6.5 inches in d.b.h.—trees too small to yield sawlogs. Trees are typically about 70 to 100 years old, with few stands less than 40 years old and some over 200 years old.

In the d.b.h. class from 3.5 to 4.0 inches, trees are generally about 35 feet tall, with few shorter than 22 feet and few taller than 55 feet; stemwood-average specific gravity of such trees ranges from 0.36 to 0.52, but is generally 0.40 to 0.44 (based on ovendry weight and green volume). For trees 3.5 to 4.0 inches in d.b.h., crown ratios are mostly in the range from 30 to 60 percent with the average slightly less than 50 percent. Below-crown stem taper (inside bark) is generally more than 0.4 and less than 0.8 inch per 100 inches, and averages about 0.6 inch.

Data from Montana lodgepole stands selected for 1985 thinning studies suggest that an average unthinned acre might contain 1,360 live stems 3 inches in d.b.h. and larger, totaling 3,400 cubic feet of stemwood, or about 43 tons of stemwood (ovendry basis). Considering all the 28 lodgepole pine stands I visited, however, it seems to me that a more conservative estimate for lodgepole in the Rocky Mountain area might be 1,000 live stems per acre measuring 3 inches in d.b.h. and larger, totaling 2,500 cubic feet of stemwood, or about 31 tons of stemwood, ovendry. When more accurate inventory data are available, even this lower estimate may prove too high.

On virtually all the acreages, post and pole operators nibble away at the pole stands, each cutting 1 to 3 acres annually near existing roads; such post and pole operations are sometimes used to achieve cosmetic thinning along these roads. These operators generally pay a stumpage fee of $5 to $7 per thousand lineal feet of product.

On Colorado and southern Wyoming acreages, some lodgepole pine Christmas trees are cut annually (stumpage fee of $3 to $5 per tree for personal use). Almost all acreages have a significant market for dead stems sold as firewood (usually $2.50 to $12.50 per cord stumpage fee). Firewood stumpage values frequently exceed sawlog stumpage values.

Occasionally, a sawlog sale of 15 to 500 acres is made, but virtually always at a stumpage cost less than that required to prepare the sale. Sawlog sales of more than 12,000 board feet per acre are unusual, and stumpage fees usually are in the $6 to $10 range with some sales made at $1 per thousand board feet (Scribner log scale), and few as high as $25.

Costs of preparing and executing a small-acreage, low-volume sawlog sale, exclusive of road construction cost, vary greatly among administrative units and also depend on the characteristics of the sale area. Sale costs per thousand board feet of sawlogs are inversely related to sale acreage and to timber volume sold per acre. Sales in the areas studied usually encompass less than 40 acres, with lodgepole pine sawlog volume generally less than 8,000 board feet per acre.

The direct costs to Ranger Districts (or equivalent in State or Bureau of Land Management forests) were reported as low as $2 in one area, but more typically are $12 to $25 per thousand board feet, Scribner scale. When all appropriate direct and indirect costs within Ranger Districts, Supervisors' Offices, and Regional Headquarters are included, however, total sales costs per thousand board feet of lodgepole pine sold in small tracts appear to be in the range from $40 to $60, with one forest reporting total costs of $85. Such costs include not only those incurred by technicians, timber sales officers, and road planning engineers but also those incurred by specialists in silviculture, wildlife habitat, landscape esthetics, watershed quality, archeology, and law (together with all supporting staff in Supervisors' Offices and Regional Headquarters).

Volumes of forest residues resulting from sawlog sales in these problem lodgepole pine stands are generally great because most of the sawlog operators have no profitable outlet for subsawlog-size stems.

MANAGEMENT OBJECTIVES AND SILVICULTURAL CONSIDERATIONS

With virtually no exceptions, the land managers have concluded that thinning these more-or-less stagnated stands that are 70 to 100 years old is an uneconomic procedure; this is so because products recovered in such thinnings have low value, growth response is not outstanding, and thinning cost is great.

With almost no exceptions, the land managers are seeking some method to replace the stagnated and unmarketable stands of lodgepole pine with new vigorous stands of the same species—and they want to do this without expending public money. They visualize that this must be done by phased clearcutting and natural regeneration, but they have very few stumpage purchasers willing to build the necessary temporary roads, fell all diameter classes of all species, and leave the acreage with no more than 25 tons (ovendry) of slash per acre and with sufficient seed distributed on exposed mineral soil to ensure natural regeneration (fig. 3). When the managers contract such stand replacement operations, they incur costs of $200 to $700 per acre—costs that they find hard to justify economically. Most of the managers do not find it necessary to plant such clearcut areas if the seedbed is properly prepared, with mineral soil adequately exposed and viable seeds available from serotinous cones on the ground or from adjacent trees bearing open cones.

Assuming that stand replacement can be accomplished with little or no expenditure of public funds, most of the managers think that they can internally fund thinning of the regenerated stands when the trees are 15 to 20 feet tall (fig. 4); cost of such precommercial thinning is usually $60 to $85 per acre, but may be as high as $300 per acre if vegetation is dense.

In virtually all cases, the managers must give great consideration to improvement of wildlife habitat, protection of stream quality, and protection of esthetic values—but these considerations are not generally seen as prohibiting planned stand replacement as long as clearcuts do not

Figure 3—Lodgepole pine in a south-central Colorado clearcut with a steep-slope feller-buncher. Very small stems were trampled. All slash was left on the ground unpiled and unburned. Regeneration will be natural. The access road is temporary.

Figure 4—Naturally regenerated lodgepole pine in southern Wyoming precommercially thinned at about 18 years to 350 to 400 stems per acre. In the proposed utilization problem solution slash would not be piled or burned, but would remain as shown to deteriorate slowly. Stadia rod in center foreground shows 1-foot intervals.

exceed 40 acres, are spaced to maintain elk or deer hiding cover, do not disturb streams, and are located and contoured to be visually acceptable. This generalization does not apply to two or three of the Wyoming-Colorado areas where recreational use is heavy and where hiding cover for elk is limited to a narrow forest of lodgepole pine bordered by sagebrush below the trees and exposed rock above.

Although controlled or wildfire might appear to offer a solution on some acreages, few managers are willing to embrace the idea of deliberately wasting the enormous tonnages of wood that would be consumed by such fires. And such fires would have limited usefulness in protecting stream quality, habitat, and esthetic quality of the forests.

SUMMARY OF THE PROBLEM

In brief, the land manager faces the problem of how to clearcut and regenerate large acreages of stagnated or otherwise unproductive stands of lodgepole pine without expenditure of public funds to cover the direct costs. Additionally, managers must accomplish this stand replacement according to a management plan without jeopardizing the other values of the forest—wildlife habitat, stream quality, and esthetic quality. Such stand replacement with vigorous new stands is done in contemplation of thinning to a prescribed stocking density when the new trees reach a height of about 15 to 20 feet. Additionally, biomass resulting from the clearcuts should yield a positive contribution to the economy—as contrasted to waste through destruction by fire, or by insects and disease.

At the same time, the industrial manager of the operation performing the clearcutting, site preparation, and utilization of the material removed faces the problem of making an appropriate profit on investment in harvesting, transport, and conversion facilities. This after-tax return should be at least 15 percent annually on the entire investment, assuming no borrowed funds.

PROPOSED SOLUTION

At the outset it should be understood that the contemplated operation in the forest is a stand replacement, not a timber sale. That is, the company planning to utilize the biomass will—in a no-cost exchange for most of the biomass on each acre—agree to:

- Build the necessary minimum-quality and temporary access roads to permit making the required clearcuts prescribed by the long-range management plan; at least in the initial decade of the plan, these clearcuts will be made on land having slopes less than 55 percent. It will be the responsibility of the land manager to construct the principal haul road serving the area.

- Shear (or saw-fell) and remove from the forest essentially all of the aboveground biomass of all trees of all species larger than 3 inches in d.b.h. (with the exception of sufficient cone-bearing branches to favor regeneration). If the stand lacks sufficient viable seed, it will be the responsibility of the public land manager to provide supplementary direct seeding at the appropriate time.

- Trample all stems 3 inches and less in d.b.h.; this should result in less than 25 tons (ovendry basis) of slash on the ground; this slash would be neither piled nor burned—simply compacted by trampling and subsequent snowfall.

- Equip feller-bunchers and skidders with treads designed to expose a maximum of mineral soil to favor natural regeneration. In areas with insufficient mineral soil exposed because they were logged in deep winter snow, or for other reasons, it will be the responsibility of the land manager to roller chop—or otherwise adequately prepare the seedbed—according to prescription.

- To avoid unnecessary drain on the forest nutrient pool, restrict pile and burn operations to landings only, where slash may accumulate.

Harvesting

Steep-slope feller bunchers equipped with accumulators and shears (fig. 5) teamed with fast grapple skidders (fig. 6) or forwarders, capable of operating on slopes up to 55 percent, will comprise the primary harvesting equipment. In addition to felling, bunching, and forwarding (1,000 feet) about 1,400 trees per 8-hour day, these vehicles should be able to effectively trample most of the small trees during all seasons, and accomplish needed mineral soil exposure under all but deep-snow conditions.

Transport of Trees to Plant

Trees from most acreages will have small crowns and will be transported to the mill (fig. 7) with crowns attached. Stems from some stands will have such heavy crowns that they will have to be delimbed before transport.

Storage of Trees at the Mill

Trees will be offloaded by crane at the mill, stored in high decks, and sprayed with water in summer when risk of fungal stain is high. Unresolved is the problem of winter retrieval from the high decks without major stem breakage under conditions when the stems freeze together into unmanageable blocks; some experienced mill managers believe that trees with crowns intact have less tendency to freeze together than limb-free stems.

Delimbing

Before passing to the debarker, all stems will be delimbed mechanically. After delimbing but before debarking, tree portions (from both live and dead trees) suitable for cabin logs will be removed by crosscut sawing and shunted into storage preparatory to hand debarking and further manufacture.

Figure 5—Track-mounted steep-slope feller-buncher equipped with self-leveling platform carrying a boom-mounted tree shear that can accumulate sheared stems preparatory to depositing them in a bunch.

Figure 6—Track-mounted grapple skidder rapidly moving bunched trees down a steep slope.

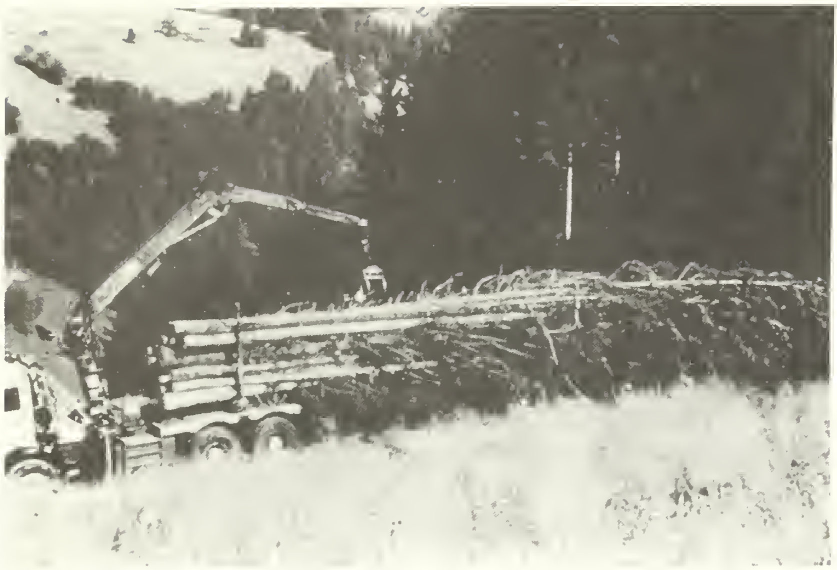

Figure 7—Whole pines with small crowns loaded full-length on a truck for transport to mill.

Debarking

With the exception of tree portions removed for cabin logs, all stems will then pass through mechanical ring debarkers, and the bark will be conveyed to a processing plant for conversion to soil-amendment products or to heat energy.

Stem Merchandising

From the debarkers, all stems will pass to a merchandising machine equipped with scanners and computer-controlled bucking saws designed to segment each stem into pieces of maximum value for later conversion into roundwood products such as tree props (a pointed dowel 2 to 2.25 inches in diameter and 6 to 12 feet long), post and rail products of various kinds, joist flanges (fig. 8), stud logs, and telephone or power poles.

Most of the output will be tree props and flanges for fabricated joists (Koch and Burke 1985) because these are high-value, high-volume products and because most of the stems will have diameters appropriate for these products. Because the market for fenceposts and rails is limited, only a small portion of total output will be converted into these products (some of which will be pressure impregnated with the preservative CCA, as required by the market).

Residues

Stembark (see Debarking, earlier) will be combined with organic wastes (perhaps sewage sludge) and processed into soil-amendment products with value sufficiently high to warrant shipment to distant markets. Alternatively, it can be burned for heat energy.

Branchwood and branchbark (most foliage will be lost during skidding and transport) will be used as fuel to warm the plant during winter, and to satisfy the heating requirements of kilns to dry joist flanges and lumber cut from the stud logs.

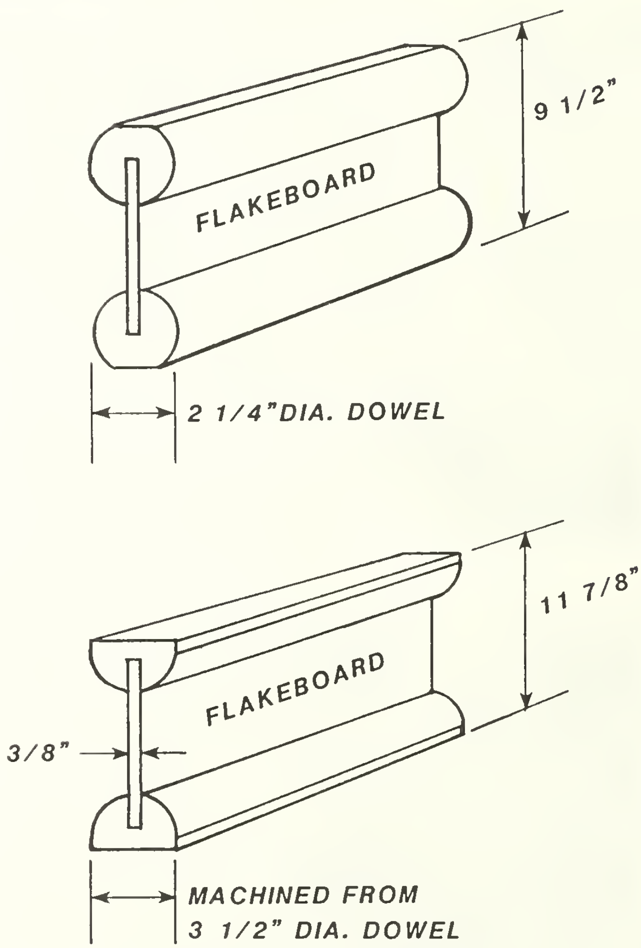

Figure 8—Joists fabricated with minimally machined lodgepole pine dowel flanges and 3/8-inch-thick flakeboard webs. By finger jointing flanges into long lengths, joists of any desired length can be fabricated. By varying dowel (or half-dowel) diameter and spacing, joists with desired stiffness and load-carrying capacity can be constructed.

Most stemwood green residues will be converted to flakes 3 inches long, about 0.020 inch thick, and generally less than 1 inch wide. These stemwood residues will come from several sources:

- Thirty-two-inch-long stem sections cut from stems that have butts shattered by felling shears (32 inches, because this is a length appropriate for conversion by a disk flaker).

- Thirty-two-inch-long stem sections removed because they include short crooks.

- Eight-foot-long stem sections too defective or crooked for conversion to roundwood products (8 feet, because such bolts can be crosscut into three 32-inch lengths before flaking).

- That tapered portion (about 50 percent of each stick doweled) of stemwood removed during doweling operations; the problem of designing dowelers that will produce a residual flake having the qualities needed for flakeboard is unresolved.

- All stems of species other than lodgepole pine (for example, alpine fir, aspen, spruce) will be crosscut first to 8-foot lengths and later to 32-inch lengths for flaking.

Unavoidably, some random-length stem sections shorter than 32 inches will result from cutting random-length stems into products that for the most part have specified lengths. These trim ends will be chipped for pulp; alternatively they can be added to the chipped branches to fuel the dry kilns and provide plant and process heat (including heat needed for the flakeboard hot press).

Also, stemwood tops with butt diameters less than 2.25 inches likely are too small for flaking and will have to be chipped for pulp or fuel. Such tops might each contain about 0.1 cubic foot of wood and have an ovendry weight of perhaps 2 pounds. This portion of harvested stemwood residue probably will total about 1 ton per acre (ovendry).

Additionally, green sawdust from the studmill and dry planer shavings from stud planing operations (as well as sawdust and shavings from manufacture of joist flanges) will help fuel the dry kilns and provide plant and process heat.

Flakeboard Manufacture

Flakes residual from manufacture of roundwood product, will be dried and screened. About 80 percent of the dried flakes will be accepted for conversion into structural flakeboard (fig. 9). Fines comprising the remaining 20 percent will be routed through a suspension burner to provide heat for the flake dryer. Unresolved is the question of economic control of emissions from the suspension burner-dryer mechanism.

The manufacturing operations, and hence the scale of harvesting operations, will be sized to yield structural flakeboard production of about 100 million square feet annually, 3/8-inch basis. Such board might typically weigh

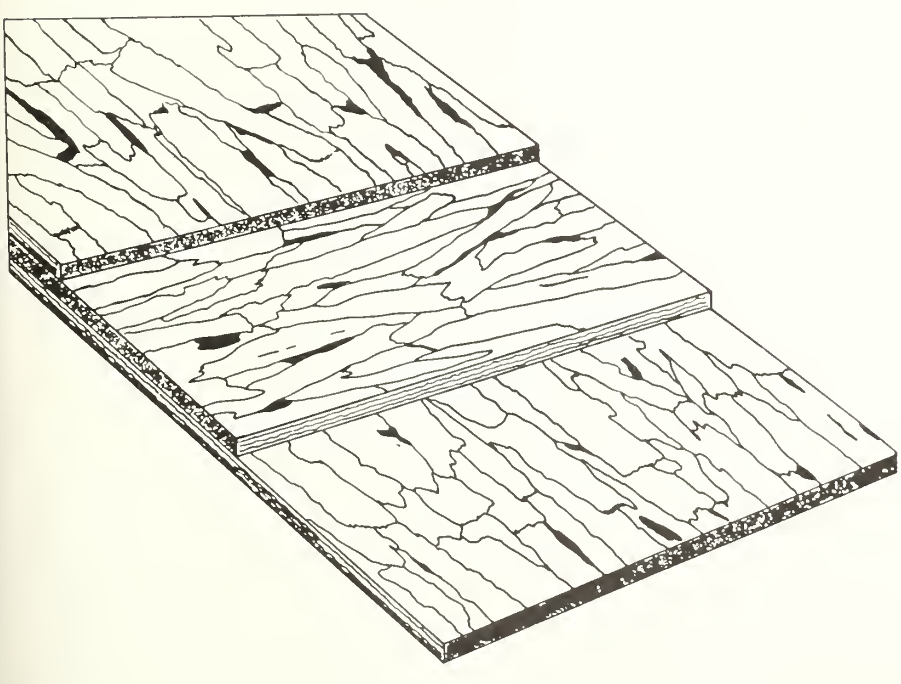

Figure 9—Structural flakeboard. Such board can have random orientation of flakes, or as shown here, be comprised of three layers each with strands oriented. In oriented strand board, flakes in the two face layers are aligned with grain parallel to the 8-foot edges of 4- by 8-foot panels, and those in the core at right angles to this.

about 4 pounds per cubic foot ovendry basis. With resin and wax content subtracted, each cubic foot of board might contain 39 pounds of wood, ovendry basis.

If 75 percent of the stemwood harvested goes to the flakeboard plant, and four-fifths of this leaves the plant as salable board, then annual stemwood harvest can be estimated as 101,563 tons per year, ovendry.

If, as Montana data suggest, an average acre yields 43 tons (ovendry) of stemwood from trees larger than 3 inches d.b.h. (1,360 of such trees per acre), then the annual area to be clearcut will total about 2,362 acres.

If, however, an average acre in the Rocky Mountains yields only 31 tons (ovendry) of stemwood per acre in trees larger than 3 inches in d.b.h. (1,000 of such trees per acre), then the area to be clearcut annually will total about 3,276 acres.

Economic Feasibility

It remains to be seen whether the operation described is economically feasible. A study to make this determination is scheduled for 1987.

Comment on Scale of Operations

There are only a few locations where an operation of the scale described (2,300 to 3,300 acres to be clearcut annually) might be feasible. Needed in addition to the proposed large-scale operation, but not yet conceived, are economically viable stand replacement operations for much smaller acreages that would clearcut 250 to 500 acres per year over a plant life of 20 years.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Clinton Carlson)—Do you think that whole-tree removal of lodgepole pine will reduce site nutrient content, leading to long-term degradation of site?

Q. (from Walt Knapp)—Your example showed extensive use of whole-tree harvesting and there are many concerns regarding nutrient depletion as a result of whole-tree harvesting—do you have a good cheap option?

A.—Both of these questions concern the same subject, so I will combine my answer. First, all of the biomass is not removed in my proposed operation, that is, trees 3 inches and smaller in d.b.h. are trampled flat with tracked vehicles so that 20 to 25 tons per acre (ovendry basis) of small stems, branches, and foliage are more-or-less uniformly distributed over the harvested acreage. Second, in the process I propose, no slash burning (or piling) is allowed—two practices that either diminish the nutrient pool or, at best, give nutrients uneven distribution. The contemplated rotation of the naturally regenerated stands is perhaps 70 years, and during each of these 70 years the litterfall is about equal to the weight of wood laid down in the trees (ovendry basis). In short, I think my proposed system of distributing small slash in the amount of 20 to 25 dry tons per acre and prohibiting bulldozing, root raking, and burning is a step forward in maintaining the nutrient pool. The combination of trampling by tracked vehicles and heavy snowfall in these lodgepole pine areas will bring the slash to within 10 inches on the ground in nearly all cases.

Q. (from George Howe)—You propose trampling small lodgepole pine trees prior to natural regeneration; what proportion of the ensuing regeneration will have emanated from the small trees and how dysgenic will this be?

A.—First, not all seeds will come from the trampled small trees because the feller bunchers inevitably will shake some cones loose in the rather violent shearing and bunching operation; also some tops will break off during felling. Such broken tops will, however, tend to be concentrated under the bunched trees and not evenly distributed. South of the Canadian border, most stands have both open- and closed-cone trees, so some seed will be broadly distributed into the relatively small clearcuts (< 600 ft wide) from adjacent open-coned trees. If conditions warrant such action, all bunches can be gang-topped in place in the forest (with a chain saw) to reduce overall length to perhaps 45 to 50 feet in contemplation of whole-tree transport to the mill; such a procedure would leave a significant proportion of the cones from dominant trees adjacent to the bunches. Spreading of the severed tops, however, seems too expensive. Finally, if the silviculturist in charge feels that the seed supply is inadequate, he or she can supplement available seed by means of a light direct-seeding operation. After spending some 10 hours with the managers of each of the 28 "hopeless-case" lodgepole pine areas I visited in the summer of 1986, I got the impression that in most areas seed supply would be adequate, and dysgenic effects from my proposed operation would be minor. I would, however, recommend research to study cone and seed distribution on acres harvested by the method proposed.

TIMBER QUALITY CONSIDERATIONS FOR FOREST MANAGERS

Thomas A. Snellgrove
James M. Cahill
Thomas M. Fahey

ABSTRACT

Wood quality is defined as the aptness of the material for a particular end use. Once the end use is determined, forest managers have many opportunities to manage for quality: species selection, genetic selection, initial spacing and stocking control, rotation length, fertilization, and pruning. Results from an empirically based economic model of young-growth Douglas-fir are used to illustrate the potential benefits from pruning. Results show that higher sites and earlier pruning generally yield higher returns, and that these factors are also interactive with age at harvest and interest rates.

INTRODUCTION

The incentives for foresters to manage for wood quality differ considerably. The forest manager who also owns a pole yard is inclined to grow "pole" timber, while a company that produces millwork has the incentive to grow ponderosa pine that will produce clear lumber. A public agency or small landowner who sells timber on the open market is less certain of end use and may choose to grow "generic" timber. Regardless of the incentives, silvicultural prescriptions in forest management have traditionally been guided by growth and yield considerations. The objective of this paper is to suggest ways to include wood quality considerations in the management of the forests of the intermountain area. First, we will discuss the concept of quality and, second, suggest selected references for further reading. We will then discuss some general opportunities now available to affect quality and follow that with a more detailed look at pruning as an option for cultural treatment. We will conclude with some thoughts on how quality considerations can be incorporated into forest management plans.

THE CONCEPT OF WOOD QUALITY

There are many definitions of wood quality, but most definitions share a common idea: wood quality is the suitability of the material for a particular end use (Barbour and Briggs 1986). Without defining the product it is impossible to define quality. After the product is determined, however, specific wood properties and tree characteristics that are important can be identified:

	Product		
	Lumber	**Piling**	**Pulp**
Wood property			
specific gravity	yes	?	yes
fibril angle	yes	?	no
permeability	yes/no	yes	yes/no
Tree characteristic			
form (taper)	yes	yes	?
limbiness	yes	?	yes
juvenile wood	yes	?	yes

Specific gravity has a substantial effect on strength, stiffness, and other mechanical properties important in lumber; it is only marginally important for poles and piling and has a substantial effect on the yields of pulp. Permeability, on the other hand, has virtually no effect on strength of lumber but is important in drying and is critical for treatability of poles and piling.

High-quality solid-wood products generally have the most stringent requirements of wood properties and tree characteristics; if the raw material will meet the requirements for high-quality select or structural grade lumber, it will generally meet the requirements for most other products. Below, we list and describe some of the more important characteristics for lumber that can be manipulated by managers.

Limbiness

Knots have an obvious effect on lumber graded for appearance (selects and shops). Knots and the distorted grain around knots also affect mechanical properties of structural grade lumber, particularly bending strength.

Piece Size

Log or tree size alone does not affect quality, but it frequently acts as a surrogate for other quality-related attributes such as the proportion of juvenile wood and the amount of clear wood produced. Conversion of round logs to rectangular lumber is more efficient for larger diameters; consequently, yields are greater. Larger logs are also generally less expensive to harvest and process. A premium is usually paid for wide lumber that can only be produced from large logs.

Form (Taper)

As with piece size, form affects product yields more than quality. In extreme cases, however, it can affect product quality by producing excessive slope of grain.

Juvenile Wood

Juvenile wood is the term used to differentiate young wood from older wood and is usually the fastest grown wood in the tree (fig. 1). It is the first rings formed from the pith outward and because juvenile wood is generally formed in or near the live crown, it develops throughout the tree. The number of annual rings in which juvenile wood is formed varies among species and is not well defined for most species. In southern pines it is generally 10 ± 5 rings and for Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) 20 ± 5 rings. Some wood properties associated with juvenile wood are low specific gravity, high fibril angle, and short cells. These properties have two important effects on lumber: they reduce strength and stiffness and increase warp. In short-rotation forestry the proportion of juvenile wood will be high because of the rapid early growth rate and the relatively short period for forming mature wood.

Ring Width and Uniformity

Uniformity and rate of growth affect machinability and appearance of lumber. Rate of growth is a limiting factor in high-quality structural grades of lumber; wood must average at least 4 rings per inch to meet the criteria for Select Structural, No. 1 or No. 2 grade lumber under the structural light-framing rules. For specialty items such as scaffold, joists, beams, and stringers, it must average more than 6 rings per inch. In the past, rate of growth was frequently blamed for lower strength and stiffness and higher warp that sometimes occurred in "managed" young-growth timber. Many of the problems thought to be related to fast growth, however, are really due to the age of wood formation (juvenile versus mature wood).

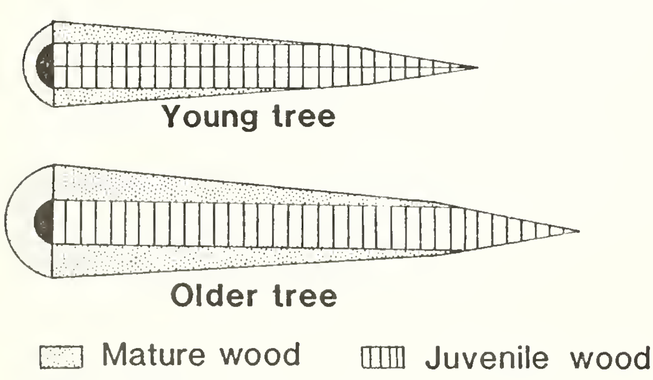

Figure 1—Juvenile wood is formed in all coniferous trees, including "old-growth." The lower portion of the stem typically has a shell of mature wood around the juvenile core; the top portion is virtually all juvenile wood.

Specific Gravity

Wood density is a key property for predicting strength, stiffness, and other mechanical properties of clear wood specimens. In the past, it was generally considered to be the most important property for predicting mechanical properties, but recent work (Bendsten 1987) suggests that fibril angle and cell length may be equally important.

Certainly other tree characteristics and wood properties are important for lumber, but these are some of the most obvious ones that can, to some degree, be manipulated by forest managers. A more detailed explanation of these characteristics and their importance is covered in the references we suggest for further reading.

SELECTED REFERENCES

There is a wealth of information relating silvicultural practices to wood quality. In fact, a recent literature review listed 852 citations (Barbour and Briggs 1986). We have selected four references that will give forest managers a general understanding of the relation of silviculture to wood quality. These papers were selected because most of them are current and the authors assimilated much of the existing research into documents tailored to foresters.

Barger (1986) provided an overview of harvesting and utilization considerations in stand-management practices for the intermountain area. The paper is unique because it includes harvesting as well as utilization considerations.

Bendtsen (1987) presented a summary of wood properties from fast grown trees which are important to solid wood utilization. He provided a comprehensive discussion of the problems related to juvenile wood and related wood properties to mechanical properties and, in turn, to product quality.

Megraw (1986) provided an overview of the microstructural properties of wood and how they affect the performance of wood. He related silvicultural practices to these basic properties. Although the paper emphasized Douglas-fir, general principles should be appropriate for other conifers as well.

Larson (1972) bridged the gap between forestry and forest products by explaining, from a physiologist's view, the ways in which trees respond to various silvicultural treatments.

OPPORTUNITIES TO AFFECT WOOD QUALITY

As forest managers you have more opportunities to affect wood quality than you may realize; you routinely apply them. Among the common practices are: species selection, genetic selection, rotation length, initial spacing and stocking control, fertilization, and pruning.

Species Selection

We said that wood quality is best defined as the suitability for a particular end use. It becomes apparent that economic considerations are the common denominator among various end uses. Thus, species selection plays an important role in assessing quality.

The selection of species to be planted is generally determined by economic and ecological assessments of the site. Douglas-fir, for example, has routinely been planted in the Pacific Northwest coastal regions because it is well adapted to the climate, it gives high yields per acre, and it makes an excellent product. Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and western larch (*Larix occidentalis* Nutt.) have been planted in the intermountain area for the same reasons. In the case of Douglas-fir some companies are reconsidering their options, however, because of future markets around the Pacific Rim. Many of the Asian markets prefer the nondistinct growth rings and fine texture of Sitka spruce (*Picea sitchensis* [Bong.] Carr.) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.). Although growth rates and yields per acre are critical components in species selection, potential markets should also be given consideration when selecting species for the intermountain area.

Genetic Selection

Genetic selection can affect nearly every aspect of timber quality. Most seedlings currently planted have resulted from some level of genetic selection with primary emphasis on growth rate and tree form. The greatest opportunity for improving overall quality, however, is with specific gravity. Specific gravity is one of the most heritable traits of trees (Megraw 1985) and is a key property for a wide array of products. Genetic makeup of the planting stock probably exerts a greater influence on specific gravity of the tree than anything the forest manager will subsequently do. McKimmy (1986) discussed opportunities for improving wood quality through genetic selection and affirmed the importance of specific gravity.

Rotation Length

In classical forestry, rotation length is theoretically determined by the culmination of mean annual increment. In practice, however, rotation length is influenced as much by immediate concerns over wood supply to mills, market fluctuations, and other resource management goals such as visual quality and watershed values.

The length of rotation primarily affects piece size. Rotation length can therefore be used to affect the proportion of juvenile wood and, with pruning, the amount of clear wood.

Initial Spacing and Stocking Control

Forest managers can affect a number of tree characteristics with initial spacing. Among the most important are limb size, tree form, ratio of juvenile to mature wood, and ring width. Management strategies that include very low initial stocking have some obvious "up-front" cost advantages, but the consequences for wood quality should also be considered. Extremely wide initial spacing will increase limb size and tree taper and, depending on subsequent growth of mature wood, may also generate unacceptable proportions of juvenile wood. Ring width will increase in the juvenile core and may create problems with nonuniform wood if subsequent growth slows dramatically.

Once a stand is established, stocking control through precommercial thinning or commercial thinning can be used to modify wood quality. Growth rate (ring width) can be a problem in southern pines and in Douglas-fir, but because of overall growing conditions it doesn't appear to be as serious for most of the intermountain forests. Ring uniformity is desirable, particularly for molding and millwork, but again it is not likely to be a major problem in the intermountain area. Probably the greatest opportunity to alter quality through stocking control is to increase the amount of mature wood grown on the juvenile core or, similarly, to maximize the amount of clear wood produced in conjunction with pruning. If an increase in internodal length results from spacing control, improved lumber quality would be expected for species used in the molding and millwork industry.

Fertilization

In general, fertilization can increase ring width and decrease specific gravity. Megraw (1986) discussed the effect of fertilization on specific gravity and showed an average reduction of 5 percent for a 27-year-old stand of Douglas-fir. Because of moisture and climatic limitations, growth rate is unlikely to increase to the extent that it would materially affect quality in normal situations in the intermountain area. Fertilization would be expected to increase piece size, but timing would be important in improving the ratio of mature wood to juvenile wood and the proportion of clear wood to knotty core if used in conjunction with pruning.

PRUNING

Considering the growing conditions, the rotation lengths proposed by forest managers, and the limb retention characteristics of most species in the intermountain area, the growth of clear wood in unpruned young-growth stands will be minimal. Wikstrom and Wellner (1961) discussed opportunities for pruning in the Northern Rocky Mountains and the intermountain area. They showed substantial economic returns for pruning, but their evaluation was based on a theoretical analysis. In 1961, the percentage of D-select and better lumber made up only 2 to 15 percent of the lumber sold in the region and the value of selects was 80 percent more than No. 2 common lumber. Since that time the economic attractiveness for pruning has probably increased; less select grade lumber is being produced as younger stands are being harvested, and the difference in price between select and No. 2 common is now between 300 and 400 percent.

A major obstacle in evaluating the economic merits of pruning has been the lack of actual product recovery information from pruned trees. And as Wikstrom and Wellner stated (1961), "Theoretical yields from pruning...like theoretical mink farm yields should be viewed with a certain amount of caution. It is easy to be carried away with figures."

Although we know of no current empirically based analysis of pruning for intermountain species, a recent study of pruned coastal Douglas-fir illustrates potential recovery from pruned logs (Cahill and others in press). In this study pruned and unpruned logs were selected from the Voight Creek Experimental Forest located near Tacoma, WA. Site index (50-year) in the forest averaged about 115. Several hundred crop trees were pruned to a height of 17 ft between 1949 and 1951; stand age at the time of pruning was about 38 years. The stand was thinned to various intensities. About 200 pruned and 100 unpruned butt logs were selected for processing into lumber and veneer. The sample was selected to represent the range of sizes of trees when initially pruned and the amount of growth since pruning; the amount of "clear shell" was used to select individual trees. The unpruned control trees were selected from the same stand. Half of the sample was sawed and half was peeled. There was no difference in the volume of products recovered between pruned and unpruned logs of the same size. A substantial difference was found in the proportion of high grade lumber and veneer recovered, however; this difference was highly correlated with the amount of "clear-shell" produced after pruning (fig. 2).

This recovery information was combined with growth and yield data and economic assumptions to develop a computer model for evaluating pruning (Fight and others in press a). The model simulates the difference in product value between pruned and unpruned butt logs and converts that to a difference in present value (PV) attributable to pruning. This difference in PV represents the maximum amount that could be spent for pruning and achieve the specified rate of return on the investment; costs of pruning are not included in this analyis.

$$PV = \frac{\text{Value pruned} - \text{Value unpruned}}{(1 + i)^n}$$

where:

Value pruned = value of products from a pruned log
Value unpruned = value of products from an unpruned log
i = rate of interest
n = number of years from pruning until harvest.

Figures 3 and 4 show the increase in PV attributable to pruning under two interest rates for several situations. Key assumptions in the analysis are: growth and yield data are from Curtis and others (1982); the projected price for select lumber is about $900/MBF, and for structural lumber about $400/MBF; the 50-year site index is 125 except where otherwise specified; there is no effect from pruning on the unpruned portion of trees; and no more than one-third of the live crown is removed in pruning.

It is not surprising that figure 3 shows higher PV on high sites; more clear wood is produced in a shorter time. The PV from pruned stands is also substantially higher for fertilized stands than for unfertilized stands. In fact, the returns from fertilized low sites frequently exceed the returns from unfertilized higher sites. Figure 4 shows that both the age at time of pruning and at the time of harvest

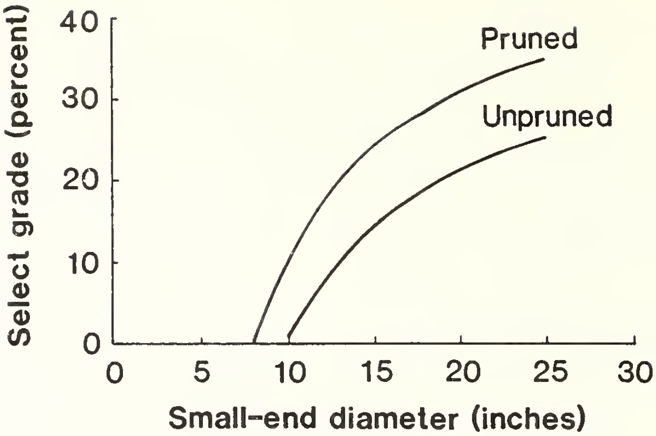

Figure 2—Proportion of select grade lumber as a function of small end log diameter for pruned and unpruned logs. Generally the larger logs had produced more clear wood since pruning, thus the proportion of select lumber increased. Veneer recovery showed a similar relationship.

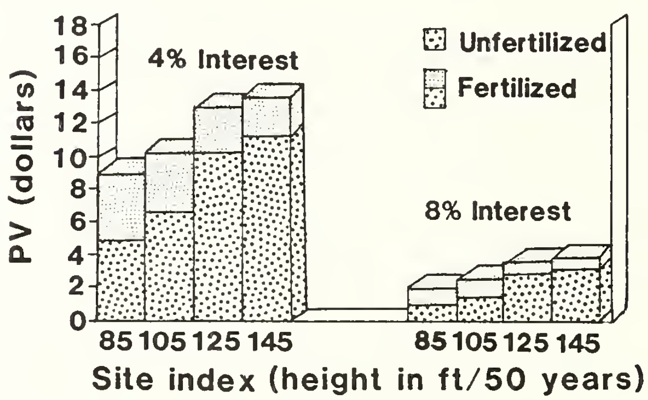

Figure 3—The effect of site index, fertilization, and interest rates on present value from pruning coast Douglas-fir stands.

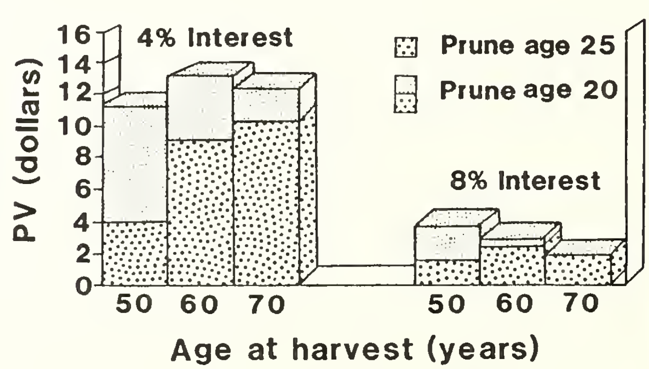

Figure 4—The effect of age at pruning, age at harvest, and interest rates on present value from pruning coast Douglas-fir stands.

make a substantial difference in PV. It is also obvious in figure 4 that interest rates are important and are interactive with age at time of pruning and time of harvest. All of the tools necessary for analysis of PV from pruning Douglas-fir are available and results are reported in Fight and others (in press b).

Although the results from this study are not directly applicable to intermountain species, they can be used to illustrate the potential magnitude of benefits from pruning. Ponderosa pine and western white pine offer the best opportunity for pruning in the intermountain area and probably elsewhere. The fine texture and machinability of these species make them suitable for a variety of products, such as molding and millwork, that depend on clear cuttings. A somewhat superficial analysis of PV from pruning ponderosa pine using current product prices suggests that benefits would be substantially higher than for Douglas-fir. Although growth rates would usually be lower, the difference in value between the select grades and common grades is substantially larger.

INCLUDING WOOD QUALITY IN FOREST MANAGEMENT

Studies on the effects of silvicultural treatments on wood properties have been conducted for years, but they have several shortcomings: first, there are few examples representing a wide range of silvicultural treatments over an entire rotation; second, little has been done to assess effects on product quality; and third, the work has not been incorporated into a comprehensive analysis. Silvicultural decisions affect timber yields, costs of management,

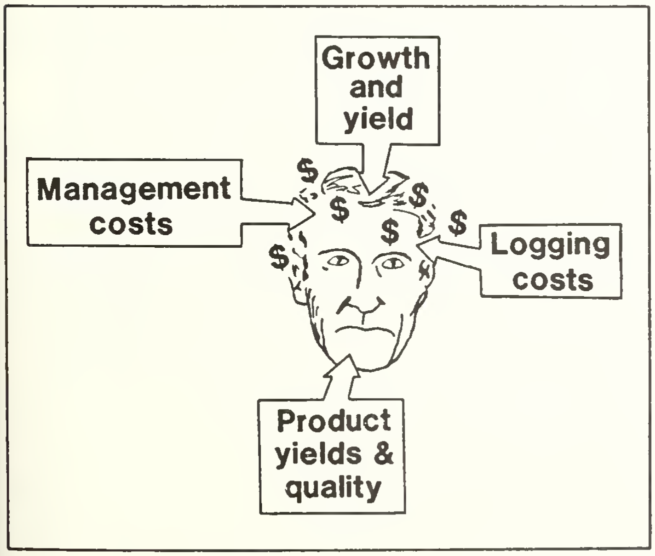

Figure 5—Key components in a holistic analysis of silvicultural regimes. Product yields and quality can be vital in a comprehensive analysis, but in the past few data were available to use in these evaluations.

logging, and manufacturing, as well as wood quality and product yield. It is necessary, therefore, to have a holistic analysis that looks at all of these simultaneously (Fight and others 1986).

In broad terms this type of analysis should include all of those things that affect either costs or returns in timber management, logging, transportation, manufacturing, and marketing. The SILMOD model (Sutton 1984) developed for radiata pine (*Pinus radiata* D. Don) in New Zealand is an example of a holistic timber analysis. The major components of such an analyis are shown in figure 5. Fight and others (1986) discussed all of the components in detail; we will address only product yields and quality.

Because silvicultural practices can affect product yields and quality, both need to be addressed in the analysis. Product yields, which are affected by piece size and tree form, can be estimated by empirical models based on product recovery studies or on simulation models such as Saw-Sim or Best Opening Face (Lewis 1985). Both options have advantages and disadvantages: simulation models are not mill specific, but they have thus far been restricted to mills sawing dimension lumber; empirical models can be used for mills that saw higher quality products such as selects and shops, but estimates from these models tend to be mill specific. Neither of these problems is insurmountable; data from a holistic evaluation are not directed to providing definitive answers in specific situations—they are more appropriately used in a sensitivity analysis in which various alternatives are compared.

Most wood quality research in the past has concentrated on wood properties. Other than the product recovery research on slash pine (*Pinus elliottii*) described by Burkhart and others (1984), little has been done to assess product quality. Estimates of product quality currently have to be based on empirical recovery studies because there are no commonly used simulation models for estimating product quality. Immediate needs are for studies that relate silvicultural practices to quality of products expected in the future. Our experience suggests that these empirical studies will have to be conducted in two phases: first, determine which of the tree characteristics are important in estimating quality; and second, determine the effect of silvicultural practices on tree characteristics. For dimension lumber, quality will have to be assessed based on mechanical properties and Machine Stress Rating (MSR) as well as on visual grades. Visual grades are used for "light framing" lumber which makes up a large part of the lumber in the housing and light construction markets. MSR lumber is generally higher quality and is used in engineered applications, a market that should increase in the future.

Long-term research should be directed to developing computer models that would simulate the development of tree characteristics based on different management practices. Likewise, simulation models should be developed that would allow estimates of product quality and yields from "computer sawing" a log. Using silvicultural input, these models should be able to simulate tree characteristics and estimate product yields and quality. They could in turn be used to more economically examine a wider group of forest management scenarios than is feasible under the empirically based model approach.

CONCLUDING THOUGHTS

Several simple approaches can be used to develop forest management strategies; we think most of them are too simple. The idea of maximizing volume per acre and letting technology take care of wood quality problems has been suggested. Technology can handle many problems, particularly if enough energy and dollars are available. But a premium will be paid to those who produce wood that is better suited to the needs of forest products manufacturers. Another idea that has been advocated is to minimize the amount of juvenile wood that is grown. Juvenile wood does have undesirable properties for many uses, but it is unlikely that minimizing the juvenile wood is the most advantageous way of managing the problem. Growing one species to a common target size has also been suggested as a management strategy. Although there are some obvious advantages in having the same size timber for harvesting and manufacturing, it is unlikely that those advantages outweigh all other considerations.

Managers aren't faced with simple rights and wrongs in choosing management strategies; there is an array of choices that all involve risk and uncertainty. We think an important consideration in developing forest management strategies, then, should be flexibility: how easy is it to shift to another strategy if in midrotation there are major changes in technology or markets? A sensitivity analysis approach as described by Fight and Briggs (1986) can be used to help select the most flexible regimes. This approach, using data from a holistic evaluation, will give the forest manager the best possible information on what strategy to pursue.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Roy Strang)—What information do you have on the effect of pruning on the mature wood/juvenile wood ratio?

A.—Juvenile wood appears to be formed in close proximity to the live crown—apparently a physiological response to auxin production. It is plausible that removal of live limbs would hasten the transition from juvenile to mature wood properties near the pruned limbs. We know of no research to substantiate this, however. We understand that Robert Kellogg of FORINTEK, CANADA in Vancouver, BC, has research under way attempting to determine how live crown affects the formation of juvenile wood.

Q. (from Dennis R. Parent)—In your opinion why have forest managers not given more thought to quality considerations in their future planning? Do you think more pruning will be done as a result of your research? Pruning seems to be one of the less "popular" forest treatments even though it has always shown good returns. Why??

A.—Information developed by wood and forest products technologists in the past could not be easily incorporated into forest management models, and the corollary, it is easier for forest managers to assume that all fiber grown is of the same quality and value.

Yes, we think it is likely that some pruning will be done because of our research. The most compelling reason is that we showed positive economic results based on actual data, but second, we have increased the visiblity of pruning as a viable management practice.

Virtually all prior analyses of pruning were hypothetical; we think there is less confidence in these results than in results based on actual data such as used in the PRUNE-SIM model. Second, pruning involves risk. In fact all forest practices involve risk, but the unknowns with pruning, such as future markets and price premiums for clear products, are highly uncertain.

WILDLIFE FROM MANAGED FORESTS—WHAT TO THINK ABOUT WHILE CHOPPING

Jack Ward Thomas
Evelyn L. Bull

ABSTRACT

Most forest land in the Mountain West will ultimately be managed. Silvicultural activities and attendant roads will be the predominant influences on wildlife habitat in the emerging managed forest. Opportunities are abundant for silviculturists and wildlife biologists to work together to produce both wood and wildlife from these forests. Such a partnership requires a means of communication and the compilation of wildlife habitat information useful in preparing silvicultural options and prescriptions. The factors that wildlife biologists consider in manipulating forest wildlife habitat are the same factors that silviculturists use to enhance wood production. Applied to one stand at a time, these treatments produce a new forest landscape—the emerging managed forest. "Multiple-use" is considered an ethically loaded ambiguity by many. Silviculturists and wildlife biologists have the mandate, the tools, and the opportunity to make multiple use a reality. Do they have the will?

PREFACE

I have read many definitions of what is a conservationist and written not a few myself, but I suspect that the best one is written not with a pen, but with an axe. It is a matter of what a man thinks about while chopping, or deciding what to chop. A conservationist is one who is humbly aware that with each stroke he is writing his signature on the face of the land. Signatures of course differ, whether written with axe or pen, and this is as it should be (Leopold 1949).

SILVICULTURE—THE KEY TO WILDLIFE HABITAT IN MANAGED FORESTS

Even after land is allocated to wilderness, parks, and other uses that preclude manipulation of the forest cover, the vast majority of forest lands of the Mountain West will, sooner or later, be managed. The euphemism "managed" means manipulated to produce an array of products. Manipulations include cutting trees, regenerating forest stands—naturally and by planting—tending stands, and recurrent harvesting of trees.

Silviculture and road systems constructed and maintained to support silvicultural activities are the primary factors influencing wildlife habitat in the managed forest. All wildlife is a product of habitat, and the silviculturists who prescribe how, when, where, and which silvicultural practices will be applied become, inescapably, the most significant managers of wildlife habitat (Bunnell 1976; Giles 1962; Thomas 1979a). If multiple-use is a guiding management principle, in most managed forests wildlife habitat will be a byproduct of timber management. It has become increasingly obvious that such clichés as "good timber management is good wildlife management" are no longer acceptable as excuses to not specifically address wildlife issues (Thomas 1979a). Wildlife objectives must be clearly stated and silvicultural prescriptions devised to provide "good" wildlife habitat management (Thomas 1979b).

The silviculturist produces or destroys wildlife habitat with each silvicultural treatment. The silviculturist prescribes stand treatments with a stated idea of what the response of the plant community will be. Tree response has been the traditional focus for the silviculturist in deciding what and how to chop. The biggest opportunity for wildlife management in the managed forest is the inclusion of wildlife habitat in what the silviculturist thinks about while deciding what to chop. The wildlife habitats considered by silviculturists and wildlife biologists are usually dictated by the landowner's objectives. In publicly owned forests, these objectives are loosely prescribed by law and are turned into specific objectives through land-use planning.

THE SILVICULTURIST-WILDLIFE BIOLOGIST TEAM

When wildlife objectives have been determined, the silviculturist and wildlife biologist must form a partnership to jointly achieve both timber and wildlife habitat objectives. The wildlife biologist must be ready to seize any opportunity for teamwork with the silviculturist, remembering that in managed forests the question is not if the forest will be manipulated to produce a mix of products but how those manipulations will take place. It is in the "how" that great opportunities for wildlife habitat management lie. The silviculturist and wildlife biologist must form an effective team (hereafter referred to as the team), seize those opportunities, and meet the obligations for multiple-use forest management.

COMMUNICATION—THE PREREQUISITE TO TEAMWORK

Stripped to its skeleton, silviculture is comprised of several attributes of managed stands that can be manipulated to achieve various desired results. Foremost among these are stand size, juxtaposition between stands, stand configuration, species composition, stand density, canopy closure, tree size, growth rate, snags, timing of treatments, spatial arrangement of stands, and site preparation. These are the same stand attributes that the wildlife habitat manager would consider in making habitat manipulations. The team can jointly decide how to manipulate these stand attributes to benefit both wood production and wildlife habitat.

Key to facilitating this teamwork is a means of communication—a "Rosetta stone"—that bridges the language barriers that have evolved between the subcultures in natural resource management. The first step is to develop a common understanding of the basic concepts of the forest ecosystem and decide which building blocks of that system are to be considered (see Thomas 1979a for an example). The second step is to compile and summarize information on how forest wildlife is related to habitat in a way that is meaningful in the context of silvicultural alternatives. Fortunately, such data bases for forest wildlife have been completed for some areas and are being developed for other areas in the United States and Canada. After initial efforts to summarize and synthesize information on wildlife relationships to habitat by Patton (1978) for the Southwest, Thomas (1979a) and colleagues for eastern Oregon and Washington, and Verner and Boss (1980) for the western Sierra Nevada, the Forest Service, U.S. Department of Agriculture, established its Wildlife and Fish Habitat Relationships Program to develop similar tools for other areas in the United States. Publications since 1980 include those of Brown (1985a, 1985b) for western Oregon and Washington, Hoover and Willis (1984) for Colorado, DeGraaf and Rudis (1986) for New England, and Maser and Thomas (1983) for the Great Basin of southeastern Oregon. Information for other geographical areas has been developed and is being used but has not been published.

In addition, habitat models (known as Habitat Evaluation Models or HEP) have been developed for individual wildlife species (Schamberger and others 1982; USDI Fish and Wildlife Service 1980); these can be used in prescribing silvicultural treatments that include management of individual wildlife species' habitat. Also, habitat evaluation models for species such as the Rocky Mountain elk (*Cervus elaphus nelsoni*) in different areas of the Mountain West have allowed the use of site-specific informa-tion to give agencies and individuals confidence in the habitat models (Thomas and others in press b).

What important forest stand attributes can be manipulated to achieve the desired wildlife habitat becomes the question for the team? The answer depends on the management objectives—for wood production and wildlife habitat. These objectives must clearly state the habitat conditions to be produced and maintained by silvicultural methods, but they must be expressed in terms of the silvicultural factors listed earlier—stand size, juxtaposition between stands, and so forth. Then, and only then, can the team clearly understand the job to be done and the tools to be used. Then, and only then, can the team and the responsible managers be held accountable for performance.

THE EMERGING FOREST LANDSCAPE

Silvicultural treatments are considered and applied on a site-by-site or stand-by-stand basis. This can be conceived of as microsite management. Each such treatment is analogous to the stroke of an axe that Leopold (1949) described as the process of writing a signature on the face of the land. What is just now emerging is the recognition that these strokes are cumulatively producing the landscape that will emerge as the managed forest. The concept of forest management is changing from one of microsite management to one of macromanagement. Adjustments in silvicultural prescriptions to achieve joint objectives for wood production and desired wildlife habitat are not a small thing, not merely a minor adjustment in the way of doing the business of forest management. Repeated year after year and in place after place, these treatments will become the dominant force that forges the evolving forested landscape—the signature of the perpetrators (Thomas and others 1986).

STATING AND MEETING WILDLIFE HABITAT OBJECTIVES

Examination of two common wildlife objectives for managed forests on the National Forests in the Blue Mountains of Oregon and Washington can give some idea of how silvicultural prescriptions can be modified to meet wildlife habitat objectives, how these objectives can be stated so that the team members communicate with each other and cooperate in achieving management objectives, and how achievement can be monitored.

Managing for Species Richness

The Forest Service is expected, as a result of the National Forest Management Act of 1976 and regulations issued since, to maintain the diversity of vertebrate wildlife in viable populations well distributed on managed forest lands. This is a clearly stated objective. Such an objective has been referred to as a requirement for species-richness management (Evans 1974). The available information base for the Blue Mountains (Thomas and others 1979d) identifies 378 terrestrial vertebrate wildlife species and records their association with plant communities and the successional stages or structural conditions for breeding and feeding. Species-richness management is achieved through adequate representation of plant communities and successional stages in appropriate proximity to one another to ensure interchange of animals between habitats. Some stands must be large enough to contain the territories or home ranges of species that rely solely or mostly on such habitat.

A positive relation exists between stand size and the number of species of plants and animals expected to be found there; it is called the species to area curve. At some point, however, the increase in the number of species per additional unit of area will approach zero. In management, that is the point that can be used to describe the average stand size that may be assumed to meet size requirements for achieving the diversity goal stated for wildlife. This average stand size was estimated at 84 acres for the Blue Mountains (Thomas and others 1979c).

The consideration of edge—the meeting of plant communities or differing stand conditions—is also important. Edge is particularly productive of wildlife species that require both habitat conditions represented and those adapted to the conditions that exist in the ecotone (Leopold 1933). High contrast in vegetative structure between adjoining communities or successional stages may enhance wildlife species diversity along edges and in each of the adjoining stands (Thomas and others 1979c).

The wildlife habitat diversity objective for one National Forest might be expressed as follows: The managed forest will contain, within each recordkeeping unit of 3,000 to 15,000 acres, 5 percent of each forest community in each of the six successional stages. Stands will average 84 acres. A stand representing each successional stage will be within 0.5 miles of a similar stand unless natural conditions make this impossible. Contrast along edges between successional stages will average a value of three, by the procedure outlined by Thomas and others (1979c). Edges between stands will be created to produce an induced diversity index of 0.40 or more, by the procedure prescribed by Thomas and others (1979c). Snags will be maintained at or above the 0.30 management level as described by Thomas and others (1979a).

When objectives are so expressed, the team knows what is to be achieved and which silvicultural tools can be used. In this case, stand size, condition, juxtaposition, shape, and arrangement in time and space are the operative factors. Meeting the management objective requires consideration of the whole emerging landscape. Further, such criteria can be monitored so that management objectives are met and can be judged.

Managing for Featured Species

In addition to meeting diversity objectives for wildlife habitat, the team is commonly given habitat objectives for a single species, called featured species management (USDA Forest Service 1971). The species most commonly singled out for such treatment in the Mountain West is the Rocky Mountain elk.

A review of the evolution of elk habitat guidelines and habitat evaluation models can be found in Thomas and others (in press a). The first attempts at meeting elk habitat needs were guidelines for silviculturists making prescriptions. There were similar directions for road builders and range managers. The most complete and best supported guidelines are found in Lyon and others (1985). Items of particular interest to silviculturists include:

> To assure that forage produced in clearcut is . . . available for use by elk, openings should satisfy the following criteria:
>
> —slash cleanup inside clearcuts should reduce average slash depths below 1.5 ft. Slash in excess of 1.5 ft will reduce elk use by more than 50 percent.
>
> —openings should be small, even though openings up to 100 acres may be acceptable where the adjacent forest edge supplies adequate security.
>
> —. . . thinning adjacent to clearcuts is not recommended.
>
> —additional security, which will significantly increase elk use of clearcut openings, can be provided with appropriate road closures.

Such insights emerging from research will remain essential tools in managing elk habitat, and they are the stuff from which mathematical models grow. No model, however, can capture all of what should be considered in evaluating or manipulating habitat.

One of the first models of elk habitat that received widespread use, attention, evaluation, and revision was developed for use in the Blue Mountains (Black and others 1976; Thomas and others 1979b). The evaluation criteria and associated assumptions were tested by Leckenby (1984). The model was modified to take advantage of Leckenby's efforts and other evaluations (Lyon 1984) and developments in modeling and remote sensing technology. The present version has been described by Thomas and others (in press a; 1986).

Other models describing elk habitat appeared after 1976, each with modifications to suit local conditions and biologists with different experiences and views. Among these models are those of the Interagency Study Team (1977) for northern Idaho, the Montana Department of Fish and Game and the Forest Service (1977) for central Montana, the Forest Service and the Montana Department of Fish and Game (1977) for eastern Montana, Leege (1984) for northern Idaho, Wisdom and others (1986) for western Oregon and Washington, and Thomas and others (in press a) for eastern Oregon and Washington. In addition, Lyon and others (1985) reported on elk habitat evaluation criteria for the Bitterroot, Kootenai, Bridger-Teton, and other National Forests. Lyon and others (1985) noted that "almost without exception, prescriptions for maintaining productive elk habitat now include both the physical components (thermal cover, hiding cover, foraging areas) and some components related to elk behavior within the physical environment (cover interspersion, road density, livestock management, and traditional use) . . . ."

The model currently used to evaluate Blue Mountain winter ranges (Thomas and others in press a) is used here as an example of management criteria for a single species. The model is expressed as follows:

$$HE = (HE_s \times HE_r \times HE_c \times HE_f)^{1/n}$$

where:

HE = overall habitat effectiveness for elk
HE_s = habitat effectiveness as influenced by size and spacing of cover and forage areas
HE_r = habitat effectiveness as influenced by the density of roads open to vehicular traffic

HE_c = habitat effectiveness as influenced by cover quality

HE_f = habitat effectiveness as influenced by the interaction of forage quality and forage quantity

$1/n$ = nth root; suggested by the Fish and Wildlife Service (1981) as a means of expressing compensation between interacting habitat variables.

Each of the habitat variables assumes a value between 0.01 and 1.0; criteria are precisely described by Thomas and others (in press a). Quality is expressed in categories based on stand height and canopy closure. Management objectives for elk habitat can be expressed by the *HE* value and, if desired, for each component. For example, management objectives could be expressed as follows: maintain *HE* at or above 0.50 with HE_s at or above 0.30; HE_r at or above 0.60; HE_c at or above 0.40; and HE_f at or above 0.50.

The team has clear objectives for elk habitat and can identify the silvicultural factors that are the key to achieving the objectives. Meeting the HE_s objectives is accomplished through attention to the size of regeneration units and the timing and location of those regeneration cuts. HE_c objectives are met by maintaining adequate proportions of cover in condition where stands are 40 feet or more tall, with canopy closure equal to or greater than 70 percent. HE_r reflects the impact roads per unit of area open to vehicular traffic have on elk use of adjacent habitats and can be manipulated through the amount of roads constructed or with road closures—if the closures are effective. Finally, meeting the objective for HE_f requires that livestock be managed so as to graze vegetation to a designated height.

SUMMARY

The mechanisms, the means of communication between silviculturists and wildlife biologists, and the tools to make wildlife habitat a product of silvicultural treatments are being rapidly improved. The opportunity to simultaneously satisfy wood production and wildlife habitat objectives is obvious—so obvious that it cannot be avoided. The land-use planning and resource allocation processes underway by Federal land management agencies have emphasized that pressure will be increased to move the multiple-use concept of managed forests from the realm of platitudes to reality where multiple objectives are clearly set and progress measured. The pressure is on. The opportunity is great. The tools are at hand. Do we, the natural resource manage-ment professionals charged with writing our signature on the face of the emerging managed forest, have the will? The answer will be apparent when the managed forest emerges from its formative chaos.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q.(from Stephen L. Donnelly)—Considering the open road density of the elk habitat evaluation model you discussed: (1) what is the weight and effect on viable populations, and (2) is the road factor considered to "manage the bullet" or other factors?

A.—The information used to evaluate the impact of the number of roads per square mile open to vehicular traffic was taken from information developed by Perry and Overly in Washington and L. Jack Lyon and associates in Montana. Obviously, there is no impact of roads where there are no roads. As roads are created there is a loss in elk use of habitat adjacent to the roads. Use approaches zero at about 6 miles of open road to 1 square mile of habitat.

These relationships were worked out in areas where elk are subject to hunting. Studies in National Parks, where there is no hunting, show that elk do not show as much adverse reaction to roads.

Q.(from George Chaffee)—With a highly intensive, prescribed silvicultural treatment to meet habitat and forage requirements of elk, how do we address the severe impacts of logging and other roads?

A.—It seems clear that roads open to vehicular traffic have a negative impact on elk willingness to use habitats adjacent to such roads in areas where elk are hunted, whether legally or illegally. The portion of the habitat model makes that very clear. The model that was used here as an example would indicate that, in the situation you described, an aggressive and effective road management program would be required if good results for elk were a desired product of the forest management applied. Without an effective road management program, the model would predict a low habitat effectiveness score for elk.

OPPORTUNITIES FOR ENHANCING LIVESTOCK FORAGE ON FORESTLAND

Frederick C. Hall

ABSTRACT

Typical range management concepts must be modified when applied to forestland. Stocking level control of trees is the main method for enhancing forage for livestock: it causes changes in herbage production, species composition, and accessibility for animals. Logging disturbance of forage producing vegetation can reduce livestock capacity if grasses are not seeded.

Forest vegetation in the greater Pacific Northwest was divided into three general kinds for discussion: climax pine which has natural livestock forage, successional pine formerly maintained by underburning which is now being reduced in forage production as climax fir colonizes the sites, and highly productive hemlock-fir which does not naturally produce livestock forage but which can be grazed for 5 to 15 years following regeneration cutting.

INTRODUCTION

Before discussing opportunities for enhancing livestock forage on forestland, I must ask how forested rangelands fit into the context of typical range management. This discussion will focus on the traditional concepts of condition and trend.

Range Condition

Range condition is based on density and composition of climax plant communities, a concept developed on Great Plains climax grassland (Dyksterhius 1949). Lower range conditions, fair and poor, are due to overgrazing by livestock; certain species are reduced in density and composition (decreasers) by excessive use.

Range condition is interpreted as follows: Good means no significant change in vegetation by livestock and implies satisfactory management with few problems. Fair suggests past moderate overgrazing and, therefore, past moderately poor livestock management; current management may need change. Poor indicates past overgrazing for a long period of time, past unsatisfactory livestock management; a change in management is probably required. Very poor indicates enough excessive livestock use that palatable climax species are absent and even nonuse by livestock may not permit change for 20 to 50 years.

Range Trend

Range trend is change in density and composition or forage production of the plant community due to livestock grazing which discourages (or encourages) certain plant species. Downward trend is change away from climax conditions due to heavy selective grazing by livestock. Those species that livestock prefer to graze sustain excessive use and are reduced in their density and composition, thus they are called decreasers. Static trend is no change in density or composition of the plant community. Upward trend is change toward good condition or climax density and composition. It means that decreasers are not being damaged by grazing, therefore, they can outcompete other species and regain their dominance in the community.

Downward trend indicates unsatisfactory livestock management and requires immediate consideration for change. Static trend is desired in top range condition. In fair and poor condition it indicates that past livestock management has changed enough to halt downward trend but still is not satisfactory enough to foster an upward trend. Upward trend is desired in all range conditions except good. It indicates satisfactory livestock use, light use, or no use.

Livestock Management

Livestock management is the right animal in the right place at the right time in the right numbers to attain upward trend to best range condition. Objectives are optimum meat production in the best vegetative condition possible, generally native vegetation.

Revegetation is designed primarily to enhance livestock production. Seeding of introduced (or preferably native) species is primarily a last resort on very poor condition range. Spraying, chaining, or burning are often used to retard succession toward tree- or shrub-dominated vegetation that is less productive for livestock.

Forestland Range Concepts

Forested rangeland violates **all** concepts because the dominant vegetation is not grass but trees (Hall 1978). Tree density greatly influences grass density and thus forage production. Tree canopy cover less than about 30 percent has little effect on density and forage production of native plants. However, as canopy increases past 40 percent cover, shrubs and herbaceous species decrease in both density and production. Many times, dominant grasses also decrease in their percent composition (Young and others 1967).

These changes are a downward trend in forage plants not caused by livestock grazing. Forage plant density and composition under 80 percent tree canopy is quite different from that under 40 percent canopy—a new "range condition." Range condition is not based on climax

Table 1—Range condition guide for mixed conifer-pinegrass-elk sedge plant association of the Blue Mountains in Oregon (USDA 1967)

	Tree canopy cover				Condition rating
	Under 40%	41-70%	71-90%	Over 91%	
	Percent				
Percent composition	75	60	40+	15+	Good
of pinegrass	45-74	35-69	22-49	10-15	Fair
and elk sedge	15-44	10-34	8-21	5-14	Poor
	0-14	0-9	0-7	0-4	Very poor

CWG1-12 condition rating table for percent comparison (table 1)(USDA 1967).

vegetation. Instead it is based on tree cover to characterize the maximum density, composition, and forage production possible under existing woody vegetation. This often results in two to four condition ratings (for example, less than 40 percent, 40-80 percent, and over 80 percent tree cover), each with its condition classes of good, fair, poor, and very poor (table 1). In this way, effects of livestock grazing on forage plants can be separated from effects of tree cover.

Timber management affects range condition and trend by changing stand density and damaging ground vegetation (Hedrick and others 1968; Young and others 1967). Stand density is changed by thinning and regeneration cutting (Hedrick 1975). Range trend is caused by these treatments as forage plants respond to tree canopy cover. Data for estimating range condition are changed by the treatments when condition is based on tree cover.

Stand treatment can directly damage forage vegetation (Garrison 1960; Skolvin and others 1976; Young and others 1967). Fifteen percent of the vegetation is often killed with high risk cutting. This is downward trend of two-thirds of a condition class. Should this change in condition be reflected in range condition even though livestock has nothing to do with it? Would a change in livestock management have prevented the downward trend?

Range condition in forestland must be based on tree canopy cover, not on climax stand conditions (Hall 1973, 1978; Young and others 1967). Livestock management will not alter a downward trend caused by increasing tree cover. Trend in forage species must be interpreted according to the cause of trend—trees or livestock management (Hedrick 1975; Young and others 1967). Timber management is a major factor affecting livestock forage. It is often more important than livestock management. On forestlands used for both timber harvest and livestock grazing, timber management can be used to enhance livestock forage.

FACTORS FOR ENHANCING FORAGE

The land manager needs six kinds of information to make a sound decision or plan for enhancing livestock forage on forestlands.

1. Current vegetation: timber stand condition such as regeneration, old growth, or stagnated saplings; current species of trees, shrubs, and herbs by dominance, current production, apparent trend in vegetation, and range condition.
2. Soil: surface protection; erodability; trafficability; suitability for revegetation; response to fertilization, irrigation, or mechanical treatment such as hardpan fracturing; stability; mechanical characteristics for road construction; and water development.
3. Topography: slope steepness; length of slope; slope aspect; slope shape such as concave, flat, convex, rough, terraced, or smooth; canyon form such as sharp V or broad overflow bottom, and ridge form such as knife-edge or broad.
4. Current use of the area: livestock primary or secondary range; season of use; big game season and intensity of use; active or planned timber sale; administrative restriction such as campground, streamside management area, revegetation area, planned nonuse area; grazing system currently in use, or exclusive grazing by a rancher or use in association with other ranchers.
5. Juxtaposition of the tract: location of fences; distance and route of access to water; road location particularly for timber management; kind of adjacent vegetation and soil such as stringer meadows in fir types or islands of ponderosa pine in scabland; size of tract and its relative palatability in relation to adjacent vegetation (for example, is it an "ice cream" tract or can it carry its proportional share of the allotted number of animals?).
6. Site potential (plant association, habitat type): production potential; plant species composition; tree regeneration characteristics; range condition data or standards; revegetation and reforestation characteristics; reaction to stand treatment; and the interaction of silviculture and grazing treatment (range trend). The plant association provides opportunities and limitations on treatment (Daubenmire and Daubenmire 1968; Hall 1973, 1983; Pfister and others 1977).

Items 1 through 5 define what the manager has to work with. Item 6, the plant association (habitat type), provides opportunities and limitations on possible treatments. It helps predict reactions to treatment and thus provides a basis for prescribing treatment.

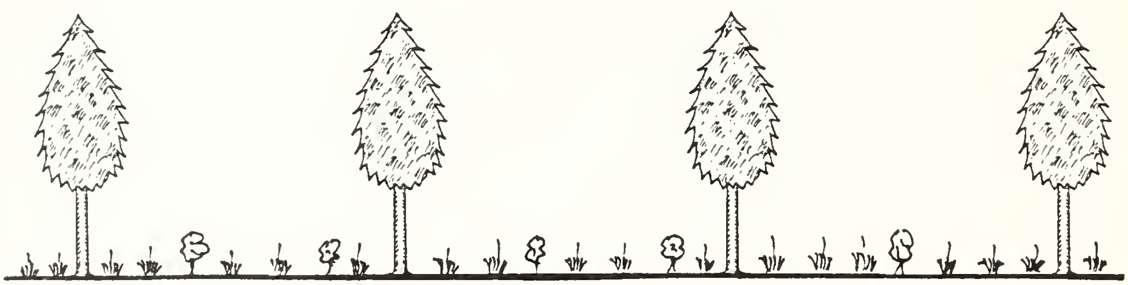
TIMBER MANAGEMENT-THE ENHANCEMENT FACTOR

Timber management deals with planning and accomplishing stand treatment to attain specified goals. Height and diameter growth of trees are usually part of the goals, as might be enhanced forage for livestock and cover for wildlife. Once goals for a stand are established, stand condition dictates what might be possible within the constraints of soils, topography, and location of the tract. Site potential (plant association) and current use influence the established goals. One factor often part of stand treatment is stocking level control. Height and diameter growth of trees are dependent on stand density; both are required not only to produce the desired timber products but also for wildlife habitat (such as 21-inch d.b.h. trees for pileated woodpecker nest sites). Stand density also is a primary factor influencing forage production for livestock and wildlife (Hedrick and others 1968, 1975; Young and others 1967).

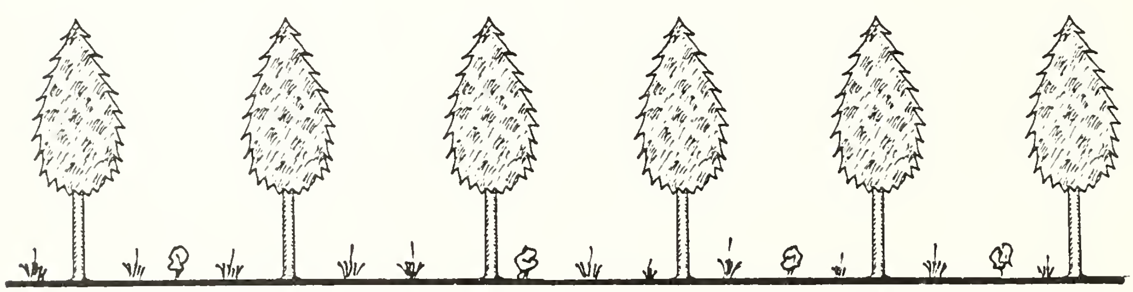
Stand Density Control

Site potential for stockability (stand density possible on a site) varies much more widely than site index because a given site index can have several stockabilities associated with it (Hall 1987). One index of stockability is called growth basal area (GBA)(Hall 1987). GBA is that basal area per acre at which dominant trees grow at the rate of 1 inch in diameter per decade. All other trees in the stand grow at equal or slower rates.

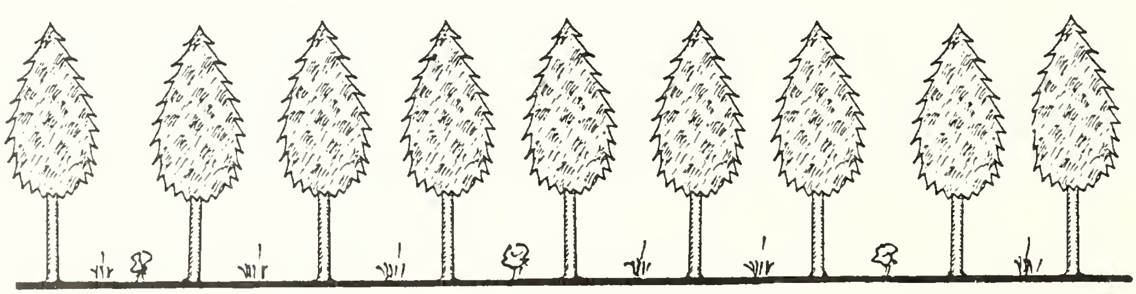
For example, ponderosa pine (*Pinus ponderosa*) can range in site index from 50 to 150 ft while growth basal area can range from 30 to 300 ft^2 basal area per acre. These basal areas are directly related to tree crown cover, which in turn is directly related to productivity of ground vegetation (nontree vegetation). Figure 1 illustrates crown cover of 70-ft tall ponderosa pine in relation to GBA.



Forage production 600 pounds per acre under 35% canopy at 35 ft^2 BA per acre.



Forage production 400 pounds per acre under 50% canopy at 65 ft^2 BA per acre.



Forage production 250 pounds per acre under 70% canopy at 130 ft^2 BA per acre.

Figure 1—Canopy cover of ponderosa pine as influenced by basal area per acre and the effect on forage production (from table 2).

Ponderosa pine 70 ft tall would be about 100 years old for a site index 70. A site index 70 can range widely in its GBA, from 55 to 196 ft^2 basal area (BA) per acre. For example, the ponderosa pine/bitterbrush-bunchgrass association has only 55 ft^2 GBA (Volland 1982), ponderosa pine growing on the Douglas-fir/bearberry-bitterbrush association has 98 ft^2 (Williams and Lillybridge 1983), and ponderosa pine growing on the white fir-ponderosa pine-sugar pine/sticky current association has 196 ft^2 BA per acre (Hopkins 1979).

One objective of timber management is to grow trees to commercial size in the desired amount of time. For example, first commercial thinning may require an average stand diameter of 10 inches d.b.h. by age 60. This would require an average of about 1.5 inches per decade diameter growth which also requires less BA per acre than GBA. Stand characteristics for the three site index 70 plant associations are summarized in table 2.

The three site index 70 associations require three very different stand densities to attain the same tree size in the allotted time. They also have different canopy covers resulting in significantly different herbage production. Adjusting stand density by site requirements of GBA greatly influences herbage production for a given timber management objective.

Different management objectives influence herbage production within a given GBA class, for example, 98 ft^2 BA per acre. Table 3 lists stand characteristics for ponderosa pine growing on the Douglas-fir/bearberry-bitterbrush association with a site index of 70 and GBA of 98 ft^2 (Williams and Lillybridge 1983). Three rates of diameter growth are depicted: 2.5 inches per decade to reach commercial size in about 40 years, 1.5 inches for 60 years, and 0.7 inches per decade which could result in maximum time and maximum stand volume production.

Herbage production ranges from 250 to 600 lb per acre depending on stand density as a result of timber management objective. The rate of 0.7 inches per decade not only produces maximum cubic volume of wood per acre but also roughly represents stand stagnation and onset of significant suppression mortality.

These differences in canopy cover and the resulting herbage production clearly illustrate the need to adjust "range condition" to the canopy cover on the site. Range condition at 250 lb per acre is just as good at 70 percent canopy cover as is condition at 600 lb under 34 percent canopy cover. No adjustment in livestock grazing can create an upward trend to 600 lb under 70 percent canopy— only thinning the stand can accomplish that. On the other hand, 250 lb under 34 percent canopy should rate only poor condition. Livestock adjustment should provide for upward trend and greater herbage production. But one other factor must be considered when enhancing forage production in forested range: the effects of timber harvest on ground vegetation.

Table 2—Stand characteristics when dominant trees grow at 1.5 inches per decade in diameter at three growth basal areas; average stand d.b.h. is 10 inches

Growth basal area	BA for 1.5 inches[1]	10 inches d.b.h.TPA[2]	Canopy cover	Forage production	MAI[3] of wood
-------- *Ft²* -------			*Pct*	*Lb*	*Ft³*
55	35	65	35	600	15
98	65	120	50	400	27
198	130	240	70	250	55

[1]See Hall (1987) for estimation of basal area (BA) required for 1.5 inches diameter growth.
[2]TPA = trees per acre.
[3]See Hall (1987) for estimated MAI (mean annual increment).

Table 3—Stand characteristics for a growth basal area of 98 ft^2 per acre for three rates of diameter growth for a site index 70 stand at 10 inches d.b.h.

Diameter growth	BA per acre[1]	10 inches d.b.h. TPA[2]	Canopy cover	Herbage production	MAI[3] of wood
Inches/decade	*Ft²*		*Pct*	*Lb/acre*	*Ft³*
2.5	33	60	34	600	18
1.5	65	120	50	400	24
0.7	128	235	70	250	28

[1]See Hall (1987) for estimation of basal area (BA) required for various rates of diameter growth.
[2]TPA = Trees per acre.
[3]See Hall (1987) for estimation of MAI (mean annual increment).

Ground Disturbance

Harvesting timber by ground equipment usually disturbs the soil surface and vegetation. Garrison (1960) reported about 15 percent disturbance with selective harvest of old growth ponderosa pine. This represents an instant two-thirds condition class deterioration in range condition when four condition classes are used (good is 75 percent or more of potential, fair is 50-74 percent, poor is 25-49 percent, and very poor is less than 24 percent of the potential density and production under existing canopy cover). Cutting more timber usually results in proportionally more area disturbed. Regeneration cutting, even in shelterwood, can cause up to 70 percent ground disturbance and thus nearly three condition classes downward trend not caused by livestock impacts (Hedrick 1975). In some cases, ground disturbance is planned to prepare the site for tree regeneration.

In all cases, herbage production is reduced and livestock levels must be adjusted to the lowered forage available, unless grasses are seeded in the disturbed areas (Hedrick and others 1968). The amount of increased forage provided by seeding depends on the canopy cover of the remaining trees and amount of soil disturbed. In many cases, seeded grass under reduced tree canopy will produce more forage than native vegetation (Hedrick and others 1968).

Regeneration cutting poses the greatest concern between timber and livestock goals because it provides maximum opportunity for grasses to reduce timber yields. Seeding sufficient grass to enhance livestock forage will often reduce tree height growth and survival. However, if grass is seeded at 2 to 4 lb per acre immediately after harvest and live trees ready to grow are properly planted the next spring, each can compete effectively with the other. If tree planting is delayed 1 year, expect 30 percent reduction in survival; if 2 years after, expect at least 60 percent reduction in survival. Two to 4 lb of grass seed on a prepared seedbed should produce 1,200 to 1,800 lb of herbage by the third year, most likely two to four times more than native vegetation (Hedrick and others 1968).

With suitable tree survival, such as 350 trees per acre, these regeneration units should produce abundant forage for about 10 years; after that time production tends to fall rapidly as tree crowns shade out the grasses. Lower tree stocking rates, such as required on low GBA sites, tend to prolong high forage production.

Major Tradeoffs

Any time two different goals are programmed for a single tract of ground, each will have to produce at less than maximum efficiency. Tree regeneration and growth versus forage production for livestock are excellent examples. Maximum forage requires no trees, while maximum wood production requires instant regeneration and maximum stand density.

Many of the tradeoffs occur in the regeneration phase of stand management. If only moderate amounts of grass are seeded in regeneration units (2-4 lb per acre) less forage will be produced for livestock; and tree survival and tree height growth will be somewhat reduced. There will be increased chances of unacceptable tree stocking, yet livestock forage will be prolonged. Increased chances of reduced wood production due to low tree stocking would also prolong moderately high forage production (table 3).

The major tradeoff concept is that livestock forage requires low stand density. Wood production is reduced to attain acceptable levels of livestock grazing. Short rotations result in reduced wood production, increased livestock forage, and a greater proportion of the land in regeneration units are all tradeoffs to be considered. For example, a 120-year rotation has only 8 percent of the land in highly productive clearcuts less than 10 years old while a 60-year rotation has 17 percent. But these values must be tempered with biological attributes of forest rangeland.

MAJOR FOREST TYPES OF THE PACIFIC NORTHWEST

Forest types may be divided into three categories according to suitability for livestock grazing (juniper is not considered a forest type):

1. Climax pine sites that are permanently suited for livestock grazing. Either ponderosa or lodgepole pine may be climax; sometimes Douglas-fir.
2. Successional pine types where pine was maintained by underburning during pristine conditions. With fire suppression, pine is being replaced by fir causing a downward trend in forage production.
3. Fir-hemlock types that are generally not livestock range. However, clearcuts may provide grazing. These clearcuts are the only "new" or additional forested rangeland available today.

Climax Pine Types—Permanent Rangeland Potential

Common characteristics: low timber production, often less than 50 ft^3/acre/year. Many types are a savanna transition from forest to steppe. Low stocking density potential—GBA below 100 ft^2/acre, often less than 80. Severe regeneration problems are common which means maximum site preparation and thus maximum reduction in herbage production or maximum opportunity for regeneration failure. Forage species are generally the same species found in nonforest types: bunchgrasses, sagebrush, and bitterbrush.

Some dry site Douglas-fir types provide permanent livestock forage. Most notable are Douglas-fir with understories of pinegrass, snowberry/pinegrass, elk sedge, or fescue in the Northern Rocky Mountains and British Columbia.

Optimum timber management maintains rather low stand densities and thus low canopy covers, often less than 60 percent. The result is near-maximum opportunity for livestock forage production.

Successional Pine Types—Changing Grazing Potential

Common characteristics: formerly maintained in pine by underburning (Hall 1977); formerly carried a major share of forest grazing; now gradually changing from pine to Douglas-fir or grand (white) fir which results in gradual reduction in forage production. Douglas-fir climax has greater herbage production than does grand fir. This change caused grazing capacity in the Blue Mountains of Oregon to decrease 15 percent from 1940 to 1970; logging and grass seeding prevented a greater decrease. Timber production is moderate (50 to 180 ft^3/acre/year)(Hall 1973). Optimum timber management will produce moderate forage production. Seeding grass following stand treatment can double forage production compared to native production, with more nutritious and palatable species.

Ponderosa to Fir/Pinegrass Group-Climax in Douglas-Fir or True Firs—Most important forested rangeland in the Pacific Northwest. Pinegrass dominated under open pine; shrubs less than 20 percent cover.

Excellent grazing with: (1) management for ponderosa at fast diameter growth which means low tree density; (2) frequent entries with ground equipment to prepare seedbed to seed grasses (no more than three turns per skid trail); (3) seeding orchardgrass on all disturbed areas following each entry to double production over that possible with pinegrass under existing tree cover.

Fairly good grazing with: (1) management for Douglas-fir with some pine and grand fir at moderate diameter growth which means high stand density; (2) entries at 15-25 years time intervals which means seeded grass will be largely replaced by pinegrass; (3) seeding orchardgrass following logging.

Lodgepole/Pinegrass Types—Lodgepole is successional to firs; similar grazing characteristics as ponderosa to fir pinegrass types.

Ponderosa to Fir/Shrub/Pinegrass Group—Shrubs such as oceanspray, ninebark, snowberry, and spirea dominate and range from 20 percent to 80 percent cover. Poor grazing types due to low forage production and shrub canopies that hinder livestock access and use of forage.

Hemlock, Cedar, True Fir Types

These types are inherently poor livestock forage producers. However, clearcuts can provide excellent sheep and sometimes cattle grazing. Domestic grass may be seeded but forage from native vegetation is often adequate. Units apparently last 8 to 15 years. Clearcut grazing tends to have a unique set of management requirements: water must be available at most units; there must be enough units to support a workable-sized herd or band, and units must be close enough together for manageable access.

SUMMARY

1. Typical range management concepts of condition, trend, and management objectives must be modified for forested areas because trees and their harvest tend to have more impact on range condition, trend, and livestock use than do the animals.

2. Grazable forested ranges can be divided into three kinds: those with a natural, permanent ability to produce livestock forage; those that were maintained as forage producers due to underburning but are now changing to dense fir and losing their capacity to feed livestock; and those that do not naturally produce livestock forage but can be highly productive following regeneration cutting.

3. Timber management is the primary factor in optimizing range management on forested rangelands.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Bob Mrowka)—What is your opinion of the Savory Grazing System and its application in a forest rangeland situation?

A.—I do not know because I have not observed its application anywhere in forests, much less over a 5-year period or longer which would be essential for a reasonable evaluation. Savory, in his presentations, emphasizes its application in "brittle environments" and has not (as of 1965) shown its superiority in more mesic environments such as forest rangeland. His definition of "brittle environment" is one where precipitation is so low that vegetation cannot add up to 100 percent total canopy cover. Examples are winterfat, greasewood, and sagebrush communities. "Brittle" seems to relate to soil surface conditions where the soil surface is often brittle due to extreme drying.

OPPORTUNITIES FOR ENHANCING WATER YIELD, QUALITY, AND DISTRIBUTION IN THE MOUNTAIN WEST

Peter F. Ffolliott
Kenneth N. Brooks

ABSTRACT

To prepare comprehensive management plans for water yield improvement in the young, dynamic forests that will characterize the Mountain West in the future, it is necessary to recognize the opportunities for enhancing water yield, quality, and distribution. The existing knowledge relating to these important hydrologic topics is highlighted in this paper. For many forest types, increases in high quality water are possible. However, the magnitude and duration of the water yield increases are dependent on species compositions, stand structures, and management prescriptions.

INTRODUCTION

Forested watersheds of the Mountain West have long been viewed as important sources of the water on which the region depends. These high-elevation lands receive the greatest annual precipitation, much of which becomes streamflow in the region. Therefore, opportunities to enhance the yield of high quality water from these watersheds have gained considerable attention. However, important questions as to the practicality of increasing water yields given the management constraints for other products (such as wood, wildlife habitat, and recreation) remain. Furthermore, the increased water yields that may be realized cannot be of such poor quality that their use would be hazardous. Importantly, we cannot increase water yields and cause increased magnitude and frequency of downstream floods, nor should we diminish low flows in dry periods.

The purpose of this paper is to assess, in a general framework, the opportunities of managing the forest lands in the Mountain West to achieve water resource objectives. Specifically, we will consider how forests can be managed to enhance water yields without deteriorating water quality, reducing low flows, and increasing downstream flooding. Brown and Beschta (1985) recently presented a "state-of-the-art" report on water management in the forests of North America. We will concentrate here on the current status of knowledge in the Mountain West. From this information, we can impute the opportunities for enhancing water yield, quality, and distribution in the young, dynamic forests that should characterize the region in the future.

WATER YIELD

A recent summary by Bosch and Hewlett (1982) of 94 international catchment experiments pointed out that, in most instances, water yields can be increased by cutting forest stands. These authors reported that, in general, the greater the annual precipitation, the greater the magnitude of annual water yield increase following the cutting activity. Also, cutting coniferous forests resulted in greater increases in water yield than cutting deciduous forests. An implication of these studies is that, for the forests of the Mountain West, the greatest opportunities for enhancing water yields should be found in the high-elevation coniferous forests.

Troendle (1983), in summarizing watershed research in the Rocky Mountains, reported that annual streamflow could be increased between 1 and 2.5 inches for each acre of high-elevation subalpine forest managed for the purpose of increasing water yields. Such management is aimed at both reducing evapotranspiration losses and increasing the efficiency of snowmelt runoff. Significantly, it appears that these increases in water yields can be achieved without detrimental effects on water quality, peak discharges, and channel integrity. However, one problem in implementing water yield improvement programs in the subalpine forests of the Rocky Mountains is the limited extent of suitable forested areas and the long rotation periods (typically, between 100 and 120 years) of the forest stands. Troendle (1983) concluded that only one-fourth to one-third of the area could be managed for "optimal" water yield at any one time.

Potential exists to increase annual water yields in the aspen forests of the Mountain West by vegetative conversion. Increases up to 5 inches are possible from clearcutting these forests (DeByle 1976), although the increases decline rapidly when this sprouting tree species is allowed to recover the site (fig. 1). If clearcutting practices are repeated every 80 years (as might be done for sustained harvesting with forest regeneration), the annual water yield increase over the 80 years is estimated to be 0.33 inch over the area treated.

Numerous studies of the potential for increasing water yields through forest cuttings have been carried out in the ponderosa pine forests of the Southwest, as summarized by Baker (1986). Variable responses of water yield to forest cutting practices (including reductions in forest overstories and creation of cleared openings) have been

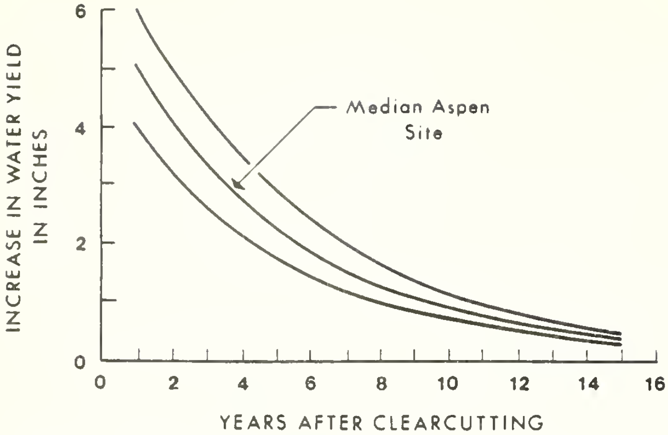

Figure 1—Increase in water yields after clearcutting aspen forests in the Mountain West, when regrowth is permitted (Hibbert 1979).

observed. Increases in annual water yields generally occurred on watersheds characterized by basal area levels in excess of 100 ft^2 per acre. The magnitude of these water yield increases was dependent, in large part, on the amount of forest cover removed and the level of precipitation in a given year. Although large variations were reported, initial mean increases in water yield ranged from 1 to 6.5 inches, values reflecting the relative importance of precipitation amounts and timing on water yields. Water yield increases diminished as the forest overstory regrew after cutting, although the effects persisted 3 to 7 years (depending on the nature of the cutting treatment).

As one looks to watersheds in the lower elevation rangelands (on which the vegetation is predominantly grasses, forbs, shrubs, and woodland species of pine, juniper, and oak), the magnitude of annual water yield increases attributable to cutting activities progressively becomes less, until we reach the pinyon-juniper type where the potential is nil. Hibbert (1983), in summarizing water yield improvement experiments in the woodlands in the Mountain West, concluded that between 16 and 18 inches of annual precipitation are needed before watershed management actions result in measurable water yield increases. Most rangelands in the Mountain West receive less than this and, therefore, possess limited potential for water yield improvement.

If water yield increases are to be realized by forest cuttings, it is apparent that a minimal level of vegetation must be present before a watershed can be subjected to treatment. As mentioned above, to realize water yield increases in the ponderosa pine forests of the Southwest through cuttings, the watersheds must be stocked with basal area levels in excess of 100 ft^2 per acre (Baker 1986). No doubt, minimal levels of vegetation are required to increase water yields in other forest types in the Mountain West, but these minimal levels are largely unknown.

The percentage of a watershed subjected to treatment also affects the magnitude of water yield increases. In general, water yield increases are related to the percentage of a watershed cleared of vegetation, as illustrated by studies conducted in the mixed conifer forests of the Southwest (fig. 2). However, without a type conversion to an herbaceous cover, the increases in water yields typically decline as the mixed conifer forests regrow. At least 20 percent of aspen-covered watersheds in the Great Basin must be clearcut to increase water yield (Johnson 1984).

Many of the research efforts in the Mountain West that have examined water yield changes in relation to forest cutting only considered the maximum effects. More recent studies also have considered opportunities for water yield enhancement within the framework of multiple-use management, the major land management doctrine in the Mountain West. Potential for water yield increases should be viewed under these more "realistic" conditions, as well as in terms of the maximum. Furthermore, Bowes and others (1984) suggested that, in areas where timber production is marginal from an economic point of view (as it is in many subalpine forests in the Rocky Mountains and ponderosa pine forests in the Southwest), the economic returns may be improved by considering the joint production of both timber and water.

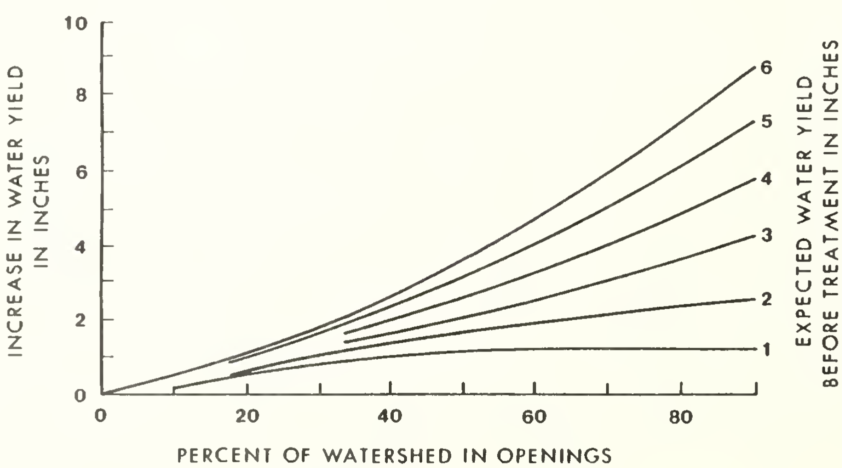

Figure 2—Potential water yield increases in mixed conifer forests in relation to the percent of a watershed in openings (Rich and Thompson 1974).

WATER QUALITY

Streamflows from undisturbed forested watersheds generally are considered to be high quality; little can be done to improve their quality. Therefore, most water quality research has been concerned with developing appropriate guidelines to minimize the adverse impacts of forest management practices on water quality.

Parenthetically, a number of laws are "on the books" to regulate the adverse impacts of forest management practices on water quality (Cubbage and Siegel 1985), but as pointed out by Brown and Beschta (1985), the success of these laws in minimizing the detrimental effects of forest management practices on water quality ultimately rests with the "on-the-ground" watershed managers.

Changes in water quality that accompany forest management activities in the Mountain West vary greatly with location, site conditions, and type of management. Much research has concentrated on studying the effects of timber harvesting on sedimentation and nutrient concentrations of the receiving water. Additionally, the impacts of chemical applications (fertilizers and herbicides) to forest lands on downstream aquatic ecosystems have been studied. A detailed discussion of all the potential consequences of forest management practices on the physical, chemical, and biological characteristics of streamflow is not possible within the scope of this paper. Therefore, we will consider the studies concerned primarily with timber harvesting activities.

Timber harvesting includes activities that can directly and indirectly affect water quality. The most serious water quality problems associated with timber harvesting in the Mountain West are due to yarding operations and the construction of roads (Megahan 1981). In general, impacts on water quality from the felling, limbing, and bucking of trees are negligible.

Logging road construction in Idaho, studied in detail by Megahan and Kidd (1972), increased erosion rates an average of 1.6 times (compared to undisturbed erosion rates) on areas affected by ground cable skidding. On the same areas, the erosion rates per unit of road constructed were 220 times greater than undisturbed area rates. The combined effects of yarding and roads, based on the entire watershed area sampled, increased erosion approximately 45 times.

Other investigations in the Mountain West also have shown the dominant roles of yarding and roads as sediment sources, especially on steep slopes (Haupt and Kidd 1965; Hetherington 1976; Leaf 1966). Fortunately, a wide variety of techniques and machines are available for yarding operations and road construction, many of which (when properly employed) can minimize damage and limit erosion.

The cutting of trees usually is followed by an increase in nutrient losses from the site and, therefore, increased nutrient loading to downstream water bodies. Following intensive timber harvesting activities, loss of nutrients (cations and nitrate) often increases from the logged areas; also, as discussed above, there frequently is an increased volume of surface runoff. The increased ionic loss, along with the increased surface runoff, tend to increase the total ionic losses more than ionic concentrations. However, if the forest grows back rapidly, the flushing of nutrients is normally short-term.

Careless timber harvesting operations that deposit large amounts of logging debris in water bodies can result in increased levels of biochemical oxygen demand (Ponce 1974). The subsequent depletion of dissolved oxygen, in turn, can adversely impact aquatic ecosystems. Oxygen levels also can be depleted in small streams when streamside timber cover is removed to the point where water temperatures increase in response to exposure to direct sunlight (Brown and Brink 1973). These examples illustrate some of the adverse water quality impacts associated with improper timber harvesting practices and, therefore, they need not occur.

DISTRIBUTION OF WATER YIELD

Many of the water resource concerns in the Mountain West are related as much to the location and timing of water yields as to absolute quantities. High-elevation watersheds generally yield most of the streamflow and are the primary recharge zones for groundwater in the region. Typically, this water is available during the spring-early summer period, largely as snowmelt runoff. Of critical importance to watershed managers are the annual extremes in the amount and pattern of the water yields.

Average hydrographs (fig. 3) for Fool Creek on the Fraser Experimental Forest in Colorado can be used to illustrate the changes in flows following a forest cutting. Fifty percent of the timber on the 714-acre watershed was harvested in alternate cut and leave strips (Troendle 1983; Troendle and King 1985). The two 15-year periods represented in this illustration are the pretreatment period, 1941-1955, and that portion of the posttreatment period least affected by hydrologic recovery, 1955-1971.

Advanced snowmelt in the strip-cuts on Fool Creek caused the hydrographs to rise more quickly than in the pretreatment period, with no subsequent effect on recession flows (fig. 3). Average peak streamflow discharge had advanced snowmelt, resulting in quicker recharge. Quite likely, the general hydrographic patterns observed on Fool Creek are representative of the effects of forest cuttings on many high-elevation, forested watersheds in the Mountain West.

Any discussion of stormflow-flooding relationships must be careful to separate onsite and downstream impacts and should define the magnitudes of the stormflow events as precisely as possible. Several watershed experiments have shown that the clearing of forests can increase onsite stormflow volumes and peak streamflow discharges to some extent (Anderson and others 1976; Hewlett 1982). However, there has not been the consistency of responses that has been observed in annual water yield changes. These differences in response are due, largely, to the fact that many factors (in addition to forest cover) influence the streamflow response of watersheds to large rainfall or snowmelt events.

Occasionally, forest cuttings in the Mountain West can increase onsite stormflow volumes and peak streamflow discharges that result from major storms. To illustrate, in analyzing the effects of a major storm in Arizona relative

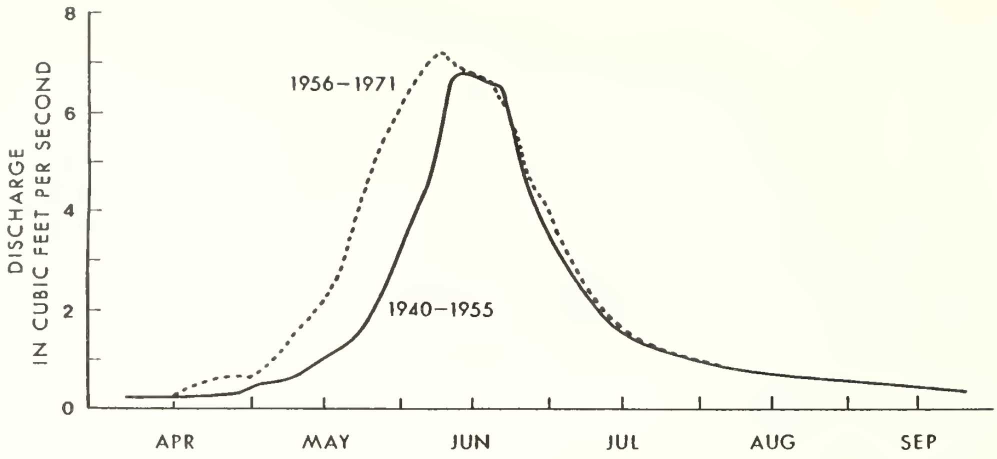

Figure 3—Average hydrographs for the Fool Creek watershed (Troendle 1983; Troendle and King 1985). Solid line is the average hydrograph for 1940-1955, before the forest cutting. Dotted line is the average hydrograph for 1956-1971, following the forest cutting.

to management practices in ponderosa pine forests, it was discovered that stormflow volumes, peak streamflow discharges, and, in some instances, total sediment yields were affected by forest cuttings (Thorud and Ffolliott 1973). Stormflow volumes and peak streamflow discharges increased (compared to controls) on watersheds that had been clearcut, strip cut, and thinned to 25 percent of the original stocking. Total sediment yield increased on the clearcut watershed. Although strictly limited to conditions on the study area, the information can be helpful in attempting to understand the relation of major storms to forest management practices.

On a broader scope, the hydrologic relationships between forest management practices and overwhelming meteorological events are difficult to isolate and quantify. Nevertheless, as widespread precipitation events become large enough to be associated with maximum streamflow amounts (sometimes floods) of a 50- to 100-year recurrence interval or larger, the effects of forest cuttings appear to diminish. Downstream flooding may result regardless of current onsite forest management practices.

Much of the early watershed management research in the Mountain West was stimulated by a desire to extend the period of high streamflow or increase the magnitude of streamflow during periods of low flow. To a large extent, the objective of this research was to determine whether a storage reservoir response could be obtained by cutting forest vegetation. Some increases in recession flows have accompanied water yield increases attributed to the clearcutting of forests. However, significant increases in flows during the driest months are rare. Forest management activities do not affect drought conditions and, therefore, do not impact low flows.

THE FUTURE

Interpretations of previous watershed management research in terms of the structures that will likely characterize the future forests in the Mountain West can provide information on the opportunities for enhancing water yield, quality, and distribution. Most of these interpretations are based, in large part, on the assumption that forest structures in the future will represent intensively managed young-growth stands, rather than old-growth forests.

No doubt, the future forests of the Mountain West will be more intensively managed in a multiple-use framework than the previous old-growth forests. As such, opportunities for water yield improvement are present. However, to achieve significant increases in water yields, a minimal level of vegetation must be present before treatment, and an appropriate percent of the watershed must be affected. A question that remains to be answered is: How well can we predict these changes in water yields?

It has been argued that, based on the evidence presented, the direction and approximate magnitude of changes in water yields due to the implementation of forest management practices can be estimated for planning purposes (Bosch and Hewlett 1982). Often, through applications of computerized simulation models, necessary refinements in the magnitudes of the estimated changes in water yields are possible. Many of the data sets collected in watershed management research to date have been incorporated into computerized simulation models to estimate water yield increases from forest cuttings not examined previously in the context of catchment studies. One example of such a computerized simulation model is WATBAL, specifically designed to predict hydrologic changes resulting from watershed management in the subalpine forests of the Mountain West (Brown and Brink 1973).

In much of the above discussion of the opportunities to enhance water yields in the Mountain West, it should be remembered that the estimates of water yield increases presented are based on the assumption that all of the treatable areas in a watershed (that is, the areas on which there are no constraints to the implementation of a water yield improvement program) will be treated at one point in time. Furthermore, it has been assumed that a uniform, single-treatment prescription will be applied to the treatable areas. These assumptions may be unacceptable. It will take time to achieve "full" water yield potentials, since large watersheds are involved, usually. Therefore, between the time that an operational water yield improvement program is initiated and the time that all treatable areas on a watershed have been treated, the magnitudes of the increased water yields will be less than the estimates of water yield increases assumed in the above discussion.

Perhaps this idea can be illustrated by an example:

Consider a 100,000-acre forested watershed. Assume that, under pretreatment conditions, the watershed is stocked uniformly to a basal area level of 125 ft^2 per acre. Thinning to reduce the basal area to 65 ft^2 per acre is proposed. Because the watershed is large, the total treatment cannot be applied at one point in time. Instead, the thinning prescription calls for one-sixth of the watershed (16,666 acres) to be treated every 10 years. With this scenario, the estimated water yield increase will vary throughout the treatment period, from less than 15 percent to nearly 40 percent of the estimate obtained in a one-point-in-time treatment.

Of course, an infinite number of scenarios are possible. Nevertheless, it will become necessary to select the most realistic time sequence to implement water yield improvement programs on large watersheds.

As previously mentioned, there is little that can be done to improve the quality of water from undisturbed watersheds. What can be done, however, is to develop appropriate guidelines to minimize the adverse impacts of forest management practices on water quality. Under "best management practices," the physical, chemical, and biological water quality characteristics should be maintained, with little effects on sedimentation and nutrient concentrations. Care must be exercised especially in yarding and road construction operations on steep slopes, where potential major problems in erosion and sedimentation occur.

The distribution of annual water yields is little affected by forest management activities. On high-elevation, forested watersheds, most of the increase in annual water yields (in average years) is on the rising side of the hydrographs, with no detectable effects on the recession side; additionally, average peak streamflow discharges can be advanced by a few days. With the occurrence of major storms, it has been observed that onsite streamflow volumes and peak streamflow discharges also can increase after forest cuttings, although these effects appear to diminish as widespread precipitation events become large enough to cause downstream flooding. However, if a watershed (for whatever reason) is largely denuded of vegetation and has bare soil exposed to the elements, the rates of surface runoff, erosion, and sedimentation can be higher than in a more protected watershed.

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ENHANCING RECREATION OPPORTUNITIES IN SILVICULTURAL PLANNING

Roger N. Clark

ABSTRACT

Recreation opportunities in forested lands are found in settings ranging from primitive unmodified wilderness to resort complexes. Many recreationists choose to engage in diverse activities in settings between these two extremes that often have evidence of resource uses such as timber harvesting and roads. To date, most areas that support timber management and provide recreation opportunities have been planned and managed with little attention to when and how recreation might best be integrated with other resource uses. Recreation use occurring in such areas has largely been an incidental result of road building and timber management practices. To expand opportunities for the future and to resolve the potential for onsite conflicts and compatibilities between recreation and other uses require an improved understanding of how recreation uses can be integrated into resource management programs.

INTRODUCTION

In general, recreational opportunities (other than in designated campgrounds) in forests managed for multiple uses are incidental results of timber management. There has been little intentional planning to manage sites jointly for recreation and other resource uses (with the exception of visual resources). Where attempts have been made to provide for both recreation and timber, management experience usually has not been documented. We often do not know what the consequences have been, whether they were positive or negative, and for whom.

Recreational uses often compete with timber, wildlife, fisheries, and other resource uses for the same sites (Clark and others 1985; Saunders 1985). An understanding of the relationships between recreation and other uses of forested lands is required for effective multiresource management. Important questions needing answers include: Who are the visitors of specific areas? What are the activities in which they engage? When? Where? What site characteristics do they prefer or require at recreation sites? What are the positive effects on recreation in areas where other resource uses are managed? How important are these effects from the perspective of recreationists? What concepts, frameworks, and management tools exist or might be developed to help mitigate adverse effects from other resource uses on recreation? The overriding question is not simply whether recreation should be or can be integrated with other resources uses, but where, when, and how such integration can best be achieved.

Most important decisions are made about recreation site management well before a tree is cut (or left alone), or a road designed, located, and constructed. There are a variety of perspectives that must be considered when deciding what is appropriate management at a site from a recreation perspective. These range from the Nation as a whole, to a geographic region, to a drainage, to a stand, and to the individual tree. For example, areas with national or international significance may require different approaches than areas with only local significance. Issues related to user needs, tastes, and preferences, use patterns, local and regional economies, and the relative availability of diverse recreation opportunities must all be considered.

This paper summarizes knowledge about relationships between forest resource management activities (timber in particular) and recreation opportunities. First, specific findings from the literature on relationships between recreation and other uses are briefly summarized. Second, several important concepts related to how recreation opportunities can be protected, enhanced, or created through silviculture are described. Third, an approach for considering recreation sites as habitat is discussed. And finally, suggestions and examples for using existing knowledge and concepts to manage recreation in areas where logging is planned are briefly discussed. In the discussion, I focus on situations where timber management is expected to occur. I do not specifically address potential effects from timber management on either wilderness or developed campgrounds. However, it must be recognized that there may be serious implications for silvicultural alternatives in or near those areas as well.

SUMMARY OF LITERATURE

My conclusion after reviewing the literature about the relationship between recreation and other resource uses is that current knowledge is insufficient to know what exactly should be done from a recreation perspective at any specific place for any individual, group, or activity. Answers to the questions posed above are generally incomplete in either research or management. No one set of prescriptions is available that can be applied in every situation.

The literature, however, does provide important and useful clues to help us understand how recreation relates to other resource uses. The findings should be of help in developing more rational approaches for considering recreation in the context of other values. Planners and managers will be required to find creative ways to integrate recreation concerns as timber management alternatives are developed. The information summarized here should help in making such decisions more responsive to recreational concerns.

—Relatively few studies have focused on direct interactions between recreation and other uses such as timber management—how and when recreation activities may be facilitated or impeded by other resource programs. We do know that some people participate in numerous recreational activities (camping, driving, hiking, hunting, boating, fishing) in areas where resource uses such as logging and livestock grazing occur (Clark and others 1982, 1984). A great deal has been written about the visual resource and people's preferences and about visual management in areas where resource development has occurred or is planned (Elsner and Smardon 1979; McCool these proceedings; USDA Forest Service 1977).

—Timber management affects recreation in various ways at different stages of operation (Clark and others 1984). During active harvest recreationists may interact with workers and equipment and the sounds, smells, and sights of logging. After logging, residuals such as roads, logging units, and slash provide either barriers or opportunities for recreationists.

—Some potential impacts on recreation activities from timber management practices have been documented: road development (Clark and others 1984; Lucas 1963); the location of log storage facilities (Faris and Vaughan 1985); noise (Anderson and others 1983; Harrison and others 1980); and inadvertent or planned destruction of campsites and trails during road building and logging (Clark and others 1984; National Trails Coalition 1985; Spring 1985). Some of these impacts affect recreational uses by modifying or destroying important recreational sites; others change the general character of the larger area in ways that discourage use by people who find such changes unacceptable.

—The basic values, preferences, and trip purposes of visitors to the area or site determine if interactions between recreationists and the effects of other resource uses are acceptable (Boster and Daniel 1972; Branch and Fay 1977; Brun-Chaize 1976; Clark and Stankey 1979a; Levine and Langenau 1979; Palmer 1979).

—Studies show that people's preferences for recreational settings are diverse and range from sites that are primitive, with no evidence of human activity, to sites intensively developed for resource use or recreation. Such diversity is a theme found frequently in the literature (Manning 1979; Stankey 1977). Providing an array of diverse opportunities ensures that people can find opportunities consistent with their desires (Clark and Stankey 1979a).

—The incompatibility of resource uses and primitive forms of recreation (wilderness use in particular) has been well documented (Hendee and others 1978). People seeking primitive recreation opportunities generally choose not to visit areas managed for other resource activities.

—For other recreationists, the chosen site may include evidence of other resource activities. They not only use areas where roading, logging, and other uses occur or have occurred, but they also prefer many of the attributes and activities associated with such areas; some changes (roads, turnouts, openings, fences, water impoundments) either are not seen, or are accepted and used (Clark and others 1984; Field and others 1985; Gundermann 1981; Koth and others 1982; Litton 1974; Lockett 1980). Roads built for access to timber, minerals, and range are commonly used for recreation, either as access to opportunities people desire or as an end in themselves, such as driving for pleasure or exploring.

—The appropriateness of other resource uses from a recreational perspective depends on the nature and extent of those uses, for example, the size and number of partial cuts or clearcuts, and the design and distribution of roads in an area (Benson and Ullrich 1981; Clark and Downing 1985; Fischer 1965; Haakenstad 1976; Hanstein 1967; Lucas 1963, 1970).

—The intensity of forest practices in an area is more important to some people than the distance from logging (Romashov and Dudnik 1981).

—Acceptance of logging depends on how it is done (Becker 1978). Some people do not notice evidence of logging (Echelberger and Moeller 1977); smaller cutting units generally are more acceptable (Clark and others 1984; Vesikallio 1980).

—We are unable to predict with certainty how changes in an area will affect people's choices (Stankey and McCool 1985). Not all users who find changes unacceptable will stop using the site or leave the general area (people will often develop coping behavior to deal with dissatisfying conditions). The nature and extent of change (the "threshold of disruption") that will make people not use sites must be determined (Clark and Downing 1985; Clark and others 1982).

—There is often a lack of correspondence between expressed recreational preferences and actual behavior. For example, often people will camp in areas with more or less tree cover than they prefer (Hancock 1973).

—Favorite and often visited sites are definable and people form strong attachments to them (Clark and Stankey 1985; Clark and others 1982, 1984). In many areas, recreationists have established their own campsites, and they are concerned about the relationship between other resource uses and these sites; many want their favorite campsites protected from the effects of logging (or other resource uses) (Clark and others 1984; Clark and Stankey 1986; Downing and Clark 1979).

—The type of access is the key to most recreation and exerts strong influences on use patterns. As a group, people who recreate in roaded forest lands want roads of various designs and standards, but they do not need to be paved in all cases. Many people do not want any more roads in the area they presently use; people seem to like the status quo with respect to roads in their favorite areas (Clark and others 1984).

—Site attributes affect, in many often predictable ways, how recreationists make choices (Stankey and McCool 1985). Some attract (scenery) or detract (bugs and poisonous snakes); some facilitate (sheltered boat anchorages) or constrain (steep terrain) (Clark and Stankey 1986). Attributes that have been determined to be particularly important in dispersed areas include: water (marine, riparian, lakes, streams), trees (of various species, densities, and age), flat areas, naturalness (or natural appearing), and privacy from others not in own party (much like wilderness users). A knowledge of these attributes will aid in determining what is possible, desirable, or necessary at a particular location to protect, enhance, or create opportunities for recreation.

—A key problem for recreation management is providing sufficient information about the range of recreational opportunities available in an area so users can make choices consistent with their preferences, requirements, and trip purposes (Clark and Downing 1985; Clark and Stankey 1979a; Stankey and McCool 1985). Education and information are important tools for ensuring that people's expectations are met onsite (Simpson and others 1976). Silviculturists have an important role in helping to develop the necessary information.

In summary, the literature provides general, yet useful information for determining the implications of forest management actions on recreational values. Although the findings and conclusions from research completed to date do not allow us to specify what exactly should or should not be done at a particular location, they do help sensitize us to potential concerns of a diverse recreational clientele.

CONCEPTS TO AID IN MANAGING FORESTS FOR PEOPLE

From this brief overview of the literature, it is evident that a holistic, systems perspective is needed to help integrate recreation and other resources. The recreation resource is unusual, compared to some resources, in that it is represented by the combination of all other physical and biological resources and how they are managed. The complex interrelationships among these resources have important implications for recreational opportunities and use (Clark and Lucas 1978; Clark and others 1985).

The questions posed earlier in this paper can be resolved only by adopting a more holistic perspective that recognizes the nature of potential onsite interactions between recreation and other resources. Past management has focused primarily on recreation apart from other uses; expanding the opportunities for the future and addressing the potential for onsite conflicts and ways to resolve them require an improved understanding of the complex system of which recreation is an integral part.

I argue that we must understand the complex system of which recreation is a part. There remains, however, a lack of comprehensive knowledge and site-specific guidelines to facilitate effective integration of recreation and other resource uses at the site level. With the exception of visual resource management, there are few tested approaches for managing what often appear to be inconsistent uses at a specific location. Several important concepts that are helpful in understanding some of the questions that must be considered to achieve effective onsite integration are briefly described here. Although none of these concepts will give specific answers about what is appropriate, they can help develop more rational and explicit approaches for resolving undesirable effects from interactions between recreation and other uses. Readers should review the references in detail to gain a more complete understanding of these concepts.

The Recreation Opportunity Spectrum (ROS) (Clark and Stankey 1979a) helps identify ways to provide recreational opportunities ranging from primitive and undeveloped to intensively developed places with modern conveniences. The ROS describes a range of recreation settings and recognizes the potential compatibility between recreation and other resource uses for some portions of the continuum (Brown and others 1978; Buist and Hoots 1982; Clark 1982; Stankey 1977). In some areas, the nature and extent of other resource uses may preclude most remote and natural recreational opportunities, yet allow use by people who find evidence of other resource uses such as roads and timber cutting acceptable. In other areas, opportunities for semiprimitive and, perhaps, some primitive recreation may be possible even in or near areas where silvicultural activities are planned. The purpose of the planned project (whether for timber harvest or wildlife habitat improvement, for example), the scale of the project, and how it is executed over time and space, in large part determine possible outcomes for recreation. The ROS can be used to help identify management objectives for an area (whether the area should be managed for semiprimitive or primitive recreation, for example) and judge the acceptability or unacceptability of management practices from a recreational perspective.

The Limits of Acceptable Change (LAC) considers an approach for determining the acceptable levels of resource impacts (Stankey and others 1985). The LAC helps specify biophysical and social conditions that must be maintained to protect recreational and other resource values. Although initially applied in a wilderness setting, the approach is applicable across the ROS and should be useful in determining acceptable silviculture and roading opportunities with regard to recreation.

The nature and extent of changes acceptable to users varies. People seem to have different expectations for macro- versus microsites (Clark and Downing 1985; Clark and others 1984). The microsite seems more susceptible to adverse changes; that is, management activities acceptable in the general (macro) area may not be at the campsite (micro). Changes can be evaluated both in terms of their intensity (change per unit area) and their extensity (proportion of area affected). The importance of changes must be evaluated from a recreationist as well a management perspective (Clark and Stankey 1979b).

MANAGING RECREATION HABITATS

Many of the concepts from the literature on wildlife habitat (Thomas 1979) seem applicable when considering recreation. Indeed, human behavior is often influenced by the same bio-physical conditions that affect wildlife behavior. The places where recreation occurs are a fundamental component of recreation and in many respects represent recreation habitat that can be purposefully or inadvertently influenced by management (Clark and others 1984). I suggest below how some well-established wildlife concepts may help us understand human recreation behavior when managing for these recreation habitats. Understanding these concepts should help silviculturists evaluate the potential effects of alternative prescriptions for recreational opportunities.

—"Home ranges" within which most recreation occurs can be documented. Recreation tends to be community-centered for resident populations. Other recreationists are migratory (tourists) and often frequent sites well beyond their usual home range. The size of the home range is influenced by the relative availability of recreational opportunities desired by the population, competition among users for these opportunities, and mode of travel, among other things. When considering silvicultural options for recreation, it is important to think in terms of specific populations, rather than some vague, ill-defined public.

—"Travel corridors" are definable. Access is influenced by established travel routes (roads and trails), and physical-biological conditions (such as steep slopes, dense vegetation, and bodies of water). Knowledge of present, as well as potential, travel corridors should help in predicting the effects of silvicultural practices on recreational use patterns.

—People are "territorial." They form strong attachments to favorite and most often visited sites and generally want them left in their present condition. It is of utmost importance to identify the location of these sites prior to any on-the-ground management, either for recreation or other resource uses.

—People choose among a combination of setting, activity, and experience opportunities to satisfy their diverse desires. These opportunities can be considered as the recreational "browse" within the home range. Silviculturists are in a position to influence the browse, so the consequences of planned changes should be explicitly identified and evaluated.

—"Site attributes" influence how people make choices and how they can use the forest. Some attributes constrain activities and others facilitate. Knowledge of how site attributes influence recreational choices can help in designing and locating silvicultural modifications.

—"Hiding cover" is important particularly at campsites. People desire privacy and quiet and generally want to be separated from those not in their party, as well as from the evidence of other resource uses (such as clearcuts and main roads). This seems to be as true for people in dispersed roaded areas as it is for people who prefer wilderness. Such isolation can be achieved by appropriate screening or maintaining adequate distances between recreation sites and other uses. Care must be taken when managing roadsides for visual concerns (for people driving through an area, for example) not to inadvertently destroy hiding cover at nearby campsites.

—"Edges" seem to influence recreation use. For example, sites near openings (whether natural or artificial) and water (lakes, riparian, and coastal areas) appear more frequently used than other locations. Such locations often provide opportunities for temperature control ("thermal cover or exposure").

—"Essential or critical habitat" or sites likely exist for some types of uses. For example, in marine areas where recreationists need access to the shoreline for upland activities, suitable anchorages and absence of offshore rocks and shoals are required. Such locations need to be identified so that they can be protected, if necessary.

—Expressed site "preferences" may differ from actual site "requirements." Requirements are essential elements to support recreation (flat ground for camping, water for boating); preferences may operate in addition to them and add quality to an experience if they can be achieved.

—Recreational opportunities must be "effective" both in terms of their usability (flat areas for campsites) and time and distance from communities (they need to be within the home range). Providing a supply of superlative recreation sites well outside the bounds of the usual home range may not be satisfactory to either present or future users.

—As a group, people like "diversity" in terms of sites they like to visit and activities in which they like to engage. Alternative silvicultural prescriptions vary in how they affect recreational opportunities; many options may be possible to provide the diversity people desire.

—Habitats are "dynamic" with natural changes and human-caused disturbances influencing the nature of recreational settings. Indeed, the type and location of recreation activities can change with physical alteration. Such change can be managed both spatially and temporally to achieve desired goals.

—"Adaptation" occurs as recreation habitats are modified. Recreationists can stay and alter their expectations (as long as basic requirements are met), or move on (thus becoming displaced) if the changes exceed their accepted limits. Either outcome may be appropriate. But consequences should be evaluated in advance to ensure that irreplaceable opportunities will not become "threatened," "endangered," or destroyed.

The recreation habitat approach helps focus management on sites (present and potential) and helps evaluate how resource management activities (as well as natural changes) will affect these sites and the choices recreationists make. A benefit of this approach is that it treats recreation at the same level of resolution as other resources and recognizes that recreation is part of a complex and dynamic resource system.

APPLYING KNOWLEDGE AND CONCEPTS

There are three basic challenges in providing quality recreation habitats: protect existing sites, enhance existing sites, and create new sites. Each challenge requires knowledge about existing and potential sites and recreation use patterns, demands, preferences, and requirements. To achieve desired goals, silviculturists must consider primary and secondary effects from silviculture on recreation habitats; they must keep in mind the role of the stand, site, and tree to recreationists both now and in the future.

In the absence of specific answers and guidelines to apply at the site level, there are several important things that should be considered when developing silvicultural prescriptions.

—There is a need for inventory focused on existing as well as potential recreation sites. Fieldworkers need to be alert for evidence of recreation sites and uses during inventory for other resources and layout of roads and cutting units. It may not be necessary to protect all such sites, but decisions need to be made explicitly.

—Silviculturists need to work closely with other specialists to define management goals and ways to achieve them. The home range concept implies that people from various jurisdictions must work together in this endeavor.

—Possible silvicultural options range from silviculture for recreation, with no timber considerations; to silviculture for recreation, with timber as a by-product; to silviculture coequally for both; to silviculture for timber, with recreation as a by-product; to silviculture for timber, with no recreation considerations. Most past resource management has been focused on the latter two categories, a situation that has resulted in some public mistrust of multiple-use management.

—Various types of plans (transportation, viewshed, vegetation, project) may give direction about the most desirable and feasible alternatives for recreation. Such plans, hopefully, will have had substantial public involvement from users with diverse preferences and requirements.

—A variety of approaches have been proposed for mitigating the effects of large- and small-scale resource development on recreation. Roading and silvicultural options include spacing, design, and timing considerations (Anstey and others n.d.; Ashor and McCool 1984; Brush 1976; Clark and others 1984; Duffield 1970; McGee 1970; USDA FS 1977). Even in areas scheduled for road building and timber harvesting, the identification and protection of recreational sites is important (Clark and others 1984; Clark and Stankey 1986).

—Although most attention has been focused on mitigating the adverse effects on recreation from timber harvesting and other uses, enhancing existing or creating new opportunities for many types of recreation may be possible in areas where resource development is planned. For example, locating and designing timber harvest and roads specifically for recreational uses—turnouts for parking, access to desirable vistas, openings for views or camping—and managing understory vegetation to either increase or reduce screening would be appropriate in some places, for some activities, and for some people.

Tools To Help Do the Job

Most if not all forest management activities will affect recreation. What is less clear is exactly what the effects will be from a particular action, at a specific place, for a particular user. Some of the things that can be manipulated to protect or create recreation habitats and influence use are listed below. The type of modification must be evaluated based on how it will achieve desired objectives.

Changes in the macroarea:
- —visual resources (see McCool, these proceedings)
- —transportation system (road and trail networks)
  - —location (spacing, alignment)
  - —design standards
  - —management (maintenance, regulations, closures)

Changes at the microsite:
- —access to campsites and other attractions
- —overstory vegetation
  - —location of trees
  - —age class
  - —stand density
  - —species
  - —openings within a stand
  - —buffers and islands
- —understory vegetation
  - —location
  - —density
  - —species

Management approaches:
- —type of harvest system (skyline, tractor, helicopter)
- —timing and duration of logging operations (day, season, decade)
- —slash management (screening, visual resource, functional impacts on use)
- —restrictions on recreation use during or after logging
- —by-products of logging for recreation
  - —landings to create vistas or flat areas for camping
  - —roads of various design to provide access and opportunities to explore
  - —gravel pits or storage areas for parking or camping for large groups
  - —stumps as barriers or attractions

Examples

In the two brief examples described below, I attempt to show how many considerations must be included to achieve desired objectives for recreation. Both examples assume that joint goals (recreation and other resources) have been determined for the microsites and macroarea. Silvicultural prescriptions can help achieve these goals.

If the management goal in an area is to protect existing recreation sites and minimize interparty contacts, the following actions might be appropriate: The transportation system could be designed to isolate sites from main roads to maintain hiding cover. (There may be significant differences and possibilities during old-growth conversion versus second growth management in this regard.) Locate new roads in appropriate locations; close old roads that interfere with recreational requirements. If possible, maintain traditional access to existing sites. The overstory might be managed to leave islands of trees at existing sites or buffer strips between sites and roads or cutting units. Thinning to open up areas, or not thinning to maintain hiding cover, may both be possible. Short periods of logging might be considered to minimize intrusions on area users, particularly if there are no alternative locations within their home range. Understory vegetation can be managed to enhance screening at edges of sites for hiding cover. In other cases it may be necessary to encourage undesirable vegetation (from a recreational perspective) to discourage use to protect other key values such as historic or fisheries. These options imply that a thorough inventory has been conducted so that existing recreation sites and use areas have been located and described.

If the goal is to increase number of sites, perhaps because there is an insufficient supply, the following might be considered: Conduct an inventory to identify potential locations (using appropriate site attributes) that would provide quality recreational opportunities. Locate and design the transportation system to provide access to attractions (water, flat areas, vistas). Maintain a range of road types (various standards and designs) and areas without roads as user demands dictate. The overstory can be managed to provide islands or openings at target sites. The schedule and rate of harvest might be adjusted to focus on priority areas. Understory vegetation can be manipulated to encourage desirable species to enhance the site (screening, berries). Or, as in the previous example, undesirable species might be needed to decrease use and protect other resource values. Creating flat areas or barriers during logging operations (if such places are in short supply in an area) might also be considered.

In either example, alternative road locations must be well conceived in advance. Access is of critical importance in determining use patterns and who will use and not use an area. It is hard to turn off use once it is established. Some road locations may help provide diverse recreational opportunities as well as protect other resources such as anadromous fisheries. Other alternatives may be detrimental for one or both of these resources (Clark and others 1985).

INFORMATION NEEDS

Management of forested lands for recreation and other uses can be improved with additional information from management and research. The current knowledge base provides general guidance for managing recreation in concert with other resource uses. More complete information is needed about site-specific relationships. A basic need for effective integration of recreation with other resource uses is an improved information base about both the existing and potential opportunities and their users. Such information would help in evaluating tradeoffs and monitoring trends and effects of changes. Baseline information about recreational use and opportunities can be evaluated through the concept of "home range" to distinguish between local (resident) needs and uses versus those of tourists (Clark and Downing 1985; Clark and others 1985).

Improved information about relationships between recreation opportunities and timber harvesting will facilitate the development of recreational management strategies consistent with public desires. We must move beyond studies of basic recreation preferences and focus on the acceptability and unacceptability of resource management practices in the context of real places. Information of this type is presently lacking to any significant degree.

Specific topics requiring further study by researchers and managers are: a better inventory system that addresses multiresource interactions (McCool 1983); national, regional, and local data about the patterns of recreation visitation (Clark 1980; Clark and Lucas 1978; Clark and others 1984; James and others 1972; Wenger 1984); and a well-designed, well-conducted monitoring program for evaluating the effects of other resources on the amount and use of recreation (Stankey and others 1983).

The need to define critical recreational habitat and attributes associated with important recreational sites has been discussed (Clark and Stankey 1986; Stankey and McCool 1985); such information is essential for evaluating the effects of resource management alternatives on existing and potential recreational sites.

Research to address the above topics should involve researchers from various disciplines (including silviculture, recreation, engineering, and wildlife). There is a need for demonstrations to show what is possible and to test the merits of past research and management experience. This is neither a research problem nor a management problem, but one shared by both.

CONCLUSIONS

Alternative silvicultural and road building approaches vary in their ability to provide a range of high-quality recreational settings. Spacing, timing, and design alternatives must be considered in light of their impacts on large areas, as well as on specific sites.

The potential for protection, enhancement, or creation of recreation through creative silvicultural practices should not be used as an excuse to log. But once a decision is made to harvest timber in an area, providing high quality recreational opportunities may also be possible. In other situations, developing silvicultural prescriptions expressly for recreation might be the most appropriate alternative (Clark and others 1984).

To understand when and how recreation can be effectively integrated with other resource uses requires that potential conflicts and compatibilities be determined early in the planning process so that appropriate short- and long-term onsite management objectives and standards can be developed. Forest and stand conditions change through time and may provide different benefits for different clientele, at different times. Some users may inadvertently be alienated unless we recognize what the forest is providing; when, how, and for whom; and how possible changes will affect them.

Relatively little is known about the complex nature of relationships between recreational opportunities and use and other resources. We must better understand the relationships among the social, biological, and physical systems that are part of, or influenced by, the recreational system. These relationships are dynamic, and improved procedures must be developed to achieve the best possible mix of commodity and noncommodity resource uses. Better approaches are necessary to monitor and evaluate effects of future changes so that resource management programs can be modified as appropriate.

Management often cannot wait for answers to questions such as those posed earlier in this paper. Some suggestions for minimizing conflicts and maximizing compatibilities include: complete inventories of existing and potential opportunities (often this can be done in conjunction with other fieldwork); be explicit about assumptions and objectives regarding recreation; document and share experiences about what does and does not work; develop scenarios to protect, enhance, and create recreation opportunities; and seek information from users who are in the area to test your assumptions. We tend to be provincial, so think beyond your geographic area of responsibility; recreationists, like deer, do not tend to recognize artificial boundaries.

Because so many resource changes that affect recreation are outside the control of recreation managers (for example, the location and design of roads, and the nature and extent of other resource uses), integrated, multifunctional management objectives are required. Specific objectives are necessary for enhancing positive opportunities and mitigating adverse effects when onsite interaction between recreation and other uses is desired or expected.

Silviculturists cannot do the job alone; many specialists must collaborate to identify the range of possibilities and ways to achieve desired goals. There are no specific answers or cookbooks; judgments will be required and you will likely never get it "right" no matter how hard you try. Someone or some group will likely lose in most circumstances, regardless of how creative you are. The key is to make sure that possibilities and tradeoffs are made explicit before actions occur, so that the best compromise possible can be achieved in advance of any on-the-ground activities.

The bottom line is that most things forest managers do, whether planned or not, will affect recreational opportunities. Our publics react to this reality as they anticipate or discover undesirable changes in areas they value. Professionals must have empathy and be sensitive to the fact that what they do affects people and their recreation habitats. Failure to do so likely will lead to further polarization and loss of credibility.

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SESSION 2.

The Analysis Tools

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Because of the great variability encountered in forests of the Mountain West, analyses of stand conditions are needed to decide what treatments are needed to meet management objectives. This section presents an array of analysis tools that are available to help with this process. Stand analyses can link silvicultural practice with the decision to implement a cultural treatment in a stand. The tools used to analyze treatment needs also provide the means to evaluate success. When analysis tools are properly used, better decisions and more effective treatments result.

First among the analysis tools for young forests are stand density guides. Stand density is a key element, along with species composition and stand structure, in making most analyses. Stand density can be expressed in a wide variety of ways, and the papers in this section present some of the most commonly accepted methods. Second among the analysis tools are guides for multiple resources of young forests. The rapidly emerging importance of a broad array of resources makes it imperative that they be an integral part of the analyses. Papers in this section provide guides for wildlife habitat, forage production, water, and visual resources. Third, and one of increasing importance in conducting analyses, is the use of models to help predict what will happen in the future by simulating normal processes. Papers in this section describe growth and pest models available for these forests. The values derived from growth simulation can become even more useful by linking pest models to growth and yield models where forests are threatened by these damaging agents.

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DIAGNOSIS OF TREATMENT NEEDS FOR TIMBER STAND CULTURE IN THE MOUNTAIN WEST

John R. Naumann

ABSTRACT

Identifying treatment needs for immature stands is a more challenging problem than choosing treatments for stands at or beyond rotation age. As a starting point, forest managers must describe a desired residual stand in relation to resource needs, insect and disease conditions, and the surrounding forest. The most accurate analysis of treatment needs results from a combination of experience, silvicultural guidelines, and first-hand knowledge of the stand. Stand attributes that relate to wildlife habitat, water production, viewing, and forage are becoming as important as those diagnostic measures that describe growth and yield. An adequate analysis of treatment need will help the future forests of the Mountain West live up to their potential.

THE DIAGNOSIS OF TREATMENT NEEDS

Foresters analyze stands for different reasons. Simply describing a stand is a form of analysis. Evaluating stand performance in comparison to management objectives or site potential is carrying the analysis further. These analyses, however, are most useful when they determine treatment needs. Although foresters have developed and refined analysis tools like stand density guides and growth models, little attention has been given to the analysis process itself.

In the Mountain West, stand management has been practiced widely only since the 1950's. Management history is limited to 30 years or less for many sites. Early practices were not well documented, and it is therefore often difficult to draw valid conclusions from observing present stand conditions. Without reliable examples of stand performance, we are left with a need for analysis tools and a process through which to apply them.

Analyzing immature stands is more complex than analyzing treatments needed for stands at or beyond rotation age.

1. Investments in stand culture are receiving increasing challenges. The advantages of controlling stand composition and growth are not adequately valued in most economic analyses because they are not well quantified. Neither are the monetary costs of deferring intermediate treatments over the 60- to 120-year lifespan of managed stands in the Rocky Mountain West.
2. The role of stand culture in managing multiple forest resources must be defined. Many times we do not culture stands solely for timber production. Wildlife habitat, recreation, range, and watershed values can all be affected by intermediate stand treatments.
3. Intermediate treatments must be responsive to current and potential insect and disease conditions. These biological factors are an ever present force in the forests of the Mountain West, but sometimes we ignore their effects in stand level decisions.
4. The broad direction furnished by management plans and silvicultural guides seldom tailors treatments to actual stand conditions in terms of time and space. For example, all stands cannot be thinned when a yield table indicates a thinning is due.
5. The treatments that we apply must be visibly successful because we will live with the results for a long time. The forest after treatment—the residual stand—is the most important element of the analysis.

Silvicultural guidelines can indicate treatments. Some guidelines, such as those written for individual species, provide ready made prescriptions based upon certain stand characteristics. Such guides often do not address mixed species stands. Moreover, they imply that timber management is good resource management. Thomas (1979) has recognized the pitfalls of this assumption for wildlife management in the Blue Mountains. His concerns could be extended to other forest resources in most areas of the Mountain West. Guidelines can account for one resource at a time but are difficult to develop for a variable mix of resources.

Stand condition should be an element of most analyses. Stands can be perceived as too dense or too sparse, healthy or diseased, growing too slowly, or composed of undesirable species. Often stand condition is viewed in a qualitative rather than quantitative way. We need to know what stand density, species composition, level of disease, and growth rate are acceptable. A more difficult question is: What stand condition is tolerable as a minimum if limited budgets do not allow treatment of all undesirable situations?

Stand analysts must be futurists. A good analysis process begins with a vision of what the forest should look like when the project is completed. There are several reasons for clearly defining goals in terms of the future forest.

1. Treatments must relate to some specific result. For example, the objective should be to retain a specific stand density rather than to simply thin the stand.

2. End results are easier to negotiate with managers, resource disciplines, and the public during project design than are the activities and impacts associated with achieving those results.

3. We need to know when we have accomplished our goals, and we should have some basis for evaluating our performance.

How does one describe the future forests of the Mountain West as a model for stand diagnosis? That depends upon an ability to use what is known about forest growth, composition, and structure. It requires a knowledge of forests as habitat for wildlife, as water producers, as scenic vistas, and as a crop of usable wood products.

To analyze treatment needs well requires an adequate set of diagnostic measures. Traditional diagnostic measures have been those related to timber production. We have been applying treatments that redistributed growth to crop trees, produced salable-sized products, and developed wood of high quality and value. Now many foresters are asked to develop stands of a character and composition that will benefit a wider range of forest resources. Diagnostic measures are now expressed in terms of hiding or thermal cover, diversity of view, or quality of forage. Many of these measures are not easily quantified, and intermediate stand treatments that affect more than the timber resource are difficult to justify by traditional means.

Determining treatment needs results in different levels of accuracy, depending upon the kind of analysis used. Diagnostic accuracy refers to how well the proposed treatment fits the actual stand situation. In practice the analysis with the least chance for accuracy is one that simply matches a stand description to the treatment assigned to that kind of stand in the management plan. The most accurate determination of treatment need results from an indepth analysis by a qualified team that has the advantage of reliable stand data, predictions from growth models, and firsthand familiarity with the site. Between these extremes, actual practice finds diagnosis of treatment needs based upon some matching of stand data, silvicultural guidelines, and professional experience. An experienced forester with some guidelines in mind and some data in hand can visit a stand and make an acceptably accurate diagnosis of treatment need. When one or more of these elements is missing, accuracy suffers.

In the forestry business, mistakes are expensive and often irreversible in a lifetime. With a good analysis, we need not take the risk associated with guesswork and inaccuracies. By taking such risks, we stand to lose more than time or money. The more important costs are professional credibility and resource productivity.

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RELATIVE STAND DENSITY: WHY DO WE NEED TO KNOW?

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Bruce C. Larson

ABSTRACT

Measures of relative stand density assess crowding in forest stands by comparing the growing space available per tree with growing space available to trees in open-grown conditions or in maximum density stands of the same species composition and average tree size. Because current measures differ in their handling of tree size and reference line, and do not provide identical results, the measure used should reflect management objectives. Better understanding of the effects of stand structure and species composition on growth responses will improve these tools.

WHY RELATIVE STAND DENSITY?

Two concepts are key to understanding measures of relative stand density: growing space and crowding. Measures of relative stand density assess crowding in forest stands by comparing the growing space available per tree with the growing space available to trees of the same size and species in some reference condition. Growing space is the combination of all resources required for a particular tree's growth: light, water, nutrients, climate, soil properties, physical space. The minimum growing space requirement of a tree is the level of resources required for the tree to survive; the maximum growing space requirement is the upper level of resources the tree can use at its present size. A tree's growing space requirements increase as it grows. An open-grown tree always has access to its maximum growing space for a particular site; crowding occurs when the density of a forest stand exceeds the level at which each tree can obtain its maximum growing space, and natural mortality results when the minimum growing space requirements of all trees exceed the resources of the site. Relative stand density measures assess crowding by estimating the growing space per tree and comparing it to a reference level.

Measures of relative density improve the precision with which we are able to measure crowding. When accompanied by specifications of residual structure, such as the ratio of before-treatment to after-treatment diameter, and of a thinning interval, they are the most powerful tools we have to control intermediate treatments of forest stands. They also may improve our ability to predict the response to these treatments, whether our interest is in wood production on a stand or individual tree basis or in changes in water yields, forage production, wildlife habitat, or the esthetic characteristics of treated stands.

Responses of a stand after intermediate treatment depend on stand age and site quality, and on the structure, absolute density, tree size, and species composition of the residual stand. Relative density measures are based on the relationships among these residual stand variables and hence measure crowding better than any one or two of these variables. In addition, relative density measures have been shown to be nearly independent of stand age and of site quality as measured by site index (Reineke 1933; Chisman and Schumacher 1940). However, this independence has been questioned by Zeide (1985).

CURRENT MEASURES: MANY TOOLS, ONE CONCEPT

All of the measures discussed here are based on a mathematical description of stand development—often, development in the absence of disturbance or development at the maximum levels observed in a particular type. This mathematical description of stand development becomes the reference level for the relative density measure. The reference line often is portrayed graphically as a curve of maximum or average undisturbed stand development. Comparisons of individual stands to this reference level are based on an average tree characteristic, such as average diameter or average volume; that is, the reference line or equation of most measures of relative stand density is a stand development curve on axes that exclude time. An underlying assumption is that stand development proceeds in the same way on good and poor sites but occurs more rapidly on the good ones.

Figure 1 shows plots of stand development in Douglas-fir *(Pseudotsuga menziesii)* using data from McArdle and others (1961). In figure 1A, stand development is portrayed as the increase in basal area per acre as stand average diameter increases. In figure 1B, stand development is displayed as the reference line in a stocking guide using the format proposed by Gingrich (1967) and recently adopted by the Forest Service, U.S. Department of Agriculture (Ernst and Knapp 1985). In figure 1C, the same data are displayed using the format proposed by Reineke (1933). In figure 1D, logarithmic axes of average tree volume and numbers of trees per acre are used as suggested by Drew and Flewelling (1979). In figure 1E, axes of average dominant tree height and numbers of trees per acre are used, which is similar to the format suggested by Wilson (1946).

The power of measures of **relative** stand density is apparent if we use any of these graphs to compare absolute to relative measures. If we trace the line representing a basal area of 120 ft²/acre (28 m²/ha) across any of these graphs, we see that it is quite close to the curve in stands with small average diameters but represents a smaller and smaller proportion of the reference level as the stand grows. Using numbers of trees would only reverse the problem; 500 trees/acre (1,235/ha) would be a small proportion of the reference level in a stand with small trees and far more than the reference level in a stand with predominantly large trees—that is, measures of relative stand density assess

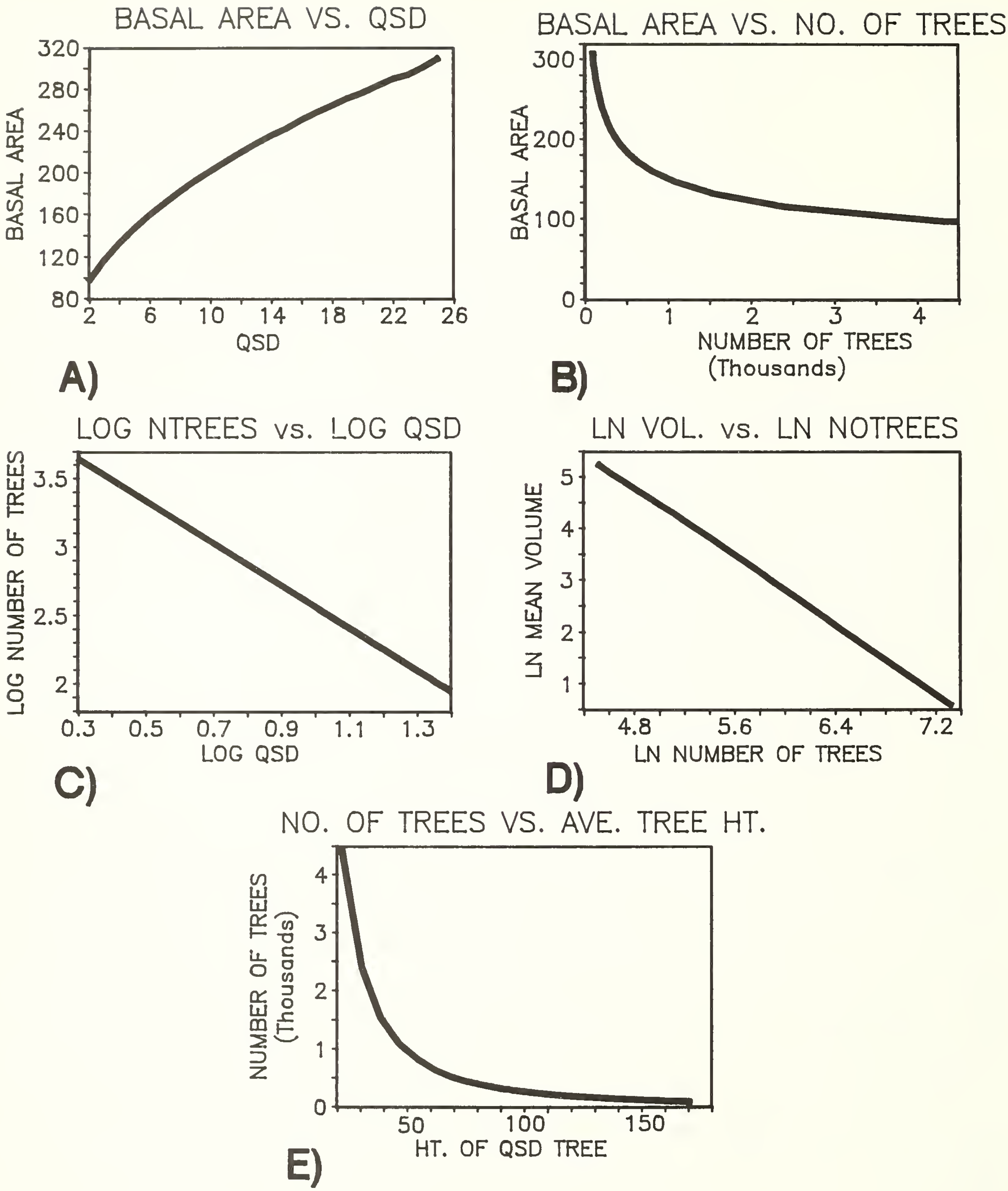

Figure 1—Graphic portrayal of the reference lines for various measures of relative stand density, using data from McArdle and others (1961). A, The increase in basal area per acre as *QSD* increases. B, The stocking guide format: the increase in basal area per acre as the number of trees per acre decreases. C, The decrease in the number of trees per acre as *QSD* increases, after Reineke (1933). D, The increase in the mean volume per tree as the number of trees per acre decreases, after Drew and Flewelling (1979). E, The increase in the height of the average tree as the number of trees decreases, a line related to the measure proposed by Wilson (1946).

competition in the context of the biological changes that occur with stand development.

The concept is like that of two capacities on the side of a school bus: "40 ADULTS/60 CHILDREN." If we know that there are 40 passengers on the bus, we do not know how crowded it is. If we know that the 40 passengers are adults, then the bus is full; its relative density is 100 percent. If the 40 passengers are children, then the relative density is 40/60, or about 67 percent, and there is more room on the bus.

The primary practical use of relative density measures to date has been to control intermediate treatments of forest stands. The development and use of relative density guidelines for this purpose is outlined in a recent Forest Service publication (Ernst and Knapp 1985) and two other papers in this volume (Puuri and others; Long). Traditionally, these guidelines have been associated with timber production, but there is a clear conceptual relationship between relative density and a variety of other stand responses. Several other papers in this volume discuss these relationships (Winn and others; Bedunah and others; Troendle; McCool and Benson). Measures of relative stand density are also used as predictors of stand and tree growth in such models as PROGNOSIS and DFSIM.

Few reports compare relative to absolute measures of stand density for the prediction of stand or individual tree growth after intermediate treatment; none compare the two for purposes other than timber production. Nelson and Brender (1963) compared Reineke's Stand Density Index, Stahelin's (1949) stocking measure (a measure of relative density based on tree-area ratio), initial merchantable cubic foot volume per acre, and basal area per acre as predictors of 5-year periodic merchantable cubic foot volume growth in natural loblolly pine (*Pinus taeda*). They found no significant differences among the measures. The best predictive equations were those that included terms for stand density, site index, stand age, and the interaction between site index and stand density. In their study, the optimum level of residual density increased with site quality with each of the tested measures of density.

Dahms (1966) compared several equations for predicting gross cubic foot volume growth in lodgepole pine (*Pinus contorta*) and found that the measure of relative density that he tested contributed a small but significant amount to the predictive power of his model. He used Crown Competition Factor (Krajicek and others 1961). In Allegheny hardwoods, a relative density measure based on tree-area ratio (Stout and Nyland 1986) is a slightly better predictor of stand basal area growth and individual tree diameter growth than basal area alone (unpublished data on file at the Northeastern Forest Experiment Station, Warren, PA).

Nonetheless, there are at least three general reasons for improving our understanding and use of relative stand density:

1. The reference lines themselves help us appreciate the complexity and universality of stand development. The measures reviewed here show that stand development can be characterized by relationships among average tree volume, diameter, top height, number of trees and basal area per acre, and growing space. These relationships apply to all forest types in which they have been tested and transcend species and size differences. Long and Smith (1983/84) have demonstrated how the use of the relationship between numbers of trees and average diameter can help us integrate our understanding of tree biology and stand dynamics.

2. Relative measures of stand density offer great promise for helping us understand similarities and differences in response to silvicultural treatments across forest types. For example, data accumulating in the eastern hardwoods suggest that relative densities of 50 to 60 percent of the average density observed in undisturbed stands of similar average tree size and species composition are universally good tradeoffs between sawtimber volume growth and bole quality. Even in stands of the same average tree size, however, this narrow range of relative densities is equivalent to a range of 50 or more square feet per acre (≅12 m²/ha) in absolute density, depending on species composition.

3. Within a forest type, relative measures of stand density can be more powerful than absolute measures for controlling intermediate treatments because they incorporate the changes in absolute density—and competition—associated with stand growth. Relative density measures can be interpreted directly as measures of crowding, are relatively independent of site and age, and their determination is not influenced by the errors often associated with determining site index and age. In some cases, they also incorporate differences in stand density associated with species composition and some variation in stand structure.

THE MEASURES

Comprehensive reviews of relative density measures (Curtis 1970; West 1983) have stressed conceptual similarities among stand density measures and explored algebraic equivalences. The brief review here focuses on the differences among five relative density measures, taking their similarities as a given. First we present each in the form of a reference line. Relative density measures are presented in a variety of units, but each **can** be expressed as a percent of the reference level. Although this procedure is not used universally, it facilitates comparisons between measures and also provides a universal language for comparing stand responses in different forest types at different relative densities. Hence, we present each as an equation to predict the number of trees per unit area; for each equation, the percent relative density can be determined by:

$$\%RD = N_0/N_r * 100 \qquad (1)$$

where $\%RD$ is the relative density percent, N_0 is the number of trees per unit area observed in the stand, and N_r is the reference number generated by the relative density equation in use.

The stocking guides (for example, Leak and others 1969) portray stand development as the relationship between the increase in basal area per unit area and decrease in numbers of trees per unit area, as in figure 1B. Ernst and Knapp (1985) describe a variety of ways to develop this reference line, including regression and tree-area ratio.

Guides such as those by Gingrich (1967) based on tree-area ratio equations (Chisman and Schumacher 1940) use a direct estimate of the average growing space per tree in undisturbed stands to characterize stand development.

Coefficients for the tree-area equation are calculated using data from fully stocked stands. These coefficients vary with species and forest type and can be used with a transformation of the tree-area equation to predict the number of trees in stands of the same arithmetic and quadratic diameters:

$$N_r = (b_1 + b_2 * \bar{D} + b_{3'} * QSD^2)^{-1} \qquad (2)$$

where N_r is the number of trees per unit area at the reference level, $\bar{D}$ is the arithmetic average diameter, $b_{3'}$ is the tree-area coefficient times the basal area constant, and *QSD* is the diameter of the tree of mean basal area.

Gingrich (1967), working in mixed central hardwoods, reported that the arithmetic average diameter term was only significant in stands with small *QSD*'s, in which it corrected for skewed diameter distributions.

With some relative density measures using the tree-area approach (Chisman and Schumacher 1940; Stout and Nyland 1986) no single reference line is presented graphically because the reference level varies with species composition and stand structure, as well as with average tree size. Roach (1977) presented seven reference lines, each representing the maximum for stands with a particular species composition.

The reference line for Crown Competition Factor (CCF) (Krajicek and Brinkman 1957; Dahms 1966) is of the same mathematical form as tree-area ratio. For this measure, however, the reference level is based on the crown width of open-grown trees and hypothetical stands in which the crowns of such trees fill the ground area but do not overlap. In the oaks, this reference level is consistently 57 to 59 percent of the undisturbed stand development reference level. Thus CCF expressed as a percent of the reference is usually greater than 100.

Reineke's (1933) Stand Density Index (SDI) compares number of trees per unit area to the maximum observed in stands of the same *QSD*. The reference level for this measure portrays stand development as the decrease in number of trees per unit area as stand *QSD* increases. Its equation is:

$$N_r = a_1 * QSD^{-1.605} \qquad (3)$$

where a_1 is a species coefficient and the exponent, –1.605, has been shown to apply to at least 12 species. This relationship is portrayed in figure 1C.

Curtis' (1982) Relative Density Index (RDI) compares observed basal area to that in a comparable "normal" stand of the same *QSD*. The reference line for this relative density measure is a transformation of the Reineke reference line to basal area/*QSD* axes, and the calculation for relative density in percent is based on observed and reference basal areas:

$$G_r = N_r * (k * QSD^2) \qquad (4)$$

where G_r is basal area at the reference level, N_r is the reference number for a stand of the given *QSD* generated by an SDI-like equation, and k is the basal area constant (0.005454154 in English units, 0.00007854 in metric). Curtis (1982) found that for Douglas-fir an exponent of –1.5, rather than –1.605, was adequate for the SDI expression used to generate the N_r.

Wilson's (1946) Relative Spacing Index (RSI) compares the number of trees per unit area to the number in a normal stand of the same dominant height. The equation for the reference line is:

$$N_r = b_1 * H^{-2} \qquad (5)$$

where H is the average height of dominant trees and b_1 is characteristic of a species. The underlying pattern of stand development described by this measure is that the number of trees in a square whose sides are equal in length to the dominant height of the stand is constant as stand height increases.

Drew and Flewelling's (1979) Relative Density (RDI) is based on the relationship between number of trees and the volume of the average tree. That is:

$$N_r = b_1 * V^{-0.667} \qquad (6)$$

where V is the average volume per tree. This relationship between numbers and plants and average plant size was first reported by Yoda and others (1963).

How Measures Differ

The most important difference among the measures discussed here is the reference variable—average diameter, dominant height, or average volume. Measures based on *QSD* alone are essentially equivalent. Tree-area ratio and CCF, also diameter-based, account for a portion of the variation in stand structure that is expressed by the arithmetic and quadratic diameters. But because relationships among diameter, height, and volume vary with age, site, average tree size, and stand structure, the reference level defined by the other measures is **not** the same. For example, Larson and Cameron (1986) showed that the reference lines for Douglas-fir data from the British Columbia Ministry of Forests **do not** overlap perfectly when portrayed on the same axes using transformations of dominant height and mean volume to *QSD*. This is also true when similar transformations are applied to the yield table values of McArdle and others (1961). The results are portrayed in figure 2. This variation in the relationships of key variables over the range of site classes and ages shows that the relationships among the relative density measures will be inconsistent and dependent on the data set used to develop the reference lines.

These differences raise interesting questions. West (1983) fit 17 reference equations for relative density to data from even-aged, regrowth eucalypt forests in Tasmania. The differences in r^2 for the reference level equations comparable to those examined here were small—ranging from 0.90 for a measure based on average volume through 0.92 for measures based on basal area and average diameter. Larson and Cameron (1986) also found that all the measures they tested fit their data equally well, despite the large differences in maximum density implied. This means that choice of a relative density measure **will** affect stand treatments implemented on the ground and their outcomes. Except for mechanically applied treatments like row thinning, we select nonaverage trees when we mark forest stands, which changes the relationships among stand average variables.

LOG NO. TREES vs. LOG QSD

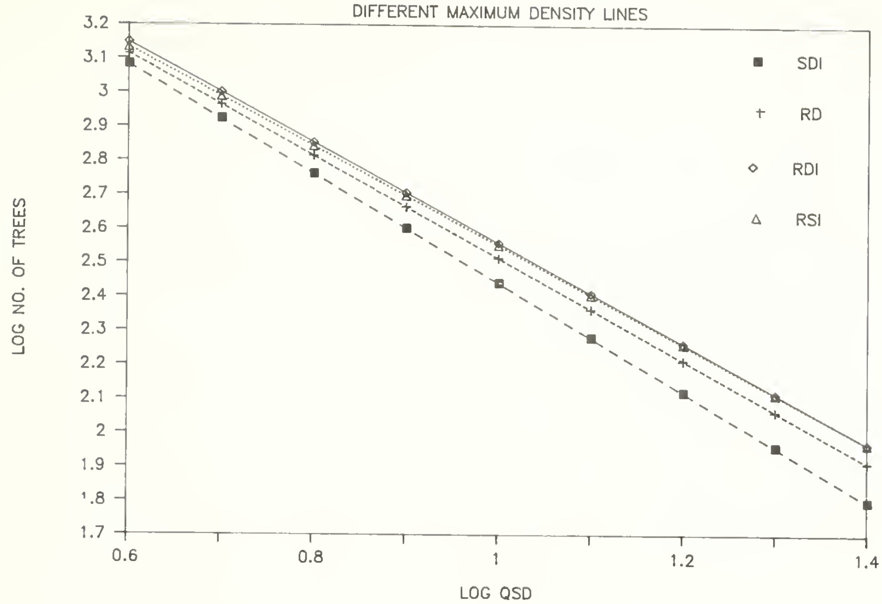

Figure 2—Reference lines for four of the measures discussed here fitted to data from McArdle and others (1961). SDI is Reineke's Stand Density Index (1933), RD is Curtis' Relative Density (1982), RDI is Drew and Flewelling's Relative Density Index (1979), and RSI is based on Wilson's relative spacing (1946).

Hence, guidelines derived from different measures will not prescribe equivalent treatments, and the discrepancies may increase with repeated treatments.

STAND STRUCTURE AND SPECIES COMPOSITION

None of these measures of relative density is sufficient to prescribe a thinning regime completely. In addition to a residual relative density, complete specifications for intermediate treatments must include residual structure, species composition when relevant, and thinning interval. Changes in structure or species composition can have more impact on stand growth after treatment than residual density itself. Oliver and Marshall (1983) showed differences of 39 percent in stand volume growth after thinnings to the same basal area but different structures; Larson and Cameron (1986) showed differences of 30 percent in simulated cubic volume growth of Douglas-fir over a 50-year period after thinning to the same relative density. Stand basal area growth of Allegheny hardwood stands differed by 45 percent over an 8-year period following thinning to different structures at 60 percent relative density (Marquis and Ernst in preparation); the structural differences were associated with a difference of 40 percent by basal area in the percent composition of the fastest growing intolerant species. In the Larson and Cameron (1986) study and the Allegheny hardwood study (Stout 1986), growth of the control plot was intermediate between the slowest growing and fastest growing thinned plot.

Fortunately, each of these studies points to the same general structure as best for residual stand growth after intermediate treatments. In each case, a structure that left primarily the best trees from the pretreatment stand and opened them up enough to improve their growth resulted in the best stand growth. Larson and Cameron (1986), for example, found that a crop tree thinning resulted in slightly better simulated growth than a thinning from below without regard for spacing. Both of these grew faster than a plot thinned from above, a strip-thinned plot, or the control.

A closely related problem is that of species composition, intimately related to stand structure. Even-aged, mixed-species stands often form multilayered canopies, in which less-tolerant, faster growing species form the dominant and upper codominant layers and more tolerant, slower growing species survive underneath (Oliver 1978; Marquis and others 1984; Smith 1986). In some of these forest types, differences in species composition in otherwise similar stands can result in differences in absolute density of 50 percent or more. Growth before and after intermediate treatments is influenced strongly by species composition; the growth of some species seems influenced more by the density of the canopy strata in which they are located than by the density of the stand as a whole (Hubbard 1977; Kittredge 1986). Assessment of relative density in uneven-aged stands is a related problem.

Research is underway to address these problems. One outcome of the Forest Service program to provide uniform stocking criteria for all of its forests is a cooperative effort to translate the existing standards and guidelines for use in mixed species types. Our own research includes efforts to account for the crown class of trees as well as their species and diameter in relative density measurement. Regardless of the measure used, the long-term goal is an unambiguous correlation between the relative density of immature stands and their growth.

The conceptual similarity of the various measures of relative density does not make them interchangeable in practice. We await eagerly the results of thinning trials such as those under way at the Lubrecht Experimental Forest; these will enable us to compare empirically the correlation of various measures with stand growth. The relationships among the measures over time may also add new insights into the complex dynamics of stand development.

SUMMARY

Measures of relative stand density are based on reference lines that describe stand development, usually at the level observed in undisturbed stands or the maximum observed in a particular forest type. Numbers of trees or basal area per unit area are compared to the reference level based on an average stand characteristic, such as *QSD*, mean volume, or dominant height, which provides better estimates of crowding in forest stands than do absolute measures. Although current measures illuminate important basic relationships in stand development, they are not interchangeable. None presently accounts adequately for species composition or stand structure in predicting growth responses to intermediate treatments, but current research may result in improvements. At present, a relative density measure for a particular forest stand should be selected according to guidelines and, when possible, supporting data and on the management objectives for the stand.

ACKNOWLEDGMENTS

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Robert D. Pfister)—Can even-aged stand density measures be used to provide preliminary stocking guides for uneven-aged prescriptions?

A.—Yes. Someone taking this approach might anticipate problems due to differences between the structure and species composition of uneven-aged stands and that of even-aged stands, particularly in forest types characterized by bell-shaped diameter distributions of shade-intolerant species. But as a manager attempts to bring even-aged stands under uneven-aged management, or in types composed predominantly of shade-tolerant species, or in other situations for which no guidelines on residual densities are available, a manager sensitive to these problems should find existing measures useful.

Q. (from A. A. Loman)—SO_2 pollution density in terms of kg km^{-2} $year^{-1}$ is 50 times higher in the States of Pennsylvania, Ohio, and New York than in western North America. How do you separate SO_2 pollution stress from normal stand competition stress and mortality in the polluted eastern forests?

A.—The jury—composed of many forest scientists and ecologists—on the long-term effects of SO_2 pollution on the eastern forests is still out. Our data do not suggest major long-term changes in stand development patterns on the Allegheny Plateau, but the theory of the relative stand density measures discussed in our paper, including tree-area ratio analysis, is that these patterns are independent of stand age and site quality (see, for example, Chisman and Schumacher [1940] and our paper). Hence, to the extent that SO_2 pollution acts to cause a deterioration of site quality in the pollution stream, we should not be able to detect its effects through these analyses.

DENSITY MANAGEMENT DIAGRAMS: THEIR CONSTRUCTION AND USE IN TIMBER STAND MANAGEMENT

James N. Long

ABSTRACT

Density management diagrams are simple stand average models that represent dimensional relationships in graphical form. These diagrams help resource specialists predict and display the consequences of stand density manipulations. Their use in a variety of management situations, including traditional wood production and wildlife habitat improvement, is illustrated with diagrams for two western conifers. Some limitations of density management diagrams and opportunities for their improvement are also discussed.

INTRODUCTION

The control of density levels in a stand has tremendous impact on that stand's structure, productivity, and ability to produce a variety of resources. Density management is the single most influential activity the silviculturist can perform between successive regeneration periods.

Reasonable density management, of course, must start with fairly specific management objectives; it is impossible to design effective silvicultural prescriptions unless desired goals are known. These management objectives must then be translated into stand-level prescriptions. Given a particular management context there are a variety of tools, ranging in sophistication from computer simulation models to spacing "rules of thumb," available to design density management regimes. Each of these tools has a place in the planning and execution of density management regimes. Somewhere between the extremes are the graphical models represented by various types of stocking control charts and density management diagrams (Long and McCarter 1985).

The most comprehensive of the graphical models are referred to as density management diagrams. The apparent simplicity of these diagrams is deceiving; they represent the complex dimensional relationships of even-aged, single-species stands. The interrelations between *Dq* (quadratic mean d.b.h.), HT_s (mean site height), *TPA* (trees per acre), and either mean or total volume are displayed in two dimensional form (fig. 1). This general format has important practical advantages, but also some limitations.

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The principal advantage of density management diagrams is in predicting and displaying the consequences of stand density manipulations. I will discuss the construction and use of the diagrams in a variety of management situations, including traditional wood production and wildlife habitat improvement. Some general limitations of density management diagrams and opportunities for their improvement are also discussed. The discussion is illustrated with diagrams representing two western species.

CONSTRUCTION

The elements of a typical density management diagram are illustrated by a diagram constructed for lodgepole pine (*Pinus contorta*) in the central Rocky Mountains (fig. 2). This diagram has *Dq* and *TPA* plotted on logarithmic axes. Growing stock levels, the diagonal parallel lines, are represented by Reineke's (1933) Stand Density Index:

$$SDI = TPA\ (Dq/10)^{1.6}$$

SDI is one of a number of size-density indexes that are particularly useful to silviculturists because they are independent of site quality and stand age (Curtis 1982; Daniel and others 1979; Long 1985).

The two families of curves represent HT_s and total volume (ft^3/acre). These curves are based on nonlinear regressions. For example, the site height (HT_s) lines are based on evaluation of the model:

$$MVOL = ((B1 + B2\ Dq^{B3})(B4\ HT_s^{B5}))^{B6}$$

where: $MVOL$ = mean tree volume
Dq = quadratic mean diameter
HT_s = mean site height.

This and a similar equation used to establish the total volume curves were fit using a nonlinear curve fitting routine. The fitted curves were tested for bias with respect to site index and stand age as well as the independent variables included in the models. An additional test of the model's validity involved checks for bias against an independent data set not included in the original curve fitting (McCarter and Long 1986). Data used to fit the requisite equations may come from research plots, as in the case of the Drew and Flewelling (1979) diagram for coastal Douglas-fir (fig. 1). Alternatively, McCarter and Long (1986) used forest inventory data to construct the diagram for lodgepole pine (fig. 2).

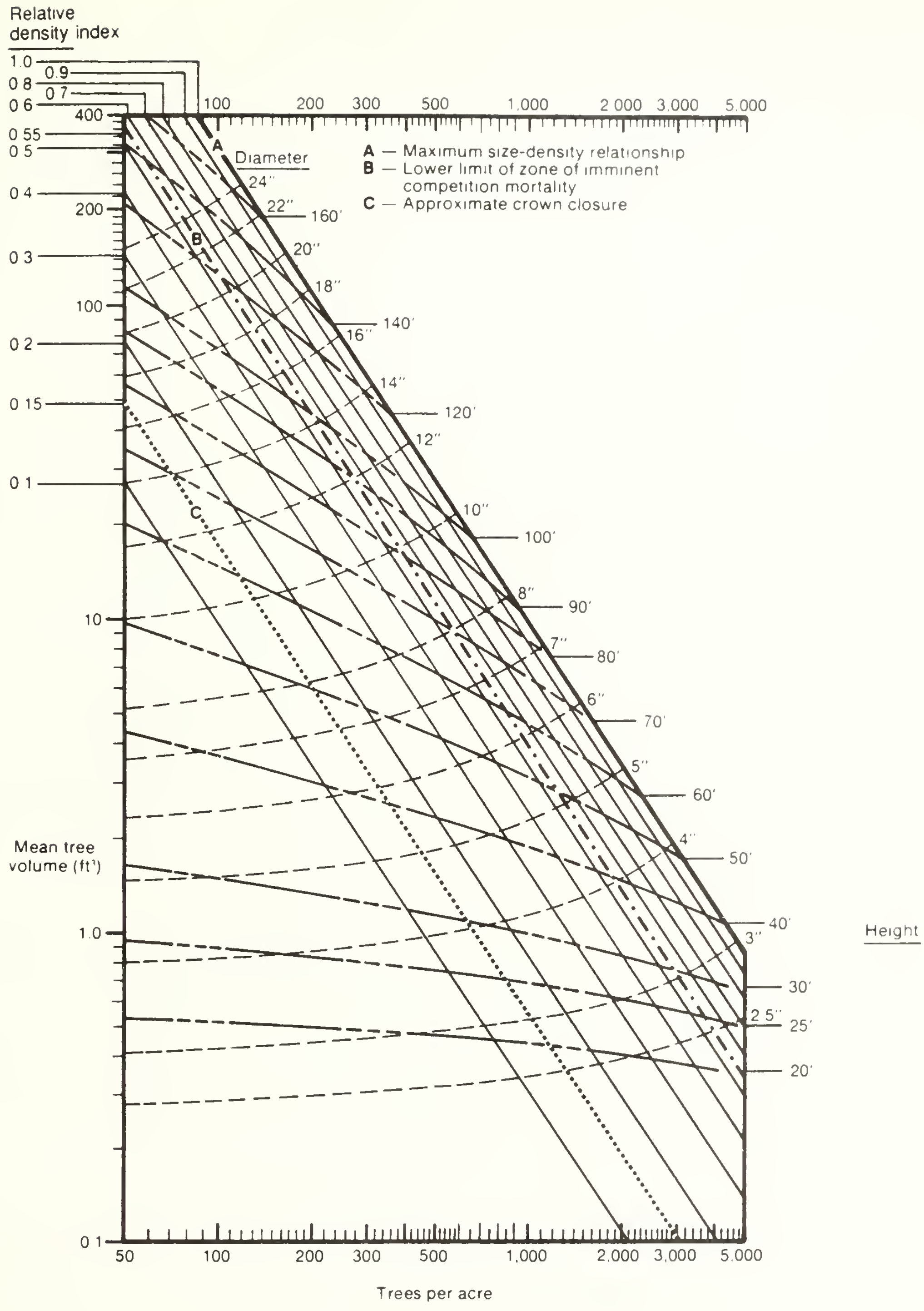

Figure 1—Density management diagram for coastal Douglas-fir (*Pseudotsuga menziesii*) (from Drew and Flewelling 1979).

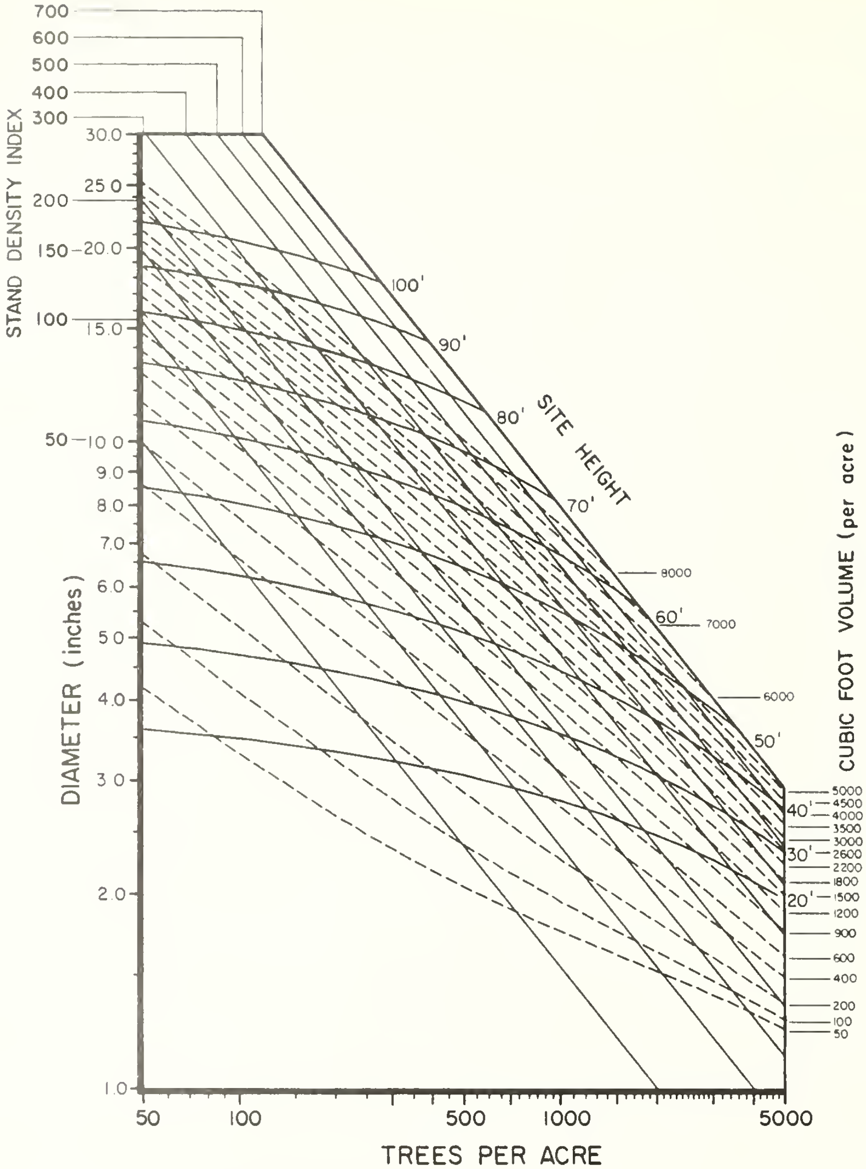

Figure 2—Density management diagram for lodgepole pine in the central Rocky Mountains (from McCarter and Long 1986).

The way in which a diagram is formatted is largely a matter of personal preference. For example, McCarter and Long (1986) chose to display *Dq* and *TPA* on the axes of their lodgepole pine diagram. They argued that these are the most commonly used variables and easiest to estimate in the field. This choice of axes influenced their decision to use *SDI,* a function of *Dq* and *TPA,* as the index of growing stock. Drew and Flewelling (1979) use *MVOL* and *TPA* on the axes of their Douglas-fir diagram. Their use of an index of growing stock based on *MVOL* and *TPA* was therefore logical.

USING DENSITY MANAGEMENT DIAGRAMS

The principal value of the diagrams is their usefulness in planning for, and evaluating the consequences of, alternative density management regimes. Figure 3 illustrates three alternative regimes for a hypothetical lodgepole pine stand. Estimates of volume and HT_S indicated by the diagram and an appropriate site index curve (for example, Alexander and others 1977) make it possible to create simple yield tables for each of the alternative regimes (table 1).

Given reasonable assumptions about biological and economic constraints, the diagrams facilitate the effective display of density management alternatives. An example of a biological consideration in screening alternative regimes is the risk of mountain pine beetle attack at various diameters and stand densities (Berryman 1982). Harvesting and handling costs associated with different average stand diameters exemplify an important economic consideration. Those alternatives that are incompatible with management objectives can be quickly eliminated from further consideration.

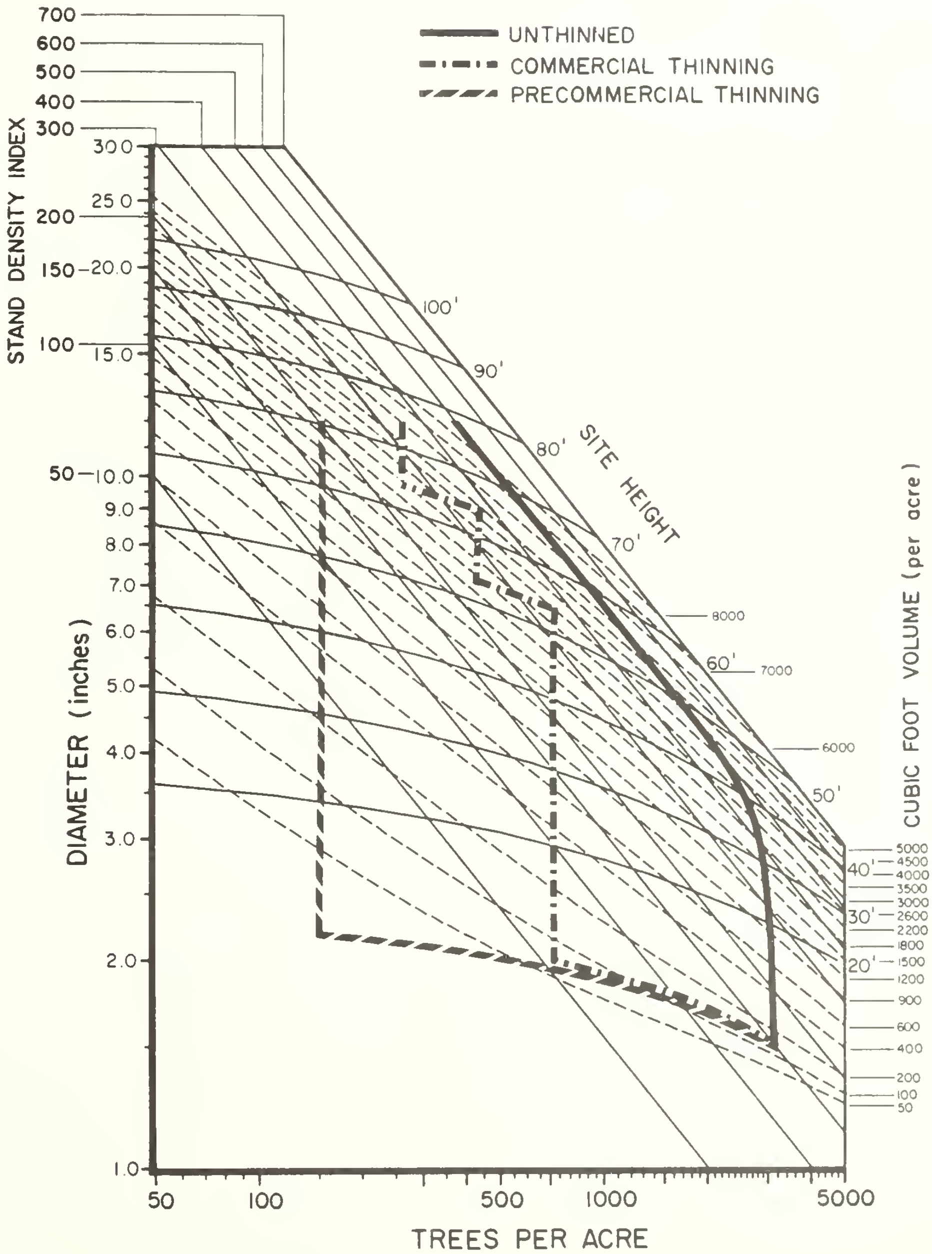

Figure 3—Alternative density management regimes (from McCarter and Long 1986).

Table 1—Comparison of three density management alternatives; mean annual increment (MAI) is based on age at final harvest and includes commercial thinnings and final harvest (from McCarter and Long 1986)

	Age	Ht_s	*TPA* Before	*TPA* After	*Dq* Before	*Dq* After	Volume removed
	Years	*Feet*			*Inches*	*Inches*	*Ft^3/acre*
Unthinned							
Final harvest	102	78	375		12.0		9,000
Total yield							9,000
MAI							88 ft^3/acre/yr
Commercial Thinning							
PCT	5	8	3,050	725	1.5	2.0	
CT1	45	53	725	420	6.3	7.0	1,000
CT2	59	64	420	260	8.8	9.6	1,100
Final harvest	76	75	260		12.0		6,000
Total yield							8,100
MAI							107 ft^3/acre/yr
Precommercial Thinning Only							
PCT	5	8	3,050	150	1.5	2.1	
Final harvest	72	70	150		12.0		3,400
Total yield							3,400
MAI							47 ft^3/acre/yr

The diagrams may also be used to evaluate objectives other than timber production. For example, the density management diagram for lodgepole pine has been used to evaluate the ungulate hiding and summer thermal cover status of lodgepole pine stands (Smith and Long 1987). The resulting stand structure/cover diagram (fig. 4) lets the resource specialist determine those combinations of *Dq* and *TPA* that will result in adequate hiding or thermal cover under existing cover guidelines. Stand structure, and therefore cover provided by the stand, are dynamic and can be silviculturally manipulated. Appropriate site index curves and the estimates of HT_S can be used to predict and plan for these changes.

LIMITATIONS AND POSSIBLE IMPROVEMENTS

These diagrams, like all tools used to evaluate density management regimes, have advantages and disadvantages. One limitation is their lack of "memory" concerning the effects of competition prior to thinning. This can be illustrated with a simple example using the Douglas-fir diagram (fig. 1).

Assume a stand with 1,000 *TPA* which has grown, without prior thinning, until the mean volume is 7 ft^3, the *Dq* is 6.7 inches, and the HT_S is 70 ft. Now assume that the stand is thinned to a density of 100 *TPA*. As is customary in using the diagrams, we assume that a low thinning does not change HT_S; thus the estimate of after-thinning mean volume and *Dq* are 25 ft^3 and 13 inches, respectively (fig. 1). However, these are the same estimates of mean volume and *Dq* for a stand in which HT_S equals 70 ft and which had never experienced the reduced level of individual tree growth associated with a higher level of competition. Thus the simplicity of the diagrams increases their practical utility but can result in biased estimates of mean tree size in relatively late, heavy thinnings. Since such thinnings are rarely prescribed, this limitation of density management diagrams is probably not serious.

Another potential source of error results from the assumption that there is a single maximum size-density relationship or stocking rate for a species. Some recent work suggests that maximum *SDI* for a species, particularly one with a large geographic range and ecological amplitude, may vary with environmental conditions (Sterba 1985; Strub and Bredenkamp 1985). While relatively minor site-specific differences in maximum *SDI* are probably of little practical significance, major differences should be considered. This could be done by constructing regional or zonal diagrams for such widely distributed species as ponderosa pine and Douglas-fir.

To date, all of the density management diagrams published for North American species are intended to represent essentially even-aged, single species stands. Obviously many density management problems involve mixed species and/or uneven-aged stands. Recent work by Japanese foresters suggests that density management diagrams can be constructed for structurally more complicated stands (Kikuzawa 1982, 1984).

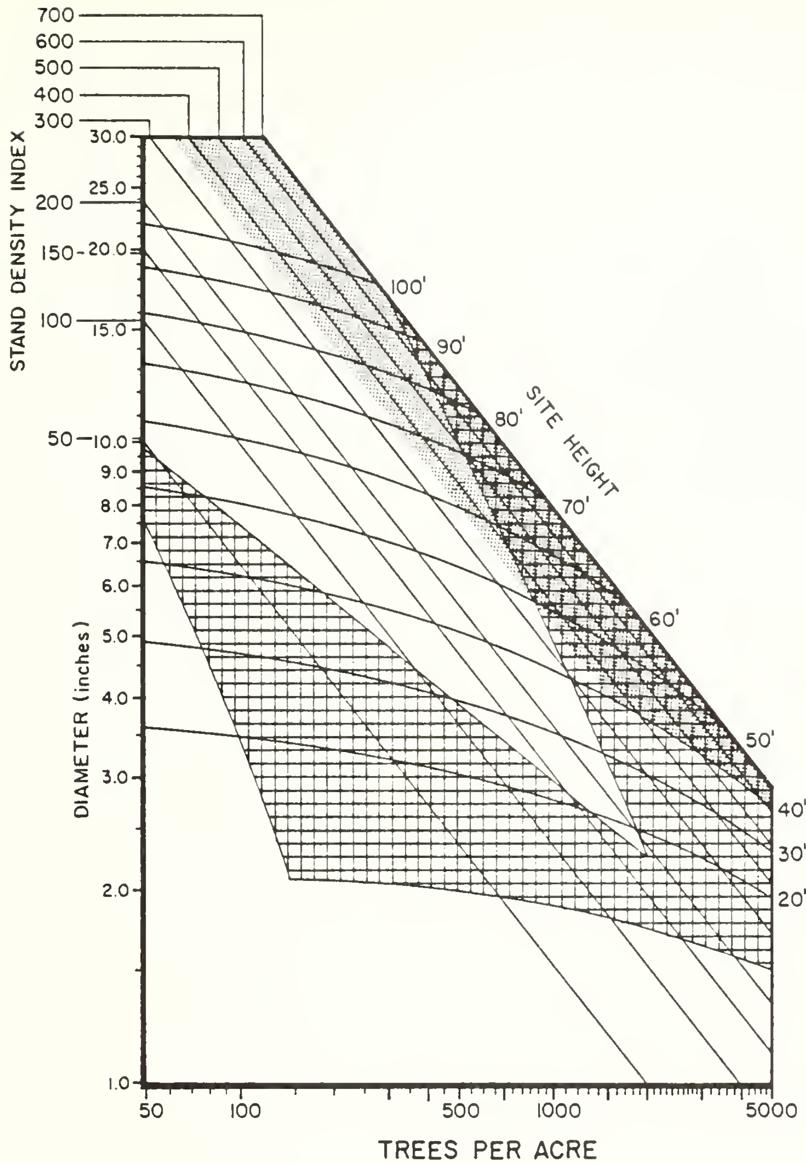

Figure 4—Lodgepole pine density management diagram modified to display ungulate hiding (hatched) and summer thermal (stippled) cover guidelines (from Smith and Long 1987).

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STOCKING CHARTS—TOOLS FOR FOREST MANAGEMENT

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ABSTRACT

Standards and procedures for the development of stocking level charts within the National Forest System are discussed. Attention is focused on the definitions associated with the development of the stocking charts and the format in which they are presented. The use and limitations of stocking charts as tools for managing immature forest stands are reviewed.

NEED FOR STANDARDIZATION

As managers of existing and future forests we need some expression of stocking to compare current stand conditions to some desired or standard condition. We need to know if a stand contains enough trees or basal area to manage for the optimum or desired amount of tree or stand growth and development. We also need to know when a stand contains too many trees and how many to leave when thinning.

In the National Forest Management Act of 1976 (USDA FS 1983), Congress mandated that all forested lands in the National Forest System shall be maintained in appropriate forest cover with species of trees, degree of stocking, rate of growth, and conditions of stand designed to secure the maximum benefits of multiple-use sustained-yield management. Carrying out this mandate required a critical evaluation of all aspects of Forest Service activities that affect the productivity of the land.

The need for standardized terminology and format for displaying stocking levels was also identified in the Chief's 1978 report, "Evaluation of Reforestation and Timber Stand Improvement on the National Forests" (USDA FS 1978a). In this evaluation of our reforestation and timber-stand improvement (TSI) programs, existing standards for stocking-level control were found to be inadequate for determining treatment needs, setting priorities, evaluating completed work, and communicating the objectives and results of timber-management activities on the National Forests.

In this paper, we discuss standards and procedures for developing stocking-level guides within the National Forest System for even-aged stands. We display the format selected as the standard background chart for the preparation of stocking-level curves. And we describe and illustrate the use of stocking charts to determine the adequacy of stocking to meet timber management objectives.

CONCEPTS

The concept of relative stand density is not new; it has been used for many decades for comparing stands that differ in stand structure, site quality, and stand age. Stocking charts, guides, or tables have been developed for most of the major forest cover types and species occurring on National Forest lands. These guides express stand densities that are easily derived from field measurements of trees per acre or basal area per acre. Relative density, the ratio of the measured or absolute density of a given stand to some reference level, describes the degree of crowding. Stocking charts are the most commonly used method of displaying the proportion of an area occupied by trees in the stand relative to some standard reference value for full site occupancy. Standardization of the definitions associated with these guides and the format in which they are presented provide for a common understanding and interpretation of displayed relationships regardless of the species or forest type.

In their report "Forest Stand Density and Stocking: Concepts, Terms, and the Use of Stocking Guides," Ernst and Knapp (1985) pointed out the need to define terminology and concepts to ensure a common understanding, interpretation, and communication of information. With reference to "Terminology of Forest Science" (Ford-Robertson 1971), they defined the most commonly used concepts and terms. Two of the most frequently interchanged are repeated here for emphasis:

1. Stocking - A loose term for the amount of anything on a given area, particularly in relation to what is considered optimum. A subjective measure of the proportion of the area actually occupied by trees.
2. Stand Density - A quantitative measure of tree stocking expressed either relatively as a coefficient, taking normal numbers, basal area, or volume (from yield table data) as unity; or absolutely, in terms of number of trees, total basal area, or total volume per unit area.

Stout and Larson (this proceedings) make a clear distinction between the terms "absolute" and "relative" in their discussion of the importance of relative stand density in making stand management decisions.

FOREST SERVICE FORMAT

In the Chief's Action Plan (USDA FS 1978b) the Timber Management and Timber Management Research Staffs in Washington, DC, were assigned responsibility for coordinating the development of a standardized format to display timber-stand stocking curves. Standardization of the method for determining stocking levels was not a part of this assignment. The developmental process included Forest Service Regional and Research Station inputs; a special study team to review the literature, screen techniques, and recommend a uniform approach; and joint

National Forest-Research working sessions to identify problems and resolve conflicts. The resulting definitions, procedures, data requirements, and guidelines needed to use the selected format have been included as a chapter in the Forest Service Silvicultural Practices Handbook (USDA FS 1985).

The format described by Gingrich (Ginrich [sic] 1976) for upland oaks and discussed in detail by Ernst and Knapp (1985) was determined to be the most appropriate background chart for the preparation of National Forest stocking level guides. This format graphically illustrates the mathematical relationship among basal area, number of trees, and the quadratic mean diameter (QMD). Two of the variables needed to use this format—basal area and number of trees—are available from stand examination data and can be used for all species and forest cover types. The quadratic mean diameter can be calculated directly from these data using the equation: BA = TPA (QMD) 2 (0.005454), where BA = basal area per acre; TPA = trees per acre; and QMD = quadratic mean diameter or the diameter of the tree of average basal area. The mathematical relationship among the three variables is shown in figure 1.

The plotted relationships alone serve little purpose; specific information by species or forest type must be placed on the chart for it to have utility in managing immature stands. Perhaps the most critical step in the development of a stocking guide is the establishment of reference levels for measuring relative stand density. Stand density index (Reineke 1933), tree-area ratio (Chisman and Schumacher 1940), and crown competition factor (Krajicek and others 1961) are the most commonly used techniques for establishing these reference levels. Many stocking charts developed for eastern species (fig. 2) contain an "A" line, often derived from stand density index (SDI), tree-area ratio, or normal yield tables, as a reference for full stocking, hereafter referred to as average maximum density (AMD); a "B" line, based on the tree-area ratio for open grown trees, that represents the lower limit of full site utilization; and a "C" line that represents the lower level of stocking from which a stand could grow into the B level within 8 to 15 years, depending upon site quality.

The Forest Service standardized format for displaying stocking level curves is shown in figure 3. On this chart the AMD line represents 100 percent stocking based on

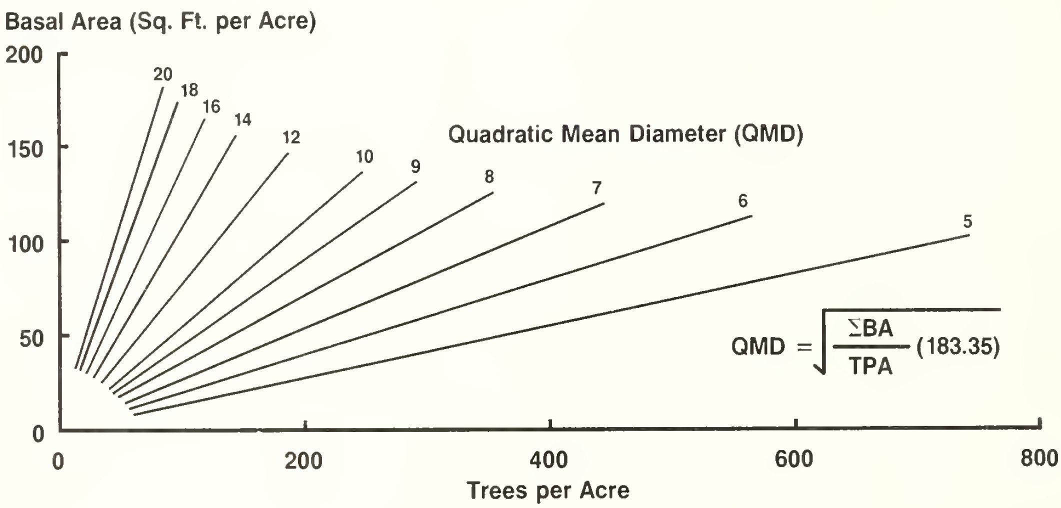

Figure 1—Relationship of basal area per acre, trees per acre, and quadratic mean diameter (QMD).

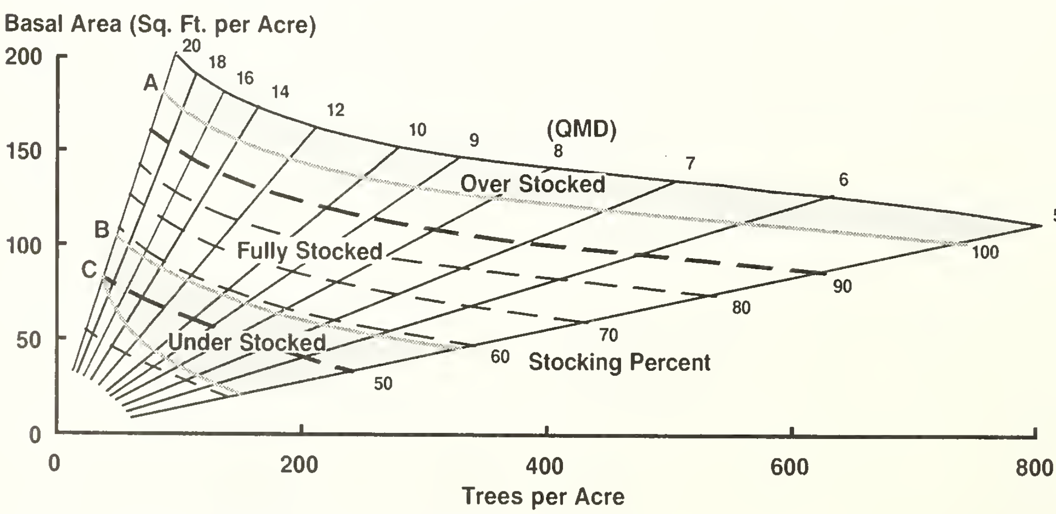

Figure 2—Gingrich stocking guide developed for upland hardwoods.

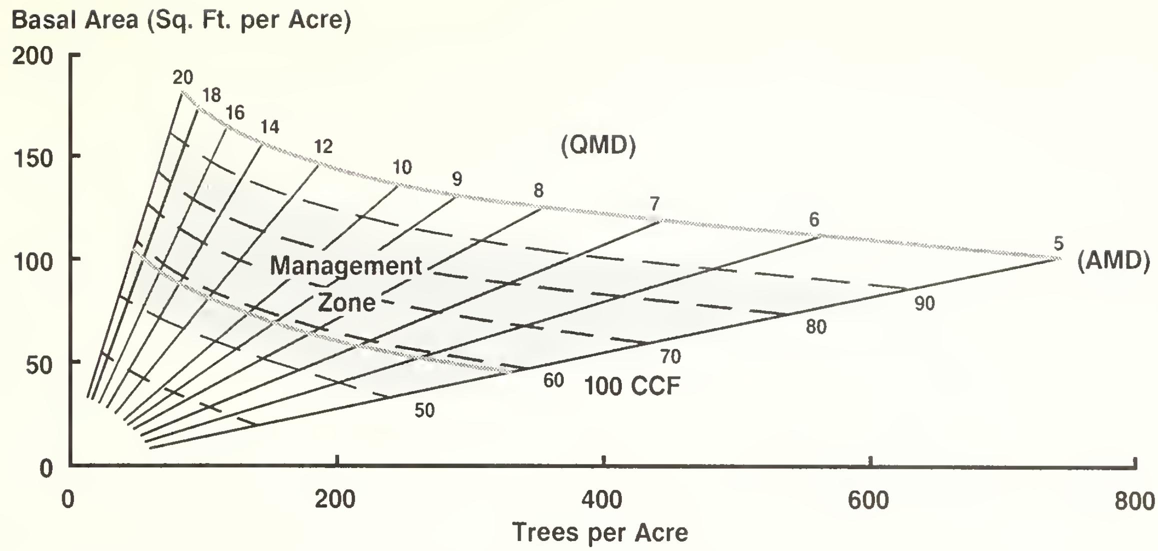

Figure 3—Forest Service standardized format with reference levels (AMD and 100 CCF) and the management zone.

SDI or normal yield tables and the 100 CCF line represents the condition where the crowns of open-grown trees are just begining to touch—that is, the cumulative crown area of all trees is equal to 100 percent of the ground surface area. The area defined by these measures of growing space gives us the range of relative densities in which we usually want to be operating to meet most management objectives. In practice, however, upper and lower stocking levels are usually established to delineate the management zone for each specific management objective and biological situation. Thus, the relative densities that bound the management zone for other resource objectives, or for conifers on more xeric sites, may not always coincide with the AMD and 100 CCF lines.

USES AND LIMITATIONS

When to thin? How much to thin? What are the alternatives? What are the benefits? These are the questions frequently asked by the forest manager. We believe that stocking charts developed using the standardized format (table 1) provide Forest Service silviculturists with a systematic way of measuring and evaluating stand conditions to determine treatment needs, arrive at recommended treatments, set priorities among types of treatments, communicate the objectives of management, and evaluate responses and benefits. Following are some examples of the use of stocking charts to determine and/or communicate management action:

Precommercial Thinning—The need for (fig. 4, point A) and the results of (fig. 4, point B) a precommercial thinning can be displayed on a stocking-level chart. The need to remove excess trees can be related to the AMD line. In addition, the effects on QMD of removing a number of smaller diameter trees can be noted. Also evident is the fact that for most stands when the stocking level is at or near the 100 CCF line, the stand will be able to grow at a rapid rate for some time.

Table 1—Summary of available timber stocking level curves by Forest Service Region and tree species or forest type

Region	Species or forest type	
Northern (R-1)	White pine Douglas-fir Western hemlock Lodgepole pine Subalpine fir	Larch Grand fir Cedar Spruce Ponderosa pine
Rocky Mountain (R-2)	Ponderosa pine Douglas-fir/white fir Lodgepole pine	Engelmann spruce, white spruce/subalpine fir Aspen
Southwestern (R-3)	Ponderosa pine Douglas-fir/white fir	Spruce-fir Aspen
Intermountain (R-4)	Ponderosa pine Douglas-fir Red fir Spruce	Lodgepole pine White fir, grand fir/ subalpine fir Western larch
Pacific Southwest (R-5)	Ponderosa pine Red fir Douglas-fir	Mixed conifers White fir
Pacific Northwest (R-6)	Douglas-fir White fir including grand fir	Western hemlock
Southern (R-8)	Shortleaf, slash/ loblolly pine Eastern white pine	Longleaf pine Oak
Eastern (R-9)	Shortleaf pine Jack pine Aspen Northern hardwoods Allegheny hardwoods (cherry, ash/poplar)	Red pine Oak White spruce Hemlock-hardwood
Alaska (R-10)	Sitka spruce/ western hemlock	

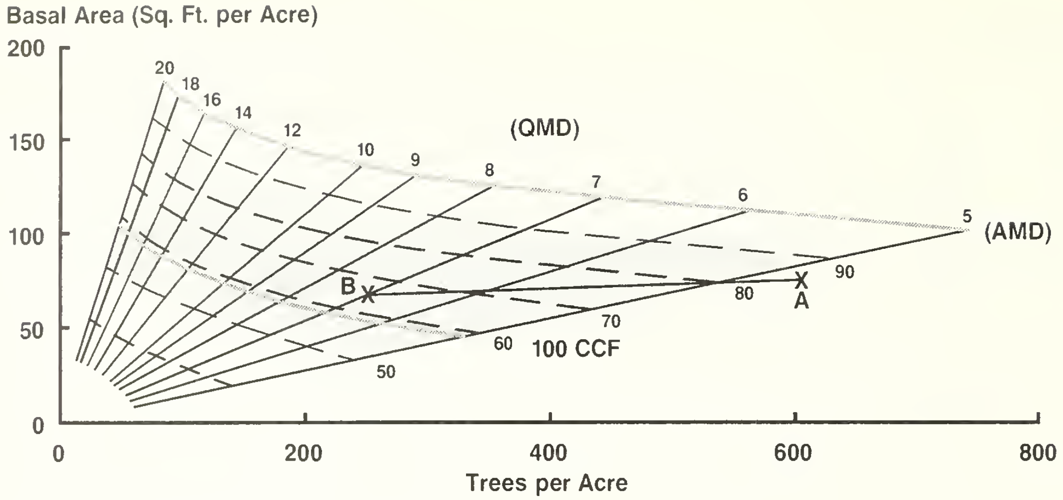

Figure 4—Stocking chart as a guide for precommercial thinning.

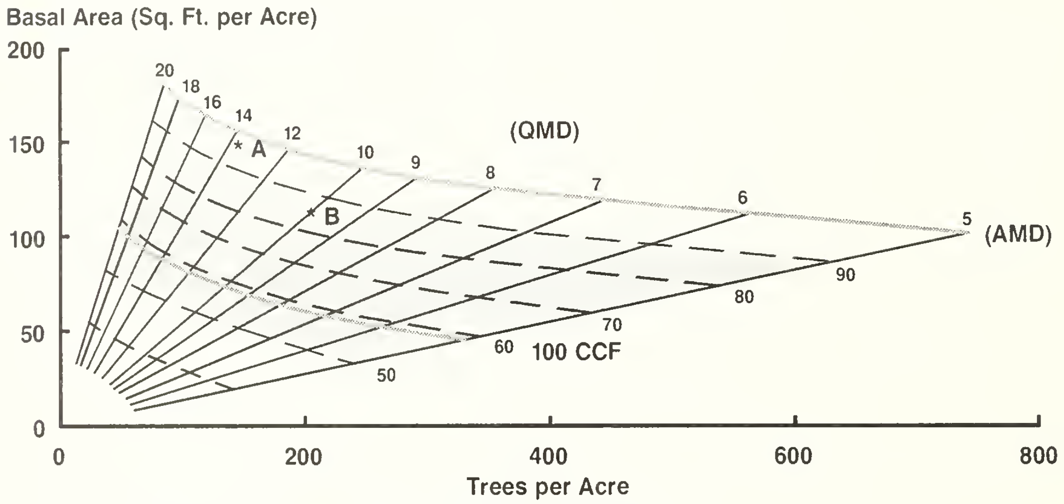

Figure 5—Stocking chart as a reference to prioritize stands for treatment.

Stand Treatment Priorities—Often a question arises as to which stand to treat first. Stocking-level charts can display the biological factors that must be considered when stands are to be regenerated. A lodgepole pine stand that is at or near the AMD line (fig. 5, point A) most likely would be considered for a regeneration cutting before a stand that is still within the established management zone (fig. 5, point B). For young stands that appear to be similar, stocking charts can be used to determine which stand should be precommercially thinned first when management funds are limited.

Response to Alternative Treatments—A stocking chart can be utilized in consort with a growth and yield simulator such as PROGNOSIS, RMYLD, DFSIM, OAKSIM, or STEMS, to display a management regime or alternative management regimes. The biological relationship to the AMD or the effects of density on growth are evident and can be used to decide which alternative treatment best meets management needs. Generally, to provide longer intervals between commercial thinnings, managers have to reduce the stocking levels more, or closer to the 100 CCF line, than if they desire shorter intervals. This can be graphically displayed based on data from a growth simulation model and used as a tool to explain the consequences of proposed management actions. Figure 6 provides an example of how thinnings (points 1 to 2 and 5 to 6), growth projections (points 2 to 5 and 6 to 9) using a simulation model, and a seed-tree harvest cut (point 9 to 10) can be displayed on a stocking chart. These charts can also be used to display the effects of alternative timber management treatments on other vegetation.

The primary use of stocking charts is to graphically display relative stand density or a density regime prescribed to meet a particular management objective. Use of these charts should not dictate stand-management decisions, nor should the charts alone be used to make silvicultural prescriptions or growth and yield predictions. Also, stocking charts should not be used to evaluate the economic efficiency or feasibility of silvicultural treatments. The selected course of action is still based on the manager's expertise; the stocking chart is only a tool to facilitate the decision process.

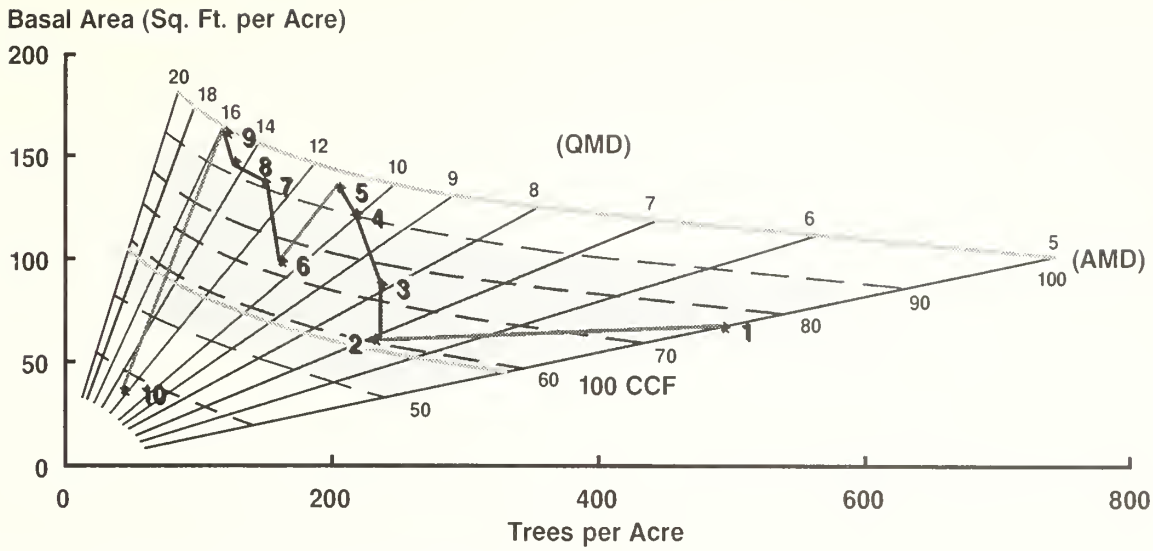

Figure 6—Stocking chart to compare management regimes.

Conceptually, stocking charts can be developed and used for even-aged stands of either single species or a mixture of species. However, there are difficulties in some applications that are thought to be due to variations in species mixtures, stand structure, and crown shape (Leak 1981; Stout and Larson this proceedings). A primary limitation of stocking-level charts is that they do not deal with the adequacy of regeneration. Hence, there is a need for research to equate satisfactory regeneration stocking, particularly for artificial regeneration, with future relative stand density.

SUMMARY

Stocking charts are a valuable management tool for diagnosing treatment needs, evaluating treatment alternatives, and communicating management plans and results. As a communication tool they are especially valuable in discussions between managers with different resource backgrounds and resource use objectives.

The Forest Service has adopted a stocking chart format that is based on the relationships among the quadratic mean diameter, number of trees per acre, and basal area per acre of the stand. Using this format, stand density can be displayed relative to the theoretical reference levels for maximum (AMD) and minimum (100 CCF) competition. Within this range of relative densities, the chart serves as a management tool for displaying the effect of alternative treatments on the number of trees and basal area of the stand. Treatments within this management zone permit managers to manipulate stand and individual tree growth and quality.

Although this format has been adopted as the Forest Service standard for displaying stocking, research continues to develop better measures of density for the management of future forests. In addition to our continuing research program, the Forest Service has organized a task force with National Forest, Research, and university representation that is currently working to: (1) develop and test methods to establish stand-density reference levels for species with wide geographic distribution, such as ponderosa pine; (2) define the use and describe a procedure for establishing the management zone on a biologically sound basis; and (3) provide a procedure to develop stocking charts for mixed-species stands.

As a result of this Forest Service management and research activity, the Regions have developed stocking level curves for many species and forest types. These curves are available at Regional Foresters' offices; you are invited to use them.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Robert D. Pfister)—For which species do you have stocking curves and where can we get copies?"

A.—Because of this question, we decided to incorporate table 1.

STAND DENSITY: A KEY TO AREA WILDLIFE HABITAT ANALYSIS

David S. Winn
Ricky E. Brazell
Robert I. Cottingham

ABSTRACT

Stand density management is an essential tool for wildlife habitat development. It is particularly important for wildlife species that rely on stem densities and canopy development for hiding, thermal, and security cover. This paper describes a process and summarizes a method for evaluating the cumulative impacts of a management area's stand density mosaic. The successional relationships between elk hiding cover and stand structure are emphasized.

The natural development of lodgepole pine stands across five decades was simulated by the Prognosis Model for Stand Development. Tree lists, generated by the model, were used to calculate elk hiding cover values for each successional decade. Within a management area, plant communities were mapped and assigned the appropriate hiding cover index. These data were used to calculate an area hiding cover index. By adjusting community values for successional change, the area's long-term potential, stand ecology, and hiding cover were evaluated.

INTRODUCTION

Management scenarios that maintain quality wildlife habitat diversity and viable wildlife populations are reliant on the planning and decision-making process. Generally, debate among resource specialists centers on "how much is enough." Just what is adequate is usually clouded by qualifications and value judgments that are influenced by broad regional conditions such as socioeconomic considerations. However, once the wildlife habitat components are identified for the target species, three basic relational factors determine the management area's total effectiveness as wildlife habitat. These factors include the size of individual patches of hiding and foraging cover, the distance between these patches, and the degree of habitat similarity that exists in the intervening habitat matrix.

This paper outlines a process for evaluating the cumulative impacts of a management area's stand density mosaic on elk hiding cover. The proposed process incorporates the juxtaposition of hiding cover, successional trends associated with the growth of managed and unmanaged stands, and the management opportunities provided by the manipulation of stand structure through effective silviculture.

MANAGEMENT AREA

The process described in this paper was tested on the Thornburg timber sale area in the northeast corner of Utah, within the Manila unit, Flaming Gorge Ranger District, Ashley National Forest. This mountainous area is part of the Uinta Mountain range and is characterized by a Precambrian quartzite substratum, poor drainage, and generally acid soils and waters. Glaciation played a major role in leveling the terrain; the shifting ice gouged lateral moraines, dotted with small meadows, potholes, and lakes along northerly oriented ridges.

The area's vegetational aspect (table 1) is a uniform coniferous forest with grass-dominated meadows. At elevations between 8,500 and 9,500 ft, this uniformity is somewhat broken within the aspen-conifer mosaic. Spruce-fir overstories invade the lodgepole pine communities at the upper elevations between 10,000 and 11,000 ft. A large portion of the lodgepole pine (*Pinus contorta*) stands is infested with dwarf mistletoe (*Arceuthobium americanum*). Over the last century the overstories have been invaded numerous times by epidemic populations of mountain pine beetle (*Dendroctonus ponderosae*). *Vaccinium scoparium* provides the predominant understory cover.

Table 1—Habitat components of the Thornburg Area, Ashley National Forest

Component	Average age	Size
	Years	*Acres*
Aspen small sawtimber	-	10
Aspen poles	-	316
Douglas-fir large sawtimber	272	597
Douglas-fir small sawtimber	187	4,268
Douglas-fir poles	159	233
Lodgepole pine small sawtimber	151	8,084
Lodgepole pine poles	102	7,270
Lodgepole pine seedling-sapling	39	84
Spruce small sawtimber	150	120
Mixed aspen, Douglas-fir, lodgepole	-	447
Noncommercial aspen	-	18
Noncommercial Douglas-fir	-	52
Brush	-	194
Water	-	298
Nonforest	-	2,518
Total		24,509

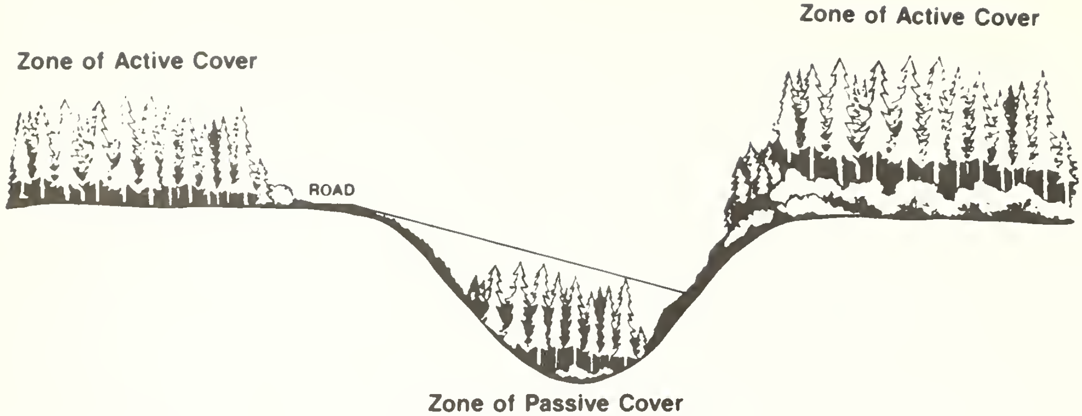

Figure 1—The relationship between roads, topographic features, and elk hiding cover.

This sale area was selected because it is large enough (24,000 acres) to address the cumulative effects of elk hiding cover and provides an excellent opportunity to improve both stand and elk habitat.

ELK HIDING COVER

Elk require a variety of cover habitats that occur in repeatable quantities throughout a herd's home range. The importance of hiding cover varies with seasonal behavioral patterns and the area's management activities. Generally speaking, the cover component can be partitioned into cover that results from topographic features (passive) and cover that is actively sought as some form of security from harassment or predation (fig. 1). Thomas and others (1976) defined security cover as the habitat required to hide 90 percent of an elk within 200 ft of an observer. This paper deals with security/hiding cover.

METHODS

Lyon and Marcum (unpublished) provided the tool to rapidly evaluate hiding cover associated with series of stand conditions. Their PC program "HIDE", which was initially written in GWBASIC for IBM compatible computers, has been modified for use on Data General mainframes. The program uses stem diameters and density information. Input data are analyzed with a series of trigonometric calculations that project the widths of randomly located trees to a distance of 200 ft from the point of observation. The percentage of the arc visually blocked is determined and evaluated on sections wide enough to hide an elk.

Smith and Long (in press) developed a computer simulation model that evaluates the elk hiding cover guidelines in lodgepole pine stands of the Rocky Mountain Region of the Forest Service, U.S. Department of Agriculture. Their model creates an even-aged stand structure from estimates of quadratic mean diameter (QMD), tree density (TPA), and tree height. The model has the flexibility of dealing with stand clumpiness and a uniform or random distribution of stems within a stand. It also outputs the average stand diameter (ASD), stand density index (SDI), and basal area for the simulated stand. The relationship that Smith and Long (in press) developed between SDI, elk hiding, and thermal cover is illustrated in figure 2.

We used the Utah variant of the Prognosis Stand Simulation Model (Wykoff and others 1982) to simulate successional structural changes within the lodgepole pine stands of the Thornburg management area. Data derived from tree lists generated by the Prognosis Model were input into the elk cover models and the hiding cover value

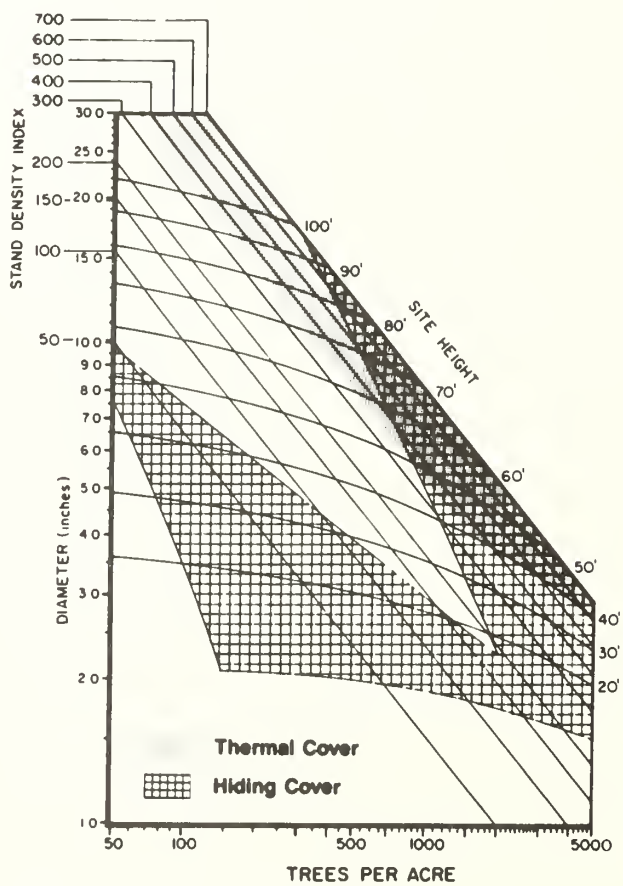

Figure 2—The relationship between elk hiding and thermal cover and stand structure (Smith and Long [in press]).

Table 2—Prognosis tree list summary for the years 1960 and 2010 resulting from the growth simulation of stand 217

D.b.h. class	Trees per acre 1960	2010
03	340	
04		144
05		158
12	260	
13		110
14	—	121
Total trees	600	533

Table 3—Prognosis summary statistics for growth simulation of stand 217

Year	Age	No. trees	SDI[1]	QMD[2]
1960	130	600	448	8.3
2010	180	533	493	9.5

[1]Stand density index.
[2]Quadratic Mean Diameter.

for each stand was calculated. Tables 2 and 3 display selected edited prognosis data entered into the "HIDE" and Smith and Long model, respectively.

Using both models, we calculated the elk cover values for a group of randomly selected stands that were representative of the management area's overstory. When we compared the results of both models, the discrepancies were minor and existed only in the calculated elk cover values. Because the models randomly position the trees, we considered the differences in model outputs to be insignificant. Based on this finding and because HIDE outputs the probabilities (table 4) associated with 100 randomly placed elk meeting the cover definition, the entire management evaluation is based on lodgepole pine stands and the Lyon-Marcum model.

We related the stand density index (SDI) (Reineke 1933) to elk habitat conditions because it represents a predictor of structural stand conditions that is not influenced by stand age or site quality. Generalizations can be made about any stand's structural condition as it relates to elk hiding cover by knowing only the stand's QMD and TPA. In addition, the index is easily related to developmental growth and incorporates the major variables used in stand modeling, thus can be used to bridge the gap among ecologists and managers with different levels and emphases in training. Finally, the index is an excellent tool for evaluating stand structure and prescribing stand management opportunities when starting density management in young stands. The early recognition and management of stand structural conditions assure that elk hiding cover is provided for longer periods of time and at an appropriate time and spatial location.

In the process of habitat evaluation it is important to keep the total needs of large free-ranging species, such as elk, in perspective. While each stand contributes to the

Table 4—The comparison of the distribution of 100 random elk that would find hiding cover along an arc 200 ft from the observer for six prognosis growth simulations

Stand	No. stems	SDI	QMD	Cycle[1]	Hiding cover class 10	20	30	40	50	60	70	80	90	[2]90+
1	200	139	8.0	0	7	7	12	10	21	12	9	2	7	14
1	200	215	10.5	5	3	2	7	2	10	16	12	12	17	19
2	602	181	4.7	0		3	2	2	3	16	22	22	26	14
2	602	356	7.5	5					3	2	7	17	17	54
3	1,251	288	4.0	0							3	14	40	43
[3]3	1,041	519	6.5	5					2	2		5	13	78

[1]10-year cycle period.
[2]Only this class is hiding cover by definition.
[3]This stand reached an SDI of 400 at age 85 years and achieved 75 percent elk hiding cover.

habitat quality of an animal's home range, area analysis is far more meaningful than single-stand analysis. Lyon (personal communication) suggests that, lacking an alternative, we can logically equate 100 acres of 50 percent cover with 50 acres of 100 percent cover. To arrive at an area hiding cover index, we adjusted the area of each stand by its hiding cover index, summed the adjusted values, and divided by the size of total sale area. This method allows for evaluating the potential management opportunities associated with the distribution of d.b.h. diameter classes and stand juxtaposition.

RESULTS AND DISCUSSION

Table 4 summarizes the simulated growth patterns of three stands with different stand densities. After 50 years of growth simulation, the quadratic mean diameter (QMD) for stand 1 (age 140) increased 2.5 inches. The projected SDI of 215 for this stand indicates that it has not reached the stage of development (SDI 400) when density-related mortality would be expected to occur (McCarter and Long 1986). The elk hiding cover index is 19 percent, which represents an increase of about 5 percent in 50 years. Should this stand continue to develop to a QMD of 16.5 inches (SDI 448), the structural regimen would improve the elk hiding cover index from 19 to 37 percent. At this point, the stand exceeds the point when density-related mortality would occur and far exceeds the age, size, and general stand conditions when catastrophic mortality, due to the mountain pine beetle, should occur (Cole and Amman 1980). However, the development of hiding cover in a typical stand with these conditions would not be expected to achieve the 90 percent level because the increase in bole size is the only variable that contributes to elk cover.

Model forecasting within this stand indicates there is little opportunity to increase hiding cover. Management emphasis should enhance other resource values.

Following 50 years of growth simulation, stand 2 (age 130) is approaching a development stage when density-related mortality would become a management consideration (McCarter and Long 1986). Over the 50-year simulation period, the hiding cover index has increased about threefold (14 to 54 percent). If an intermediate treatment (thinning from below) were prescribed to promote the future production of small sawtimber, with a stand size objective of 10.5 inches QMD, the current stand density would need to be reduced to 350 trees per acre and a target SDI of 378. This would cause an immediate decline in the elk cover index from 54 to 35 percent. By the time the 10.5-inch QMD goal was achieved the cover index would have returned to about 51 percent. Generally speaking, as stands are thinned from below the elk cover is reduced significantly because small trees with ground level crowns are removed. In a silvicultural sense thinning changed the tree size class from something not currently marketable to an acceptable sawlog size product.

However, by thinning this stand, the hiding cover index would improve to the 50 percent level. At that time the stand could be harvested and would be expected to return to hiding cover (90 percent) in about 20 years. The strategy of managing this stand at 75 percent of full site occupancy, a point when timber volume production rates are being maximized, compared with the no density treatment, results in significantly improved elk hiding cover conditions for longer periods of time.

For demonstration purposes, stand 3 (table 4) illustrates elk cover changes associated with the simulated growth pattern of a younger, dense, pole stand. Throughout the simulated period, the tree crowns are well above the height that would provide elk hiding cover. The improvement of this stand's hiding cover index from 43 to 78 percent is a reflection of bole area development and represents the highest level of cover the stand is capable of producing. From a timber production point of view, this age and density condition suggests a poor developmental stand regime. The most advantageous period of treatment (1-3 inches d.b.h. and 15-25 ft tall) for the production of sawtimber has passed. In this case, to achieve a goal of 10.0 QMD, the number of stems would have to be reduced to 245. This would drastically reduce the stand's cover index from 78 to 7 percent. Therefore, if the current stand is not critical to the area's overall cover requirement and considering its increasing susceptibility to fire, insect, disease, and other mortality agents, the most productive alternative would be to salvage the wood products and begin a new cycle more conducive to productive silvicultural manipulation, and incorporating wildlife objectives in the prescriptive goal.

Figure 2 was modified from McCarter and Long (1986) and Smith and Long (in press) and is used to illustrate the relationship between the development of lodgepole pine stands and the presence of elk hiding cover as defined by Thomas and others (1976). For purposes of this discussion the figure provides several focal points. Generally speaking, in stands taller than 15 ft elk hiding cover declines during the intermediate stages of stand development. The decline is associated with the initial period of crown closure at about SDI 125 and continues until most stands enter the lower limit of the zone of self-thinning (SDI 400) or the point at which density-related mortality begins. When the stand SDI is at 125, a broad range of d.b.h. conditions can contribute to elk cover; stand height has little influence on this cover. Thus, tree spacing and bole area size are the major stand components that result in elk hiding cover. The cover regime again improves as natural competition or thinning opens the stand and multistoried stand structures develop. During this period of stand development, it is obvious that prescriptions that thin from below temporarily accentuate the loss of hiding cover.

We evaluated the importance of the lodgepole pine component (15,438 acres) within the 24,211-acre management area. Our analysis of the no-action alternative is illustrated in table 5. At the beginning of the simulation period, the overall hiding cover index was 55.8 percent. It is interesting to note that after 50 years of development, the index remained about the same (53.6 percent). However, during the simulation period, it is important to recognize what influence each size class has on the area's total elk cover index. Significant improvements (28.3 percent) occurred among the pole timber size class while the small sawtimber class declined (28.6 percent). It is apparent from these results and considering the juxtaposition of the individual stands that removal of the small sawtimber

Table 5—The successional trends of an area's cumulative elk hiding index associated with the 50-year simulation of lodgepole pine development

Lodgepole pine component	Average age	Total size	Simulation year index[1] 1960	2010
	Years	*Acres*	------ *Percent* ------	
Small sawtimber	151	8,084	76.2	47.6
Poles	102	7,270	31.6	59.9
Seedling-sapling	39	84	96.4	90.5
Area totals		15,438	55.8	53.6

[1] Index calculated by $\sum \frac{\text{((Individual stand hiding cover \%) (Stand acres))}}{\text{Total acres of lodgepole pine}}$

component of mixed diameter class stands during the simulation period would have the smallest impact on the area's elk cover index. When the total acres available for replacement cover are considered, removal of the small timber could have a twofold effect in improving the area's long-term hiding cover objective. It is apparent that the manipulation of just the pole timber component would markedly reduce the area cover index for a significant period of time.

SUMMARY

To date, significant efforts have been made to understand the habitat requirements of elk. The results of these efforts provide criteria to evaluate goal-oriented silvicultural prescriptions. When a standard such as hiding cover is defined in terms of stand structure, the driving forces of plant community competition can be managed to provide an area stand mosaic that is conducive to long-term elk habitat and timber production goals. Management of stand structure becomes an opportunity to interject some control into the production of a broad array of forest community products.

The evaluation of an area rather than single projects assures a pool of habitat conditions across time and space. For example, stands that are developing into hiding cover may currently have visual resource values. Identification of stands early in the growth cycle enhances the opportunities to adjust an area's forage-cover mosaic and provide for the control of insect, disease, fire, and stand-density-related mortality.

The maintenance of habitat juxtaposition through a diversification of timber size and age classes ensures that special habitat considerations across a management area and throughout a planning period are adequately addressed.

The methodology designed for developing an area's elk hiding cover index outlines a process for evaluating the cumulative impacts of multiproject scenarios on long-term elk habitat and timber production goals. This is accomplished, primarily, by preventing the development of a forest community mosaic that is predominantly one size or age class.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Leo Torba)—With lodgepole pine 120 to 200 years old in dense stands of 7- to 14-inch d.b.h. trees, isn't this model for elk hiding cover going to be difficult to achieve considering the mountain pine beetle problem?

A.—The model presented was a cumulation of both an elk cover model and an individual tree growth model (Prognosis). Thus, a prediction could be made considering any mountain pine beetle problem. The solution might be clearcutting, which sets the successional stage back to what was referred to as the "Christmas tree" stage. Cover requirements are met with no influence from pine beetles. Also, higher elevation stands, like many in our study area, have not been influenced appreciably by pine beetles.

Q. (from Allen Chrisman)—Assuming that the cover meets hiding cover definition, is there a minimum height of regenerated stands that big game (elk) will begin to feel secure in again?

A.—Assuming that the cover meets the definition of hiding cover, the minimum height required would be when the average height of the crowns equals elk height.

Q. (from R. Strang)—Do the hiding classes identified in your table assume level terrain? If so, how do you allow for broken topography?

A.—The model presented does not assume level terrain. It does, however, assume "active cover" is in play, which means elk could be viewed without obstructions except for vegetative cover. Broken topography brings in the concept of "passive cover" where the adage "out of sight, out of mind" applies. Digital terrain information will be put into the model when it becomes available.

RELATIONSHIP OF STAND CANOPY DENSITY TO FORAGE PRODUCTION

Don Bedunah
William Pfingsten
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ABSTRACT

This paper reviews research dealing with the integration of timber and livestock management in the Northern Rocky Mountains and describes studies on the influence of forest canopy on understory production. Livestock production has long been an important component of multiple use in forests of the Northern Rocky Mountains; yet little information is available on improving the grazing-timber multiple use in sapling, pole, or immature sawtimber stands. The potential for improving forage quantity is great, but the potential conflicts of grazing and tree establishment are also great. The challenge facing managers is to recognize these potentials and develop management techniques that ensure optimum multiresource production.

INTRODUCTION

Although grazing by domestic livestock has long been an important component of multiple use of our western forests, there have been few site-specific studies concerning livestock-timber management interactions, especially in young timber stands (sapling, pole, and immature sawtimber stands). Most studies have concentrated on the regeneration stage because of the problems of livestock damaging tree seedlings, competition between grasses and tree seedlings, and the greater potential forage production of clearcuts. Treatments to improve forage in immature stands have concentrated on the impacts of thinning on forage production, but very little research was found on other treatments such as underburning or seeding domestic grasses to increase livestock forage. Because of the paucity of information on the potential of agro-forestry in young stands, we have broadened this paper to include research concerning livestock/timber management in the regeneration stage.

Each forest site has certain characteristics that determine its suitability for livestock grazing. Forested ranges can be separated into (1) permanent forest range and (2) transitory forest range to describe their potential to produce livestock forage. Permanent forest range is characterized by an open overstory of trees, with a permanent moderate forage supply. Such range is generally found on lower elevation, warm, and dry sites that historically were maintained in an open condition by surface fires. Transitory range is an area made suitable for livestock grazing by removing the tree overstory. As canopy cover is altered by human activities or natural factors such as fire, insect damage, or disease the value of the site for livestock production may be significantly altered. Subsequent changes in understory composition and production and the successional pattern of a site will vary with kind of disturbance, character of vegetation on the site at time of disturbance, character of vegetation surrounding the site, and history of disturbance on the site (Lyon and Stickney 1976).

The grazing potential of most forested areas is underutilized, and very little research has been directed at understanding the full potential of agro-forestry in the Northwest. Basile and Jensen (1971) described the incomplete use of lodgepole pine (*Pinus contorta*) transitory range as being a result of several administrative factors; chief among these is limited knowledge of the grazing resource, and a tendency to ignore it because it is transitory. Many forest managers also have a prejudice against livestock because of presumed grazing damage to expensive plantations and damage to natural regeneration. Livestock can be beneficial or detrimental to the timber component, depending on several management factors. Detrimental effects result from browsing on young trees, trampling, soil compaction, and increased soil erosion. Benefits may result from exposure of mineral soil for tree establishment, decreased competition to the tree seedling, less tree seedling damage by rodents because livestock reduce rodent cover through grazing of herbaceous and shrubby growth, and the subsequent reduction of flammable understory vegetation.

LITERATURE REVIEW

A knowledge of the terminology used in understory studies is necessary to understand the potential production of livestock forage. In much of the literature, total standing crop of understory vegetation (the sum of forbs, shrubs, and graminoids) is used to estimate a site's potential to produce forage. However, forage is the plant material used normally for food by a particular species of animal (such as cattle, sheep, deer, or elk). Herbage is considered as all herbaceous plant material present as graminoids and forbs. Cattle generally consume large amounts of graminoids compared to forbs or shrubs, but not all graminoids have high forage value. Likewise, some forbs and shrubs will be preferred species for cattle, but may not be preferred by another species of herbivore. Without a knowledge of the plant species present on a site and the herbivore considered, it is impossible to calculate the amount and quality of forage and its ability to meet the nutritional requirements of grazing animals.

Stand management practices affect stand density, which is a key controlling factor for undergrowth composition and production. Timber harvesting and stand improvement practices such as shelterwood cuts, selective cuts, and thinning increase understory production by increasing the availability of light, water, and nutrients to understory plants. In the ponderosa pine (*Pinus ponderosa*) zone of the Black Hills, understory production increased logarithmically with a reduction in canopy cover (Pase 1958). Grasses generally showed the largest increase with opening of the canopy and largest decrease with closing canopy. Pase and Hurd (1957) found similar trends when comparing herbage yields to basal area of immature ponderosa pine stands. In eastern Washington, McConnel and Smith (1970) found that with a 90 percent canopy of ponderosa pine, forbs produced 65 lb/acre (73 kg/ha), shrubs were absent, and grasses yielded only 2 lb/acre (2 kg/ha). As thinning reduced the canopy, grasses increased to nearly 290 lb/acre (325 kg/ha), forbs to 210 lb/acre (235 kg/ha), and shrubs to 60 lb/acre (67 kg/ha). Conway (1982) found a decrease in herbage yield as thinning spacing decreased in lodgepole pine stands in Montana; there was a negative relationship between canopy cover and herbage yield ($r = 0.70$ to $r = 0.22$ depending on the site). In central Oregon, Dealy (1975) found a 300 to 1,000 percent increase in understory herbage cover after thinning mature lodgepole pine; 13-ft and 19-ft spacings were the most productive for increasing herbage. Basile and Jensen (1971) reported that clearcutting and thinning of subsequent lodgepole pine regeneration in Montana stimulated understory production that would provide a grazing resource for 20 years or more. Herbaceous production on 4- to 5-year-old clearcuts in the Douglas-fir (*Pseudotsuga menziesii*) zone of western Montana averaged about 1,100 lb/acre (1,232 kg/ha) (Lewis 1967).

The potential for forage on transitory range is considerable because of the large amount of land area in this category, the productivity of certain sites, and the opportunity to reseed to forage species. Since noxious plant invasion is such a significant resource problem, and the spread of noxious plants creates liability concerns, seeding to domestic grasses offers added benefits because it improves livestock forage while competing with unwanted "weedy" plants. McLean and Clark (1980) reported that livestock forage yields can be significantly increased on clearcuts by seeding domestic grasses in the Douglas-fir and Engelmann spruce-subalpine fir (*Picea engelmannii*/*Abies lasiocarpa*) zones. Light grass seeding rates were recommended to reduce early competition with tree seedlings. Krueger (1983) reported a high annual yield of herbaceous plants the second year after clearcutting; however, much of the herbage was unusable as livestock forage, with over half being bull thistle (*Cirsium vulgare*). Eight years after treatment, bull thistle, strawberry (*Fragaria* spp.), western yarrow (*Achillea millefolium*), and blue wildrye (*Elymus glaucus*) dominated the clearcut. Krueger (1983) reported that seeding domestic grasses on a Douglas-fir/ninebark (*Physocarpus malvaceus*) habitat type or grand fir/*Pachystima myrsinites* habitat type significantly reduced native herbaceous species and improved livestock forage.

The impact of seeding domestic grasses on tree regeneration sites has been a major concern to silviculturists. Tree regeneration may be impacted because of competition for water and nutrients, and livestock may browse or trample tree seedlings. McLean and Clark (1980) reported that, generally, the presence of domestic grass had little effect on conifer germination and survival, except where the stand of grass became overly dense. Wheeler and others (1980) reported that there was no difference in survival or height of western larch (*Larix occidentalis*), Douglas-fir, or western white pine (*Pinus monticola*) on plots seeded to grass and unseeded plots. In cases where inhibiting effects were apparent, the competition from native vegetation was as much a factor as the competition from domestic grasses. Vogel (1985) found that elk sedge (*Carex geyeri*), and pinegrass (*Calamagrostis rubescens*) were capable of net photosynthesis at very low leaf water potentials (–35 bars); this supports the conclusion of Wheeler and others (1980) of the competitive influence of native species.

Controlled or "proper grazing" is critical to the tree regeneration question and may be the major management problem on many sites. Several researchers have reported that controlled grazing can be compatible with timber production. Doescher and Alejandro (1985) found that highly palatable seeded species served as an attractant and minimal browsing and trampling of tree seedlings was observed; grazing also increased the amount of soil water available for tree growth. Kingery and others (1987) found that where livestock grazing was light and ground cover was high, damage to tree seedlings by rodents was the highest. Edgerton (1971) reported that mixed conifer stands that had been clearcut, planted with trees, and seeded to grass were a potential source of summer forage for livestock and wildlife. After five growing seasons, grazing had neither harmed nor benefited growth and survival of ponderosa pine in the plantation. Krueger (1983) summarized 20 years of data of cattle grazing on a forest plantation and found no difference in survival of Douglas-fir, western white pine, or western larch. Trampling of tree seedlings by livestock accounted for 8 percent of total seedling mortality and did not occur after the fourth year. Browsing and uprooting of seedlings by big game and rodents accounted for 18 percent of mortality in pastures open to game animals. Height growth of seedlings was greater on grazed pastures. Wallace (1983) stated that cattle caused little or no browsing damage in the grass-seeded lodgepole pine clearcuts except under extreme conditions. Rummell (1951) concluded that heavy livestock grazing of the understory rather than exclusion of fire was the main factor in dense advanced tree reproduction on a ponderosa pine/pinegrass type in central Washington.

Although conflicts between livestock and tree regeneration have been a major concern, there are few recommendations concerning grazing management on regeneration sites. Kingery (1985) stated that close management of livestock on new plantations is necessary if losses associated with grazing are to be within an acceptable level. Timing of grazing, available forage, distribution of livestock, and class of livestock will all be factors determining "proper use." Overgrazing is likely without management of livestock, and tree seedling damage will be more prevalent. In British Columbia, McLean and Clark (1980) suggested that clearcuts should be intensively grazed only for short periods; if there is a group of clearcuts in the area, grazing should be on a rotation basis. The degree of forage utilization and the time when the forage was utilized were the most critical factors in determining tree-grazing compatibility; where the period of grazing was too long, damage to tree seedlings was extensive.

RECENT STUDIES IN WESTERN MONTANA

Our studies in western Montana provide additional data on forage production on forested sites. For 39 sites in the Douglas-fir series in Missoula County, available forage varied from 12 lb/acre (13 kg/ha) for a Douglas-fir/*Linnaea borealis* habitat type with 75 percent canopy cover to 295 lb/acre (330 kg/ha) for a Douglas-fir/*Agropyron spicatum* habitat type with 12 percent canopy cover. Comparison of sites in four ecological groups showed similar mean canopy cover and total standing crop but differences in shrub, graminoid, and cattle forage production (table 1).

We found a significant relationship between canopy cover and available forage, grass standing crop, and total standing crop. Canopy cover accounted for 20 percent to 48 percent of the variability in forage standing crop models. When the habitat types were grouped by moisture regime (dry, moderate, or wet), an additional 10 to 18 percent of the variability in forage production was accounted for in the models. No model accounted for more than 58 percent of the variability in our data. Understory standing crop measurements, such as forage production, were highly variable on habitat types grouped by moisture regime with the same approximate canopy cover. An examination of residual plots showed that several of the outliers were associated with site disturbances such as past timber or grazing management practices.

Following these surveys we initiated a controlled study to examine the influence of thinning treatments and clearcutting on understory production of three overstocked forest sites. The remainder of this presentation will present preliminary results from this study.

Habitat types are presented using abbreviations from Pfister and others (1977).

ABGR/PAMY	*Abies grandis / Pachistima myrinites*
PSME/PHMA	*Pseudotsuga menziesii / Physocarpus malvaceous*
PSME/LIBO	*Pseudotsuga menziesii / Linnaea borealis*
PSME/AGSP	*Pseudotsuga menziesii / Agropyron spicatum*
PSME/VAGL	*Pseudotsuga menziesii / Vaccinium globulare*
PSME/VACA	*Pseudotsuga menziesii / Vaccinium caespitosum*
PSME/LIBO,VAGL	*Pseudotsuga menziesii / Linnaea borealis, Vaccinium globulare*
PSME/CARU,CARU	*Pseudotsuga menziesii / Calamagrostis rubescens, Calamagrostis rubescens*
PSME/SYAL,CARU	*Pseudotsuga menziesii / Symphoricarpus albus, Calamagrostis rubescens*

Table 1—A comparison of canopy cover (percent), standing crop of graminoids, forbs, shrubs, and available cattle forage (lb/acre) in three habitat types and a habitat group in western Montana

	Habitat type, phase or group			
	PSME/LIBO,VAGL (*n*=6)[2]	PSME/CARU,CARU (*n*=5)	PSME/SYAL,CARU (*n*=6)	Warm group[1] (*n*=4)
	Percent			
Overstory Canopy cover	37 (11)[3]	37 (6)	45 (2)	21 (8)
	Lb/acre			
Standing crop:				
Graminoids	175 (66)	454 (70)	262 (64)	382 (115)
Forbs	392 (60)	429 (51)	208 (66)	343 (147)
Shrubs	203 (19)	63 (19)	65 (13)	45 (17)
Total	770 (26)	946 (113)	535 (45)	770 (257)
Forage	57 (17)	154 (16)	130 (24)	164 (46)

[1]The warm group was four sites classified as either PSME/AGSP, PSME/SYAL,AGSP, or PSME/CARU,AGSP. All abbreviations are from Pfister and others (1977).
[2]*n* is the sample size or number of sites within the habitat type/phase or group sampled. Each site was sampled by clipping ten 4.8-ft^2 plots.
[3]Number in parentheses is the standard error of the mean (Standard Deviation/*n*).

LUBRECHT STAND THINNING STUDY

Understory vegetation was measured on forest stands manipulated by recent overstory removal at the Lubrecht Experimental Forest located approximately 35 mi (56 km) northeast of Missoula. Annual average temperature in the forest for a 27-year period (1956 to 1982) was 39 °F (4.0 °C) and yearly precipitation averaged 17.9 inches (45.5 cm). Forest stand manipulation treatments were on three separate sites. The sites represented different overstory dominants and will be referred to as the Douglas-fir site, the lodgepole pine site, and the larch site. The Douglas-fir site was dominated by a 90-year-old stand of predominately Douglas-fir and was classified as a PSME/SYAL habitat type. The lodgepole pine site was a 60-year-old stand of lodgepole pine and was classified as a PSME/VACA habitat type. The larch site was dominated by 45- to 50-year-old western larch and was classified as a PSME/LIBO, VAGL habitat type and phase.

Methods

Treatments—Stand treatments were three different thinning spacings, a clearcut, and an undisturbed forest control. Thinning spacings were 10 by 10 ft (about 440 trees/acre), 14 by 14 ft (about 220 trees/acre), and 20 by 20 ft (about 110 trees/acre). Stand manipulation treatments were applied in 1982 using hand thinning and whole-tree skidding with a four-wheel-drive farm tractor equipped with a grapple skidder. Scarification of the sites was light. Some big game grazing occurred but was considered minor. Livestock grazing was excluded from treatments.

Standing Crop—Three macroplots of 0.10 acre (0.04 ha) were randomly located in each treatment. The macroplots avoided edges and inclusions of different habitat types. Standing crop data were collected by clipping nine randomly located 4.8-ft^2 (0.45-m^2) plots per treatment at a 0.5-inch (1.3-cm) stubble height. Clipped material was separated by species, ovendried at 140 °F (60 °C) and converted to pounds per acre. Standing crop data were classified into four groups: (1) total graminoid standing crop (sum of grasses, sedges, and rushes); (2) forb standing crop (sum of all forbs); (3) shrub standing crop (sum of all shrubs and half-shrubs); and (4) total standing crop (sum of graminoids, forbs, and shrubs). Standing crop data were collected near the end of the growing season in 1983, 1984, and 1985.

Forage standing crop was estimated from cattle preference values of each plant species (USDA SCS 1982); each plant species was rated as preferred, desirable, or undesirable cattle forage. Forage was then calculated by: Forage Standing Crop = Preferred Standing Crop + (Desirable Standing Crop/2). This procedure was developed to maintain preferred plants in the plant community by conservatively adjusting stocking rates since it is known that preferred plants will be utilized more heavily than desirable plants. In the lodgepole and larch sites standing crop of all desirable species was included as forage standing crop because there was almost a complete lack of species that could be classified as preferred.

Available Forage and Grazing Capacity—Available cattle forage was determined as 50 percent of the forage standing crop to maintain healthy forage plants. Grazing capacity was calculated on an animal unit month (AUM) basis. An AUM is the amount of forage required by an animal unit, in this study a cow/calf pair, for 1 month. Forage requirement for a cow/calf pair was considered to be 750 lb (340 kg)/mo or 25 lb (11 kg)/day. Grazing capacity for sites was not adjusted for distance to water, mechanical barriers, or other nonforage site factors and therefore represents an estimated potential grazing capacity.

Data Analysis—The experiment was a completely randomized design with a factorial arrangement. The factors were time (year), site, and treatment. Differences between means were determined with Duncan's New Multiple Range Test (Steel and Torrie 1960).

Results

Initial species composition and understory standing crop varied by site; site differences explain some of the interactions and will be presented in the Discussion section. The response of understory standing crop is presented by year.

1983—One year after treatment there was no difference in forb, shrub, or graminoid standing crop for any treatment (fig. 1). Across treatments graminoid, forb, and shrub standing crop averaged only 53 lb/acre (59 kg/ha), 46 lb/acre (51 kg/ha), and 96 lb/acre (107 kg/ha), respectively, which shows the poor initial state of understory vegetation for livestock production. We did find a significant increase in available forage in the clearcut compared to the control, but in 1983 no treatment produced enough cattle forage to maintain a viable cattle allotment (tables 2 and 3).

1984—Graminoid standing crop was greater in the 14-ft and 20-ft spacings and the clearcut compared to the control and 10-ft spacing (fig. 1). Opening of canopy by thinning to greater than a 10-ft spacing was necessary to increase graminoid standing crop and forage standing crop (table 2) compared to the control. Forb standing crop was greater in the clearcut compared to all other treatments (fig. 1). The increased forb standing crop was largely from an increase in thistles (*Cirsium* spp.), dandelion (*Taraxacum officinale*), and western yarrow. These species are aggressive seral species that provide little forage for cattle.

The major graminoid and forage on the lodgepole pine and larch sites was pinegrass; therefore, cattle management would be determined by this species. On the Douglas-fir site elk sedge was the dominant graminoid in the control and thinning treatments, but pinegrass increased in percent composition as the overstory was reduced. Grazing capacity of the control was only 29

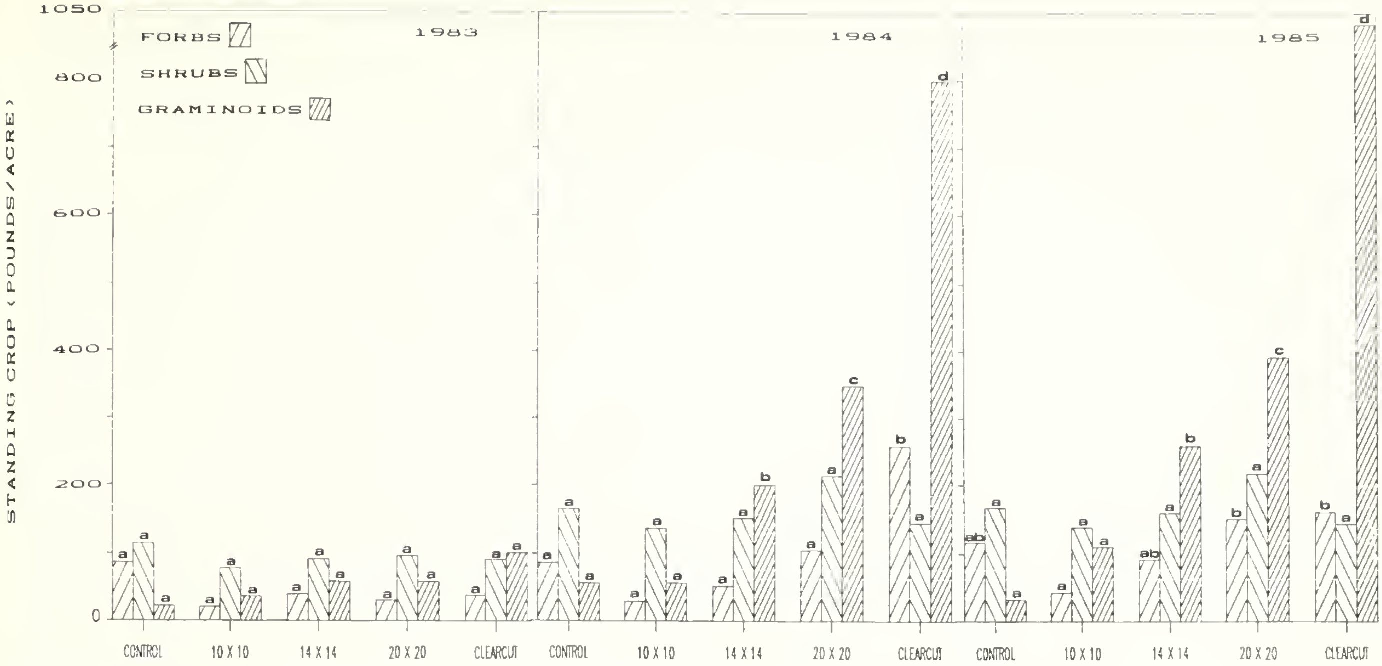

Figure 1—Influence of stand manipulation on standing crop (lb/acre) of forbs, shrubs, and graminoids across all sites in 1983, 1984, and 1985. Means appearing with a similar letter in the same year are not different at the 0.05 level of probability.

Table 2—Influence of stand manipulation treatments on total understory standing crop (lb/acre) and available forage (lb/acre) for 1983, 1984, and 1985

	Year					
	1983		1984		1985	
Treatment	Total standing crop[1]	Available forage[2]	Total standing crop	Available forage	Total standing crop	Available forage
Control	[3]224 a	13 a	311 ab	31 a	319 a	27 a
10 by 10 ft	134 a	19 ab	223 a	30 a	293 a	61 ab
14 by 14 ft	191 a	36 ab	405 b	107 b	512 b	135 bc
20 by 20 ft	186 a	32 ab	669 c	176 c	760 c	193 c
Clearcut	230 a	49 b	1,206 d	363 d	1,411 d	508 d

[1]Total standing crop = sum of graminoids, forbs, and shrubs.
[2]Available forage is the forage (lb/acre) which is available for livestock consumption.
[3]Means followed by a similar letter in the column are not different at the 0.05 level of probability.

Table 3—Influence of stand manipulation treatments on potential grazing capacity (acres/AUM) in 1983, 1984, and 1985

	Potential grazing capacity by treatment[1]				
Year	Control	10 by 10 ft	14 by 14 ft	20 by 20 ft	Clearcut
1983	[2]58.8 a	40.0 ab	20.8 ab	23.3 ab	15.4 b
1984	24.4 a	25.0 a	7.0 b	4.2 c	2.1 d
1985	27.8 a	12.3 ab	5.5 bc	3.9 c	1.5 d

[1]Potential grazing capacity (acres/AUM) was determined for a cow/calf and no cuts were made in grazing capacity for distance to water or other nonforage site factors.
[2]Means followed by a similar letter in the same row are not different at the 0.05 level of probability.

percent, 17 percent, and 9 percent of the 14-ft and 20-ft spacings and the clearcut, respectively (table 3).

1985—Graminoid standing crop remained greater in the 14-ft and 20-ft spacings and the clearcut compared to the control and 10-ft spacing (fig. 1). Precipitation for the months of May, June, and July averaged only 45 percent of the long-term average; yet, the clearcut graminoid standing crop averaged 1,015 lb/acre (1,137 kg/ha) which is similar to that of many of the upland range sites in western Montana.

The clearcut had a greater standing crop of western yarrow than other treatments, but total forb production was not different from that in the control. It was apparent that after only 3 years grass production in the clearcut had reduced the thistle biomass.

Available forage was greater in the 14-ft and 20-ft spacings, and the clearcut than the control (table 2). Grazing capacity of the control compared to the 10-ft, 14-ft, and 20-ft spacings, and the clearcut was only 44 percent, 20 percent, 14 percent, and 5 percent, respectively (table 3). By 1985 the 10-ft spacing had a trend of increased grazing capacity compared to the control. A comparison of total standing crop of understory to available forage also shows that a higher percentage of the total standing crop was forage on thinned treatments and the clearcut than the control. Only 8 percent of the total standing crop of the control was forage compared to 20 percent, 26 percent, 25 percent, and 36 percent for the 10-ft, 14-ft, and 20-ft spacings and clearcut.

Discussion

Before stand manipulation, the grazing capacity was estimated at only 32 acres/AUM, which would not provide a viable grazing allotment. A comparison of treatments, sites, and years showed that standing crop was affected by stand manipulation (fig. 1) and time (fig. 2). The increase in standing crop was the understory's response to the opening of the canopy. Thinning to either a 14-ft or 20-ft spacing or clearcutting resulted in greater graminoid standing crop and grazing capacity compared to the forest control, but there were significant site-by-year and site-by-treatment interactions. These interactions were a result of site differences in initial understory species composition and standing crop and differences in site environmental conditions. Some of the important differences that may relate to management follow.

The larch site had greater forb standing crop compared to the Douglas-fir and lodgepole pine sites and greater shrub and total understory standing crop compared to the Douglas-fir site. The greater standing crop in the larch stand was a result of greater understory standing crop in the original stand. Western yarrow increased in all

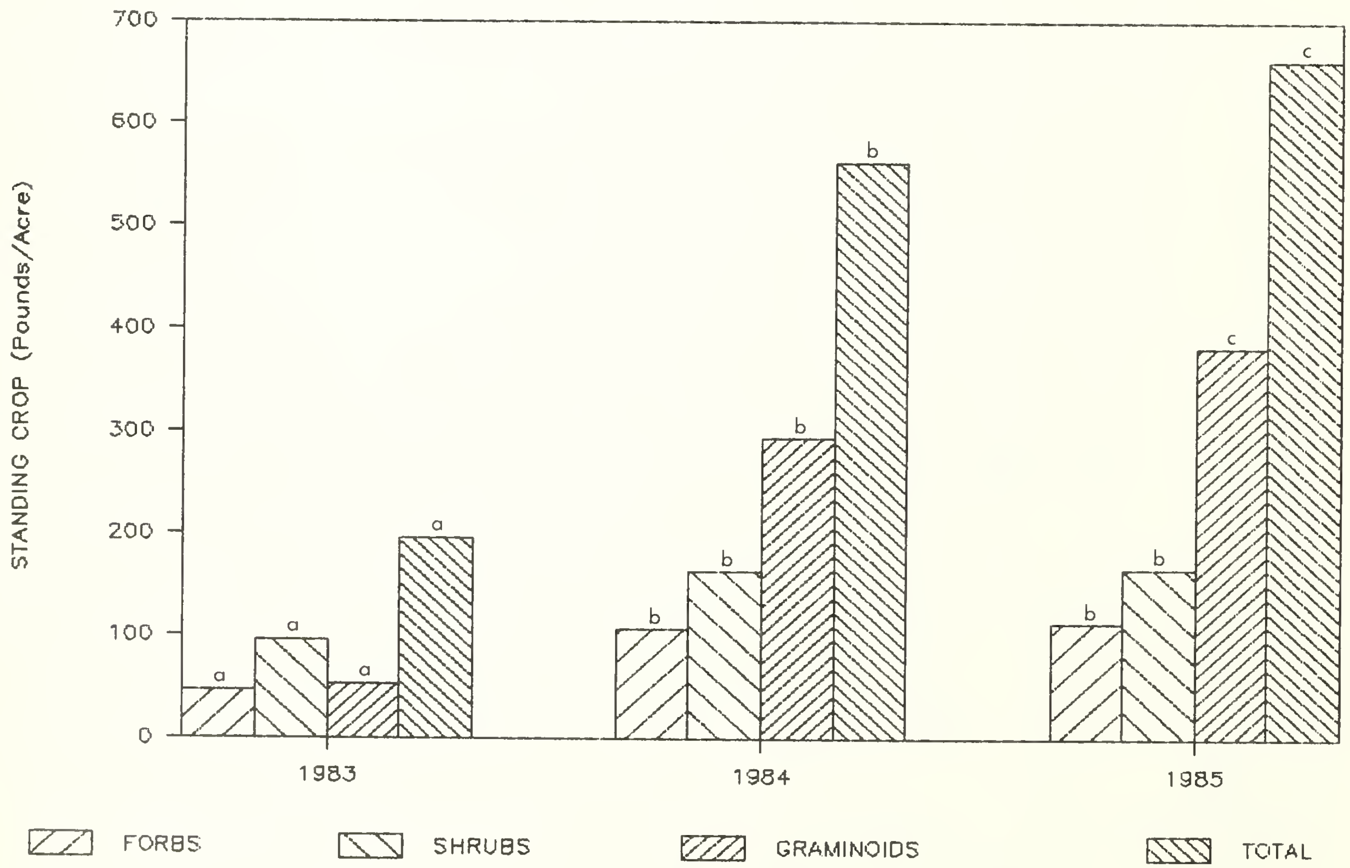

Figure 2—Influence of stand manipulation on standing crop (lb/acre) of forbs, shrubs, graminoids, and total (forbs+shrubs+graminoids) averaged across all sites. Means of the same type of standing crop shown with a similar letter are not different at the 0.05 level of probability.

clearcuts and thistles became more frequent but increased in standing crop only in the Douglas-fir clearcut in 1984. Rummell and Holsher (1955) and Terwilliger (1964) reported that logging resulted in vegetation dominated by aggressive species such as western yarrow and thistles. In their studies 4 to 5 years were required for understory species to regain their original cover. If our study sites had received a greater scarification or were grazed heavily by livestock the problem of "weedy species" would be expected to increase.

Opening of the canopy on all sites increased the diversity of understory species, with diversity increasing as the overstory was reduced. All sites had higher shrub production compared to graminoid or forb production before treatment. The major increase in the understory standing crop on the thinned sites and clearcut was graminoids, predominately pinegrass.

The drought conditions of 1985 had a pronounced effect on understory standing crop for the larch site but not for the Douglas-fir or lodgepole pine sites. The dry conditions resulted in a decrease in graminoid standing crop, total standing crop, and grazing capacity on the larch site in the 14-ft and 20-ft spacings, and clearcut from 1984 to 1985. Graminoid and total standing crop and grazing capacity remained higher in the clearcut compared to all other treatments, but there was no difference in understory standing crop between the thinned treatments and the control. The lack of differences in graminoid standing crop and grazing capacity between the control and the 14-ft and 20-ft spacings in 1985 for the larch site resulted in significant treatment-by-site and year-by-treatment interactions.

Much of the forage standing crop in the Douglas-fir clearcut consisted of several preferred species such as elk sedge, rough fescue (*Festuca scabrella*), and timothy (*Phleum pratense*), and several desirable graminoids with pinegrass as dominant. The dominant cattle forage in the lodgepole and larch sites was pinegrass, which is often considered as having low palatability. However, cattle will readily graze pinegrass in June and July but tend to avoid it later in the year as it becomes more mature; they graze it only slightly where trees form a nearly complete canopy (McLean 1972). McLean (1967) reported daily gains in yearlings of 1.75 lb (0.8 kg)/day from June to October on Douglas-fir/pinegrass range. By early September, however, cattle began to lose weight because of the low palatability and low nutritional quality of pinegrass (McLean 1967; Shovlin 1962). To avoid such weight losses, cattle should be removed from pinegrass ranges by early September or heavily supplemented (McLean 1967, 1972).

Initial results of this study suggest that thinning these sites to a 14-ft or 20-ft spacing generally results in increased graminoid standing crop, forage availability, and thus potential grazing capacity by the second year posttreatment. Thinning to a 14-ft or 20-ft spacing increased forage availability by fivefold and sevenfold compared to the control, 3 years posttreatment. Graminoid standing crop, forage availability, and thus grazing capacity were higher on the clearcut than all other treatments.

We believe that intensive forest management practices such as thinning to reduce overstocking or timber harvesting could produce greater benefits to livestock production if some sites were reseeded to forage species that maintain palatability and forage quality later into the growing season. Pfingsten (study in progress) found a fivefold increase in graminoid standing crop in a thinned Douglas-fir stand that was underburned and seeded to preferred cattle forage species compared to the unseeded thinned stand. Seeding of domestic grass in an adjacent broadcast-burned clearcut also reduced noxious weed invasion and provided a major increase in forage quantity and quality. More information is needed on the impact of seeding introduced species, compared to the impact of native species, on timber production and value associated with livestock grazing.

SUMMARY

Forest land grazing, private and public, provides a large contribution to the year-long feed supplies of livestock operators. Many ranchers need an area where livestock can graze and gain weight while they produce winter feed on their own pastures. The impact of timber management practices on grazing allotments should be considered and coordinated. It is unreasonable to create a clearcut in an important area of an allotment and then expect cattle will avoid the area (Wallace 1983). Before logging or other timber management practices are initiated, grazing systems that will reduce possible conflicts should be considered. McLean and others (1971) and Crouch (1986) stated that biomass production from any single component may not justify intensive management such as tree thinning. Intensive management may be justified if it increases forage, timber, and water yields and if a number of land users share its costs.

Regeneration problems will continue to exist on many sites. Native and introduced grasses, forbs, and shrubs will compete with tree seedlings. On Douglas-fir sites in western Montana, silvicultural treatments that expose mineral soil and reduce vegetative competition will improve regeneration. Seeding of domestic grasses, however, offers the opportunity to increase livestock forage, decrease soil erosion, and reduce undesirable plants.

We believe that more information is needed to increase our knowledge of the potential of agro-forestry in the Rocky Mountain region. Multiple-use management creates many problems but produces many benefits. We know that heavy unrestricted grazing is detrimental to rangeland and forested lands. Controlled or proper grazing is compatible and may be beneficial on some forest sites. Likewise, no grazing may be the best alternative on other sites. Currently there is little information available on improving forage quality or quantity on thinned stands by reseeding or burning. With current economic conditions, few options dealing with more intensive management may seem possible. However, in the future better coordination between silviculturalists and livestock managers could improve the use and management of forested sites as resources become more scarce.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Diane Myers)—Would it not make more sense to put cattle on allotments where pinegrass is a dominant graminoid in early June instead of mid-July? Would earlier grazing seasons damage other forage species?

A.— I believe early "turn-on" dates are desirable where erosion is not a severe problem. I have seen clearcuts in western Montana where pinegrass was grazed preferably to rough fescue or bluebunch wheatgrass early in the grazing season (before June 15). As pinegrass becomes more mature it becomes unpalatable. Early "turn-on" dates will usually improve cattle distribution because cattle will "range" much better when the forage is green and water is not as much a problem. As conditions become drier livestock will spend more time in riparian zones.

Earlier grazing seasons will be detrimental to other forage species if cattle concentrate on certain areas or plant species (very site specific). Cattle are easier to move early in the season, and I believe management practices such as herding, riding, and salting can be used to keep the animals from concentrating on a particular area. If a deferred-rotation grazing system was used (pasture was not grazed at the same time every year) I believe early grazing would not be detrimental and cattle would make better use of pinegrass types.

Q. (from D. R. Parent)—Why do timber management people have to justify management decisions economically but forage production people do not? At the current grazing value I would argue that seeding clearcuts to grass is not economical.

A.—I have approached the grazing-seeding-timber management question as a researcher trying to determine practices that will improve total "multiple use." There are certainly sites that will not be economical to seed to grass because of low grazing values or income. With the lack of information on grazing management of regeneration sites, I too would hesitate grazing sites after expensive tree planting because of the risk and low returns. I believe the "forage people" do need to justify their management decision economically, which may be done by improved forage condition, decreased "weedy" plant invasion (especially the introduced weedy species such as knapweed in Montana), and decreased soil erosion. The present value of an AUM on public land is unreasonably low and should reflect more of the cost and value of an AUM. There are several research studies showing compatability between grazing and timber management and also plenty of evidence of grazing damage to trees. We need to determine best management practices which improve the total economic return of the site. Livestock prices have been low during the last few years, but I believe the prices will increase and the demand for forage on many forested areas will also increase.

Q. (from Fred McCartney)—Do you believe that having all the slash removed is significant to the understory response?

A.—In our thinning sites any additional shading caused by slash would be detrimental to herbaceous plants. Heavy slash also acts as a mechanical barrier to livestock. In other research we have found that slash may be desirable to achieve more uniform underburning. Arnold's (1953) research in northern Arizona stated that heavy slash smothered herbaceous vegetation. Dry herbaceous vegetation was found to decrease from 4.0 to 0.1 percent coverage under heavy slash and logs following logging in the Oregon Cascades (Dyrness 1965).

Q. (from Anonymous)—Have you looked at forage quality—protein content—as affected by canopy manipulation? (answered by E. Willard)

A.—Timothy Webb and I studied the influence of tree canopy on the chemical composition of five understory species. Plant samples were collected from the understories of pure stands of Douglas-fir, lodgepole pine, and western larch, and from clearcuts adjacent and alike in all physical characteristics to these stands. Samples were analyzed for various components indicative of nutritional quality, and comparisons were made for each forest/clearcut pair. Levels of cell wall constituents, lignin, cellulose, and crude protein were usually significantly higher in forest-grown plants. Silica was also much higher in forest-grown pinegrass. Crude fat tended to be higher in open-grown samples, but varied considerably.

I am currently studying the chemical components of pinegrass and elk sedge growing on the thinning plots described in this paper. Laboratory analyses are still under way so no data are yet available.

EFFECT OF PARTIAL CUTTING AND THINNING ON THE WATER BALANCE OF THE SUBALPINE FOREST

Charles A. Troendle

ABSTRACT

Patch clearcutting the subalpine forest can increase streamflow significantly; partial cutting or thinning can be equally effective in changing the water balance, resulting in increased streamflow. Increases in streamflow have been demonstrated on watersheds in Colorado and South Dakota where 30 to 40 percent of the basal area has been removed in shelterwood cuts. Greatest increases are associated with the wettest years. Process studies in young lodgepole pine stands in Colorado and Wyoming indicate that thinning significantly reduces winter interception loss and increases net precipitation to the ground or to the snowpack. Soil water depletion (and evapotranspiration loss) is reduced and water available for streamflow is increased in direct proportion to the basal area reduced. However, because the subalpine environment is so precipitation limiting rather than energy limiting, the effect of basal area reductions on soil water depletion is eliminated in dry years. This paper presents several linear models that describe the interaction between growing stock level or stand basal area, precipitation (annual and seasonal), and site differences on the water balance of the subalpine forest.

INTRODUCTION

Wilm and Dunford (1948) conducted what appears to be the first, and perhaps one of the most definitive, studies on the effect of timber harvest on the water balance of the lodgepole pine type. Five harvest plots representing a clearcut, a control, and three levels of partial cutting (0, 2,000, 4,000, 6,000, and 12,000 board feet per acre [bfa] reserve volume) were replicated in each of four randomized blocks. Using these plots, they drew several inferences about the effect of timber harvest on the water balance of lodgepole pine in the Colorado subalpine forest.

First, Wilm and Dunford (1948) noted that the snowpack water equivalent increased proportionally as stand volume was reduced. Second, they found that net interception losses and soil water depletion also were proportionally reduced. They concluded that water available for streamflow increased because of both winter and spring interception savings and summer evapotranspiration (ET) reductions. Most of the increase in water potentially available for flow was estimated to come from reductions in evaporative losses.

Because clearcutting appeared to be more efficient in manipulating the winter snowpack and increasing water available for streamflow, much of the research in the subalpine forest zone has dealt with the effects of clearcutting on snowpack accumulation and water yield at the watershed level. Examples of these watershed studies are the Fool Creek and North Fork of Deadhorse Creek watersheds in Colorado (Troendle 1983a; Troendle and King 1985), and numerous watersheds on the James River and Marmot Creek in Alberta (Swanson and Hillman 1977).

The fact that partial cutting, or thinning, has the potential to modify the water balance and increase flow is receiving more attention now that we are beginning to better understand some of the water balance components being impacted. Although watershed experiments that address partial cutting are numerous worldwide (Bosch and Hewlett 1982), there are only two in the subalpine environment. This paper first summarizes results of those experiments and then addresses the effect of partial cutting on the winter and summer evaporative processes.

THE EFFECT OF PARTIAL CUTTING ON WATERSHED RESPONSE

Anderson (1980) reported on the effect of a partial cut in ponderosa pine on the Sturgis Experimental Watersheds near Rapid City, SD. Sturgis Watershed 3 is a 190-acre experimental watershed that flows to the north from an elevation of 5,700 ft and has a total relief of 700 ft. The basic hydrology, geology, and geomorphology of Watershed 3 and its 90-acre control, Watershed 2, are described by Orr (1969) and Yamamoto and Orr (1972).

After a 7-year calibration period, logging was begun on Watershed 3 in late summer 1970 and completed in 1971. The initial intent was to reduce the basal area on 130 of the 190 acres to a growing stock level (GSL) of 70. Postharvest surveys indicate that although only about one-half the watershed actually was harvested, approximately 25 percent of the total basal area on the entire watershed was removed (Freeman Smith personal communication).

Preliminary results of the hydrologic response resulting from the timber harvest have been presented by Anderson (1980). The average annual increase in flow was 1.9 inches ($P < 0.001$) for the years 1972-79, with a yearly range from 0.6 to 3.8 inches. Forty-two percent of the increase occurred in April, 19 percent in May, and 25 percent in June, for a total of 86 percent occurring in the 3-month runoff period.

In a manner similar to that used for the analysis of the Fraser watershed data (Troendle and King 1985), I divided annual precipitation for Watershed 3 into three seasonal values: winter (November-March), spring (April-June), and summer (July-October). During the 7 postharvest years, winter precipitation averaged 7.2 inches with a standard error of 2.6 inches, spring precipitation averaged 13.7 ± 6.1 inches, and summer precipitation averaged 8.1 ± 2.4 inches. The mean precipitation for the watershed averaged 29.0 ± 4.6 inches per year. Whether looking at total annual streamflow or the change in flow that followed harvest, spring precipitation was the parameter most significantly correlated with response ($P = 0.01$, $R = 0.50$). Winter precipitation, although significant, was only slightly correlated ($R = 0.10$) with both flow parameters. Summer precipitation was negatively correlated with both flow and the increase in flow (R = -0.42 and -0.50, respectively). However, since summer precipitation was equally negatively correlated with total annual and with spring precipitation, we can conclude that the postharvest summer precipitation (either expressed as current precipitation or lagged 1 year to represent previous or antecedent precipitation) was not correlated with either total flow or the change in flow. Summer precipitation ranged from 4.5 to 11.4 inches during postharvest years and apparently was lost on site, with only minor contribution to flow.

More recently, a portion of the Deadhorse Creek watershed, Colorado, also was partially cut (Troendle and King 1987).

Deadhorse Creek is a 667-acre gauged watershed (fig. 1) that drains to the east, at elevations ranging from 9,500 to 11,670 ft. The two separately gauged subdrainages of Deadhorse Creek are the 100-acre North Fork and the 192-acre Upper Basin. Streamflow is monitored at each gauge from mid-April to mid-October. Year-round measurement has been discontinued because very little flow occurs during the winter; streams usually recede to a reasonably constant base flow that approximates 0.2 ft^3 per second per mi^2 (cfsm). The measured flow includes all flow occurring from mid-April, when the stream gauges are opened, until mid-October, when they are shut down. Winter baseflow is not included in the estimate of annual yield. Snow courses, to index peak water equivalent; precipitation; temperature and humidity; and annual sediment export also have been continuously monitored. Comparative snow course observations between the Deadhorse Creek and East St. Louis Creek, begun in spring 1967, are used to estimate the mean water equivalent for each of the watersheds. Samples (118) of snow water equivalent are collected at 132-ft intervals on Deadhorse Creek, along transects that cross all major slope aspects and elevations.

In 1980 and 1981, unit 8 (North Slope, fig. 1) was harvested in the first step of a three-step shelterwood cut. Approximately 40 percent of the basal area was removed as individually marked trees 7 inches diameter at breast height (d.b.h.) and larger. Unfortunately, and unlike the North Fork and Upper Basin subdrainages, the partially cut unit 8 portion of Deadhorse Creek is not independently or directly gauged. The annual flow of the Upper Basin and the North Fork must be subtracted from the total flow at the main gauge for the watershed to partition out the flow from the interbasin area, which includes the contribution from unit 8. Partitioning the flow increases the opportunity for error and decreases the reliability of the experiment, but must be done for two reasons:

1. Unit 8 is only 100 acres, while the entire Deadhorse drainage is 667 acres. Any impact restricted to unit 8 would be less likely to influence total flow detectably than it would be to influence the partitioned interbasin flow.

2. The North Fork subdrainage, also 100 acres, was harvested 3 years before unit 8. Partitioning allows removal of the effect of that treatment on flow at the main weir.

Partitioning was done for total annual flow only, with no attempt made to isolate peak flow rates or timing of peak, for the interbasin area. The partial cut impacted both winter snowpack accumulation and streamflow. Unlike the North Fork, covariance analysis of the pretreatment and posttreatment regressions indicated a significant increase ($P = 0.002$) in the adjusted mean water equivalent over the entire unit 8 after timber harvest. Peak water equivalent, when compared to the control, increased 1.9 inches or 16 percent over the entire 100-acre unit. The increase is well

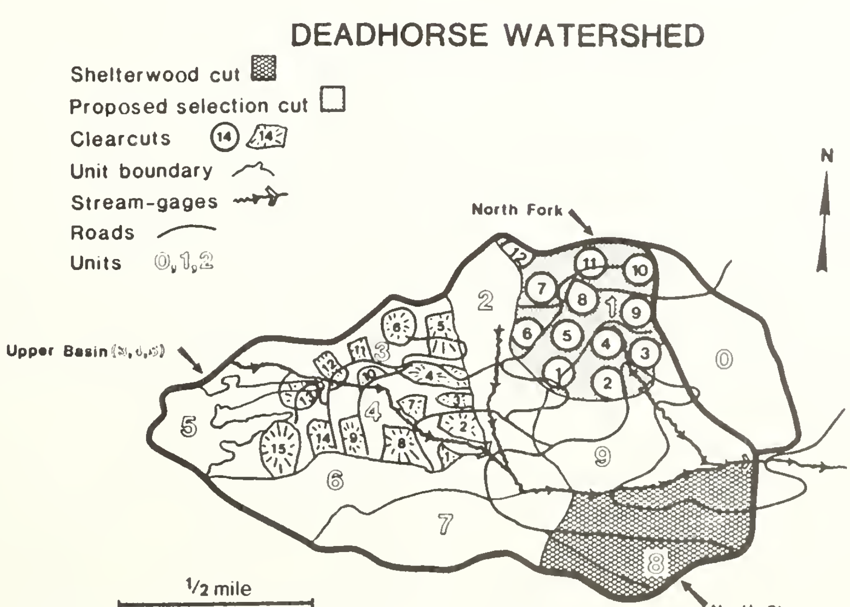

Figure 1—The Deadhorse Watershed showing the North Fork and North Slope harvest units.

demonstrated by the double mass plot of figure 2. We assume the net increase in accumulation on unit 8 (North Slope) reflects an interception savings, since the increase occurring there cannot be correlated with a decrease elsewhere either in the Deadhorse Creek watershed or on nearby Lexen Creek.

Other research (Gary and Troendle 1982; Gary and Watkins 1985; Troendle and King 1985; Troendle and Meiman 1984, 1986) demonstrates that, along with any redistribution effect in clearcuts, there also is a reduction in interception loss following harvest. The result can be a net increase in peak water equivalent on the watershed under either clearcut or partial cut conditions.

Covariance analyses of the adjusted group means for the 6 pretreatment and 3 posttreatment years indicated that flow from the entire interbasin area may have increased 1 inch ($P = 0.34$) after partial cutting. This represents a unit area increase of 3.6 inches from the 100-acre area actually harvested. Because the posttreatment record years were well above average in precipitation, the estimated increase probably is larger than what might be expected in drier years.

The Fraser watershed data, like the Sturgis data, indicate that partial cutting does increase flow, and that both total flow and the increase in flow are dominated by winter and spring climatic conditions. However, the limited watershed data presented here are not adequate to develop generalizations or models of hydrologic response, because they do not represent an adequate range in basal area reductions. Inferences about the influence of a continuum of basal area levels must be drawn from various plot studies that are available.

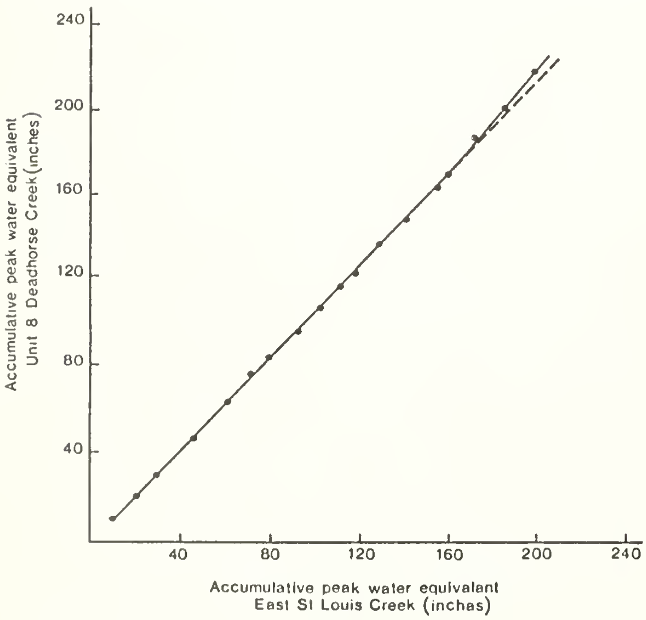

Figure 2—The effect of a partial cut on accumulative peak water equivalent, North Slope, Deadhorse Creek.

THE EFFECT OF PARTIAL CUTTING ON THE SUMMER WATER BALANCE

In 1975, a study was started in 60- to 70-year-old lodgepole pine on the Fraser Experimental Forest, CO, to test the effect of different thinning levels (GSL) on subsequent growth (Alexander and others 1985). The study area was divided into five blocks, with one block thinned each year. Within each block, four 0.4-acre plots were thinned from below, each to a different growing stock level (GSL's 40, 80, 100, 120). The first series of plots in block 1 were thinned in 1976, the last series of plots in block 5 were thinned in 1980. Additional plots in blocks 2, 3, and 4 were added in 1981 and thinned to GSL 160. Adequate stands for GSL 160 were not found in blocks 1 and 5.

In 1975, four neutron-probe access tubes were installed to a depth of 5.5 ft in each GSL plot, as well as the single control plot in block 2. They were installed later on the 160-level plots selected in 1981. Soil moisture measurements were taken at 6-inch-depth intervals periodically during each growing season from 1976 to 1983. Initially, the intent was to measure the plots as early as possible after snowmelt (recharge) and then again at the end of the growing season (maximum depletion). The objective of the study was to define the differences in soil water depletion that occur during the growing season as a function of basal area, block or site differences, and years or climatic differences.

Linear regression techniques were used to evaluate causal relationships that exist between the rate of change (±) in soil moisture per unit time (dependent variable) and basal area, block or site, midpoint date of the measurement interval, and precipitation during the measurement interval.

It has been well documented that growing season precipitation is used primarily on site and does not appear to make a detectable contribution to streamflow (Orr 1969; Troendle and King 1985, 1987; Troendle and Meiman 1986). Given this assumption, a second dependent variable, daily evapotranspiration, was calculated. This was estimated as the sum of the soil water depletion that occurred between two successive measurements and the precipitation that fell during the interval, divided by the number of days in the measurement interval. At the plot level, this number represents the best estimate of average daily water use (ET) for the measurement interval.

Daily soil water depletion was regressed on daily precipitation, basal area, date (from January 1 until the midpoint of the measurement interval), and block or site. Basal area was the least significant of the independent variables ($P = 0.01$). When the same regression was fitted for each of the individual years, the significance of basal area in the equation depended on whether it was a wet or dry year. In dry years, basal area was not related significantly ($P = 0.50$) to daily soil water depletion. Figure 3 represents a plotting of daily soil water depletion over basal area for all years of record. Basal area is significant when regressed on soil water depletion ($P = 0.01$, $R = 0.22$, SE = 0.02 inches), but it is apparent in figure 3 that there is a lot of variation about the line that cannot be accounted for by basal area alone.

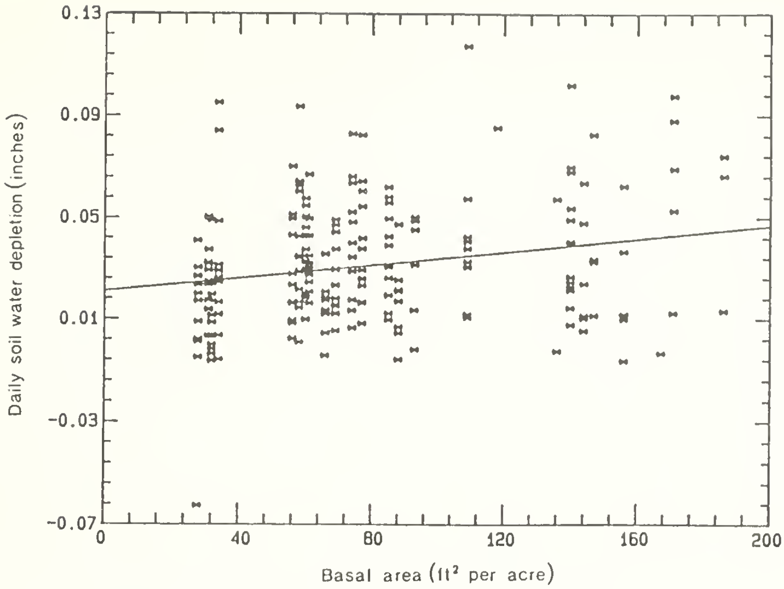

Figure 3—Relation between daily soil water depletion and basal area, all data.

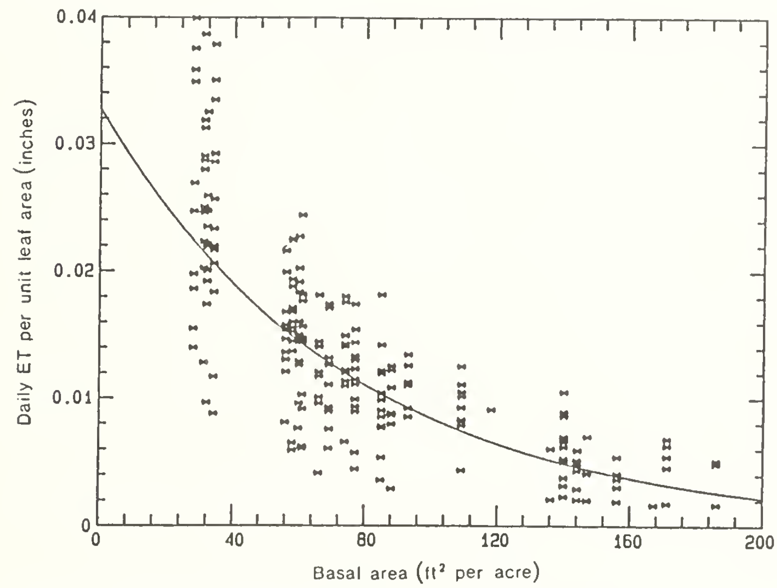

Figure 4—Relation between daily ET (soil water depletion plus precipitation) per unit leaf area and stand basal area.

Based on the average relationship between basal area and soil water depletion shown in figure 3, a reduction in basal area from 160 to 32 would result in a 2-inch reduction in soil water depletion for the period from June 15 to October 15. In the previous watershed example for the North Slope portion of Deadhorse Creek (the partial cut), basal area was reduced 35 to 40 percent or from 180 to 120 ft^2 per acre. Estimating the potential difference in depletion from figure 3, the reduction in soil water depletion would be 1 inch for the growing season. As noted earlier, there was also a 1.9-inch increase in water equivalent in the spring snowpack on the North Slope. The 1-inch average savings during the 4-month portion of growing season seems quite reasonable, considering the total increase in flow was estimated to be 3.6 inches at the streamgauge. Since any savings in April and May are not included, the combination of the 1.9-inch winter interception savings and 1.0-inch summer depletion savings represents a reasonable portion of the total (2.9 of 3.6 inches).

As noted earlier, total evapotranspiration for each soil moisture interval can be estimated by summing the precipitation that fell during the interval with soil moisture depletion (±) that occurred. This sum represents the maximum amount of water available for ET and includes any water lost to deep seepage or streamflow. However, since summer precipitation is not significantly correlated with change in flow, the assumption is made that the summer precipitation is retained on site, thereby reducing soil water recharge requirements (and apparent depletion) or evaporation. Soil water depletion differences between the different basal area levels reflect the net effect of the ET changes. Daily ET rates were not presented in a format similar to the daily soil water depletion rates, because the soil water depletion best expresses the change caused by basal area reduction. ET averaged 0.14 to 0.17 inches per day.

Kaufmann and others (1982) presented equations for converting stand basal area to leaf area index or transpiring surface. Figure 4 represents a plotting of the ratio of daily ET expressed per unit of leaf area to basal area of the stand. It notes the exponential decrease in water use that occurs per unit leaf area as the basal area (and leaf area) is decreased. It does not necessarily imply that greater transpiration occurs at lower basal area levels, but it is a reflection of the fact that in the water-limiting summer environment of the subalpine, precipitation water is vaporized almost independent of vegetal density. Many factors are involved in the ET process, and figure 4 does not represent an empirical ET model. It does demonstrate that a certain degree of evaporative compensation as increased transpiration by the residual stand, increased transpiration in the understory, or increased evaporation occurs as the basal area is reduced.

Soil moisture studies, such as this one and others in the subalpine (Potts 1984; Troendle and Meiman 1986), are not really designed to estimate ET, although the estimates of daily use appear to be quite good. The strength of these studies lies in their defining the soil water deficits that exist in the fall as a function of basal area. These recharge differences reflect the effective net change in the ET processes (relative to flow) that result from the change in growing stock levels. These differences are the net effect that is passed on to the increase in flow that occurs when recharge begins.

EFFECT OF PARTIAL CUTTING ON SNOWPACK ACCUMULATION

As noted earlier, Wilm and Dunford (1948) defined relatively linear increases in snowpack accumulation following timber harvest. Gary and Troendle (1982), reporting on observations in partially cut lodgepole pine stands in both Colorado and Wyoming, also demonstrated linear increases following different levels of partial cutting. Gary and Watkins (1985) noted in a separate Wyoming study that peak water equivalent increased 2 inches or 30 percent in a thinned stand of doghair lodgepole pine. This increase occurred with no detectable impact on snow in the upwind or downwind control forest.

Figure 5 represents a plotting of the average increase in peak water equivalent over the percentage of basal area removed for a number of studies in the lodgepole type. Each data point on figure 5 represents the average value for that plot for the length of the respective study; individual yearly values were not used. The data include the lodgepole pine harvest plots in Colorado (Wilm and Dunford 1948); the lodgepole pine GSL plots in Colorado (Troendle and Meiman 1984); the North Slope partial cut, Deadhorse Creek, CO (Troendle and Meiman 1984); the lodgepole pine thinning plots in Wyoming (Gary and Troendle 1982; Gary and Watkins 1985); and a small clearcut in Colorado (Troendle and Meiman 1986). Numerous other studies in

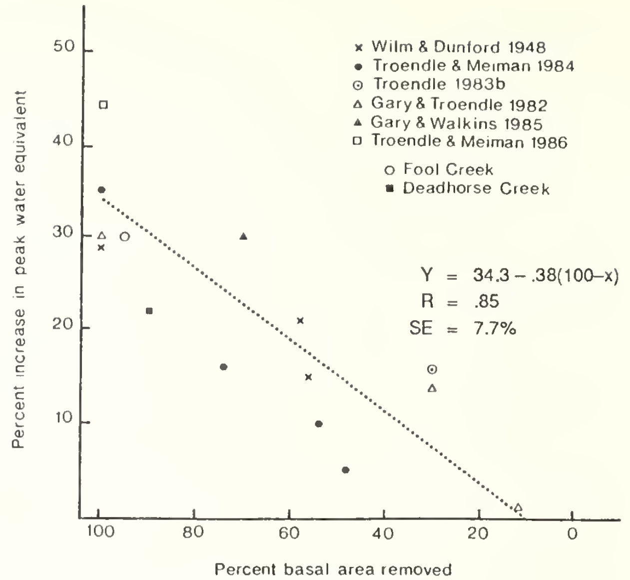

Figure 5—General relationship of percentage of increase in water equivalent as a function of basal area removed.

the United States and Canada show similar results for clearcut situations. Also plotted, but not included in the fitting of the regression line, are the mean increases for the commercial clearcuts on both Fool Creek and Deadhorse Creek in Colorado (Troendle and King 1985, 1987).

Although there is significant variation in the fit of the relationship presented in figure 5, the R^2 of 0.73 (P = 0.001 for B_1 and 0.00002 for B_2) implies a strong correlation between percentage of reduction in basal area and increase in peak water equivalent over the entire range in basal area. In most cases, the plot means for peak water equivalent ranged from 7 to 14 inches, with the observed range in yearly peak water equivalent for each plot varying from 2.6 to more than 17 inches. The increase in accumulation that occurs, particularly in the mid to lower range of basal area reductions, reflects an interception savings that, in most years, should be directly translated to an increase in flow. Because figure 5 represents a regional average response, it can be used for that purpose in conjunction with existing predictive techniques, as long as the user realizes it applies to the average.

Potts (1984) reported on a lodgepole pine spacing study in western Montana. In that continental environment, the winter snowpack is more intermittent and, in the case of his observations, peaked on December 31. Although Potts measured depth rather than water equivalent, the proportional differences in snow depth due to basal area differences he presented appear consistent with the relationship presented in figure 5.

SUMMARY

The objective of this paper was to address the effect of partial cutting on the water balance. In the past, it was felt that partial cutting would have little, if any, effect on flow (Leaf 1975; Troendle and Leaf 1980). This apparently is not the case. Thinning or reducing the overstory results in reductions in winter interception loss and summer soil water depletion that appear to be as efficient per unit area as clearcutting, at least in wet years.

Procedures are available to the manager (such as WRENSS) to estimate the effect of timber harvest on water yield in the subalpine when clearcutting is used as the harvesting technique (Bernier and Swanson 1986; Troendle and Leaf 1980). The soil water depletion patterns observed following partial cutting proportionally mimic those for clearcutting and are a function of basal area removed. As a first-generation management tool for simulating the effect of partial cutting on the water balance, I would recommend using the modifier coefficients (weighted for percent basal area removed) presented in the procedures referenced above (WRENSS) and combining them with figure 5 in this paper to adjust the precipitation for interception savings. On average, the technique will present reasonable results and give the manager a reasonable tool to predict the effect of partial cutting on water yield.

There obviously are a lot of unanswered questions when dealing with the effect of partial cutting on water yield, and we do not have adequate predictive tools. However, there are several "givens." First, no harvest has no effect. Clearcutting probably still represents the optimal strategy for increasing yield. Partial cutting, therefore, has limits on its potential effect. In some instances, it may be slightly more efficient than clearcutting, while in other instances, such as dry years, it will be less effective. Under average conditions, partial cutting probably is proportionally as efficient as clearcutting, relative to the percentage of total watershed basal area harvested. It is quite possible that response to partial cutting may be more dynamic than clearcutting, in that variation in elevation, aspect, and precipitation (and interactions) may have a greater effect on response.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Chris Tootell)—The 40 percent basal area reduction in Deadhorse Creek is a heavy partial entry in old-growth lodgepole pine. What amount and type of mortality has the stand sustained since harvest? If mortality is significant, is this type of treatment realistic silviculturally on the road to increased water yield?

A.—The north-facing slope, although exposed to the predominantly westerly winds, is moderately well protected. The cut was heavy, perhaps at the upper limit for a partial cut, and there has been a small amount of blowdown. However, we did not cut to the ridge and were careful on the more wind-exposed portions of the slope. Exposure to wind and windfirmness of trees are of paramount concern in laying out other partial cuts. This was not a predominantly overstory cut; we left a good mix and are happy with the results. In an operational mode, I expect slightly less material would be taken on the first entry.

Q. (from Bill Coburn)—What percent of the annual precipitation occurring in a well-stocked stand of ponderosa pine is used by the trees themselves? Is there a change due to the age of trees, immature versus overmature?

A.—This is a difficult question to address in generalities, since the answer is dependent on the amount of precipitation. Along the Colorado Front Range, in northern Arizona, and similar environments, the precipitation can be quite low and used on site. Fifteen to twenty inches of precipitation may yield only 1 or 2 inches of flow. In the other parts of the range, such as the Black Hills, precipitation is higher and so is the percentage that becomes streamflow. Although the response varies for many reasons, the first 15 to 20 inches of precipitation are used by the vegetation, with the remainder becoming streamflow. The opportunity to influence flow by manipulating vegetation usually is greatest in the higher precipitation zones, simply because there is less competition on site for any savings.

There is a lot of speculation on the effect of age. Again, in general, moisture use or evapotranspiration is a function of biomass or transpiring surface. Theoretically, a young, vigorous, actively growing stand with a given basal area may have a greater biomass or leaf area than an older decadent stand of similar basal area and, therefore, would use more water. In practice, these differences cannot be shown at the watershed level.

Q. (from Walt Knapp)—Has research focused on change in water yield resulting from changes in species composition; specifically, will deciduous trees (larch and aspen) reduce snow interception and consequently increase water yield?

A.—Research has been conducted at different times in several regions on the effect of tree species on water use. The only definitive study was at Coweeta, in North Carolina, and it demonstrated that a watershed converted from Appalachian hardwoods to white pine yields significantly less water. In the Rocky Mountain region, there appear to be significant differences in transpiration between spruce, fir, pine, and aspen, with spruce being the greatest and aspen the least user of water per unit of leaf area. However, it still needs to be demonstrated that the differences in water use at the tree level can be delivered to the stream without being offset by compensating losses in evaporation or understory use.

The general consensus would be that conifers use more water than hardwoods, largely because of the significant interception differences. This would be especially true in the snow zone. Our unpublished and published data indicate as much as 15 to 20 percent more water accumulates under aspen than conifer stands in the same area.

Q. (from Steve Patterson)—Are the peak flows resulting from partial cuts as potentially destructive to downstream riparian areas as those from clearcuts?

A.—Clearcutting 30 percent or more of the central Rocky Mountain watersheds appears to increase peak flows on site. Under some circumstances, the timing of the peak also may be advanced; in others, it does not appear to change. Whether or not the changes in peak are destructive depends on at what point downstream the impact is being evaluated relative to the general land use pattern above that point. Much depends on how flows integrate. For example, on the 100-acre North Fork of Deadhorse Creek, clearcutting about one-third of the area in small openings increased the peak at the mouth of the 100-acre site by 50 percent. However, this increase is not detectable at the mouth of the 600-acre watershed (a second order stream) in which the North Fork subbasin is located. The North Slope partial cut also is located within the same 600-acre watershed, and no detectable (individual or accumulative) effect on peak flow can be detected. However, the nature of the partial cut experiment and the short period of postharvest record do not lend themselves to detecting the kind of change (minimal) that could be expected. Intuitively, I suspect that the opportunity to increase peaks on site under a partial cutting is comparable to removing the same percentage of the stand in small clearcuts. I would not expect the same opportunity for timing shifts, however, since partial cuts still provide shade. I would be cautious about drawing inferences about downstream or off-site impact, however, until the pattern of flow synchronization is evaluated, regardless of harvesting practice.

Q. (from Randall Trerise)—What about water quality? Did increased flows produce increased siltation? Any difference in water quality between partial and clearcutting? Also, I take it you detected no changes in summer low flows due to logging?

A.—I will address effects on low flows elsewhere. Most harvesting operations on experimental watersheds have resulted in elevated sediment production—usually introduced from disturbances, such as roadbeds, or log decks. Our watershed studies show that significant increases in sediment production occur following harvest, and the increases return to preharvest levels in 4 to 6 years. The increases appear to be as great as 3,500 lb of sediment per acre of road surface, for the first year after construction. Stabilization is very quick when roads are not open to public or extensive traffic. The partial cut and the attendant roads were located on a 100-acre portion of a 600-acre watershed (all roads in watershed occupied less than 5 percent of total area), and any impact, if it occurred, was not detected at the streamgauge. I expect the impact on site was as great as for any harvesting practice on that type of slope, because the impact is due to access system. Basically, in our environment, the disturbances (cut and fill slopes, roadbeds, and log decks) will erode. The more frequently that water collected on those disturbances is diverted onto the slope, and the more care one spends dispersing this water and keeping it from reaching the stream, the less the opportunity to introduce sediment to the channel. Estimating introduced sediment probably is the most difficult resource response to extrapolate from research to practice, since so much depends on operator control—something much easier to do on an experimental watershed than in an operational context.

The channel systems we have are very stable, and given the range of natural flows that have occurred over the last 50 years, we do not feel the human-caused flow increases have resulted in accelerated sediment production from the channel system.

Q. (from Bill Coburn)—What percent of the annual precipitation is intercepted by a stand of ponderosa pine in a closed canopy condition?

A.—Again, it is somewhat dependent on the amount of precipitation and storm characteristics. Obviously, a greater percent of small events will be lost. In the environment this symposium addresses, most studies show losses of 20 percent to 30 percent will occur, with 25 percent loss representing the mean.

Q. (from Jim Beyer)—What is your feeling or data on the effect of partial cutting on the duration of runoff relative to patch cutting on the Fraser study?

A.—I would not anticipate near the same longevity for partial cuts, assuming a second entry is not made (this is a reality, however). Assuming a partially cut stand responds to release, it will reoccupy the site more quickly, because it has a head start. Increased snowpacks can diminish in 20-30 years; flow changes are probably equally short lived. However, if the potential increases from a partial cut are real, simulation shows that second and third entries will result in greater yield over the period of a rotation, so there is still tremendous potential in partial cutting.

Q. (from Barry Bollenbecker and Don Boone)—What is the effect of timber harvest on low (summer) flows? Is the spring increase offset by summer decrease?

A.—Two people have asked this question here and many others have asked the same thing elsewhere. I am not sure what precipitates the question, since I am unaware of any documentation of decreased summer flows following reasonable silvicultural practices in the environment we are talking about.

Part of the reason for establishing the National Forests was to maintain favorable conditions for flow, which were inferred to be moderation of peaks and maintenance of baseflow. The presence of forest (or lack of disturbance) maintains soil conditions that are characterized by high infiltration rates. Rain or snowmelt infiltrates into the forest soil and drains out slowly, dampening peaks and maintaining baseflow. Examples exist that date to biblical times, showing that when vast forests are removed and the soil is plowed and degraded, causing the infiltration character to be destroyed, rain and snowmelt take an altered path to the stream channel. In this situation, the precipitation does not infiltrate into the soil, the sediment-laden water travels overland to the channel causing floods, and the reduced infiltration eliminates the source for baseflow. A perfect example of this process resulted from cotton farming (and attendant bad agricultural practices) in the South and Southeast at the turn of the century. This sort of degradation is a real and common problem in Third World countries today, but it is not a problem when practicing good silviculture. The memory of this occurrence may be one of the factors in current concern over the effect of timber harvest on water yield and low flows.

A primary objective in good forest management is to harvest the timber with as little disturbance to the soil as possible. Except for road surfaces and log decks, the infiltration character of the soil usually is not impacted. Road water is diverted to the slope at frequent intervals to get it to infiltrate as well, and guidelines are available to the manager to ensure this. There is no reason to believe that summer low flows will be significantly reduced if the flow-generating pathway is not altered. The increased flow that is observed in the spring results from a greater percentage of precipitation reaching the soil because of reduced wintertime interception loss, and because less melt water is retained on site because of lower soil water recharge requirements. Because vegetation was removed, soil water depletion was reduced during the previous growing season.

Baseflow or low flow is generated, either directly or indirectly, from draining soil water. Every plot study or experiment to date has demonstrated that soils are always at least as wet and usually wetter following timber harvest. If we assume that timber harvesting does not cause drier soils during the growing season, then even the simplest laws of physics imply as much or more water would be available for baseflow.

I have a paper on surface/subsurface flow on forested and clearcut plots that will be presented in Vancouver, BC, in August 1987. It demonstrates, at least at Fraser, that clearcutting increases soil water content and significantly increases baseflow in the months of August to as late as January.

If good, sound practices are used and infiltration pathway is not altered, there simply is not any basis for arguing that baseflows will be decreased following timber harvest. Most likely they are increased in our region, as they are everywhere else in the United States. Bad practices still are bad practices, and as I have noted they could precipitate an exception to the rule. The key is the amount of surface disturbance, and the degree to which flow path is changed.

Q. (from Mike Abluty)—How would you expect the effects of different growing stock levels on the water balance of the subalpine forests in Colorado and Wyoming to differ from those in the higher elevations of northwestern Montana (which are more strongly influenced by a relatively moist, maritime climate)?

A.—I think the relationships presented in the paper provide the base for extrapolating to different regimes. More precipitation usually results in greater response. Winter interception losses probably are slightly less because of the higher humidity while the opportunity for summer season increases is greater on characteristics of the wetter end of the spectrum.

TIMBER HARVESTING AND VISUAL RESOURCES: MAINTAINING QUALITY

Stephen F. McCool
Robert E. Benson

ABSTRACT

The vast natural landscape of the American West, often depicted in the oils of romanticist artists, is becoming increasingly important for its visual quality. Commodity uses of the landscape frequently intrude into the natural-appearing landscape, resulting in conflict. Forest stand managers can reduce such conflicts by understanding what visual quality products the public expects and adopting prescriptions to enhance such values or mitigate the adverse effects of timber production. Viewers in the foreground prefer slightly modified but natural-appearing landscapes while those in the midground prefer natural-appearing landscapes. Removal of logging residues can greatly mitigate against the effects of timber production for foreground viewers.

INTRODUCTION

Celebrated in song and verse, America's vast natural landscape remains one of her most memorable and distinctive assets. The immensity, diversity, topographic variation, naturalness, and overwhelming grandeur of this landscape are values of extreme sensitivity and importance to this Nation. Irretrievably wedded to our history, the landscape of the West continues to play out roles of influence, conflict, and, most significantly, esthetic appreciation. Often serving as the inspiration for artists to romanticize the West, unmodified landscapes still influence our perceptions of nature and natural processes.

Nearly all commodity uses of landscapes contain the potential to irreversibly alter the character, beauty, and heritage of the American landscape. Esthetic values of landscapes, particularly those in the public domain, remain largely unquantified in dollar terms. The lack of an unambiguous economic value does not reduce their intrinsic utility to society. Such utility is often identified and expressed through the political marketplace rather than the economic one. The eventual and inevitable restructuring of our society, into one where natural resource-based amenities comprise much of our leisure focus, demands that we pay increasing attention to visual quality. Numerous examples can be found where the lack of esthetic stewardship has been addressed in the political market, resulting in more specific legislative and administrative mandates to protect visual quality.

While visual resources are valued for themselves, they are often intertwined with recreational experiences. The quality of the visual resource may serve to enhance the backdrop for a western community, or reduce the satisfactions of a family boating on an otherwise scenic mountain lake. Research has clearly demonstrated that many people prefer to recreate in esthetically pleasing settings, whether these settings are primitive or highly developed (McCool 1984; McCool and Peterson 1982).

The reality of conflicts between esthetic values and resource extraction activities inevitably finds its way into the manager's experience, either by controversy or through implementation of legislative guidelines. The National Forest Management Act of 1976, for example, permits timber harvesting only where

> . . . the potential environmental, biological, esthetic, engineering and economic impacts on each advertised sale area have been assessed, . . . cut blocks, patches, or strips are shaped and blended to the extent practicable with the natural terrain; [and] . . . such cuts are carried out in a manner consistent with the protection of . . . esthetic resources . . . .

In sum, visual quality is no longer an "optional" consideration, particularly in public land management. Management of visual quality, out of choice or necessity, motivated by desires of enhancement or practicalities of mitigation, is now an institutionalized component of sound forest stand management.

Confronting managers of esthetics are questions similar to those facing managers of other forest-dependent values:

1. What visual quality "products" does the public expect or demand from its forests?
2. What visual quality objective (VQO) should be achieved in any given stand?
3. What trade-offs among other resource values are involved in meeting this visual quality objective?
4. What stand management techniques can be used to achieve this objective?
5. How effective was a particular technique in meeting the planned visual quality objective?

The Forest Service, U.S. Department of Agriculture, and Bureau of Land Management, U.S. Department of the Interior, have systems to identify areas of visual sensitivity and establish visual quality objectives. Both visual management systems are based on a number of assumptions about preferences for landscape modification among the viewing public, and both are used as inputs into design of landscape-disturbing activities. While considerable research on public preferences exists (Elsner and Smardon 1979), much is nonadditive in nature. And such research does not tell us what visual quality objectives should be established on any given stand, although visual management systems provide a process to do so.

The Forest Service Visual Management System includes five primary visual quality objectives:

- Preservation—only ecologically induced changes in the landscape are allowed

- Retention—management activities are not visually evident

- Partial Retention—management activities remain visually subordinate to the natural appearing landscape

- Modification—the effects of management activities in the fore- and middle-ground dominate the view but appear natural

- Maximum Modification—management activities appear dominant in the fore- and middle-ground areas but appear natural when viewed as background.

Once a visual quality objective is established for an area, management activities are designed to retain that objective.

Research concerning esthetic mensuration, site classification, suitability, and resource trade-offs has not captured the attention of scientists, a problem that significantly affects our ability to provide guidance for stand management. Little research has been conducted to determine the loss in timber values, for example, in producing a retention VQO, or in the loss of visual quality from silvicultural activities. Therefore, in this paper, we will focus on summarizing research and providing guidelines for managers to address questions 1, 4, and 5.

Processes and data similar to those needed in other areas of natural resources management are essential to address these questions. For example, developing visual quality objectives requires an understanding of the current site capability. The effectiveness of techniques used to achieve a certain VQO is dependent on an understanding of the causal relationships between certain silvicultural prescriptions and the landscape dominance elements of form, line, color, and texture (Litton 1968). Identifying the mix of visual quality products requires understanding public preferences for landscapes.

WHAT VISUAL QUALITY PRODUCTS DOES THE PUBLIC EXPECT?

The answer to this question depends largely on the distance of the observer from a particular site. In general, when the site is located in the immediate foreground (less than one-fourth mile) of the observer, natural-appearing but slightly modified stands are preferred. These are stands that have usually been subject to some degree of thinning or pruning and provide the observer with an open, parklike appearance. Rutherford and Shafer (1969) found that most people preferred a hardwood or conifer stand that had been selectively cut 10 years prior over a similar uncut stand. These preferences were expressed up to the point of 80 percent removal of the volume. Hamilton and others (1973) reported that suburban forest owners gave the highest preference ratings to stands composed of neat uniform rows of pruned conifers. Stands composed of unpruned stems and invading deciduous species were among those given the most frequent "unpleasant" ratings. Their study revealed that respondents rated stands on the basis of esthetics, access, and the presence of "neat" industrious activity. Roads were even rated as "pleasant" as long as they blended into the setting.

Patey and Evans (1979) discovered that their respondents preferred open parklike landscapes to others. Walsh and Olienyk (1981) found an optimal number of stems per acre for a variety of recreational activities. Kenner and McCool (1985) found, in their study of preferences for thinned versus unthinned stands, that respondents preferred thinned stands. They also detected results that suggest there may be an optimal level of thinning from the esthetic perspective.

One recent study of particular interest involved thinning pole-size lodgepole pine stands throughout the Northern Rocky Mountain area. The stands were thinned to various spacing levels under specified harvesting conditions regarding cutting, slash treatment, and logging method. The study sites provided an opportunity to measure viewer preferences for a variety of thinning treatments (Benson 1987; Benson and Schlieter unpublished data). Briefly, the results from these studies substantiate results from previous ones: unthinned natural stands with rather close tree spacing (4- to 5-ft) and the usual accumulation of downed material and dead leaning stems were rated fairly low relative to stands thinned to 10- to 15-ft spacings. Furthermore, one dense stand that had spacing of about 4 ft after thinning was also rated fairly low, even though the larger slash had been removed. However, one stand that had been mechanically thinned to about 15-ft spacing was rated very low, probably because the slash, which was broken and jumbled by the process, remained on the site. The highest preference ratings were given to areas beside natural meadows where open-grown trees and a parklike edge gave more diversity to the scene.

An analysis also was made of how various features of the stands may have influenced the preference ratings. Ground cover of green grass and forbs appeared to positively affect the ratings while presence of slash, disturbed ground, and numerous small stems resulted in a negative effect. Landscape architects also rated the scenes in terms of the VQO which the scene represented. Most of the thinned stands were judged to meet a Partial Retention, objective while mechanically thinned stands were perceived to meet a Modification or Maximum Modification objective.

Schweitzer and others (1976) examined preferences for different types of silvicultural treatments in Douglas-fir and western larch stands in northwestern Montana. Two stands each were harvested by clearcutting and shelterwood cutting techniques. Areas cut with the shelterwood method were preferred to the clearcuts. The results also indicated that areas with undisturbed understories were preferred to those containing slash that had been bundled for removal. Benson and Ullrich (1981) returned to the

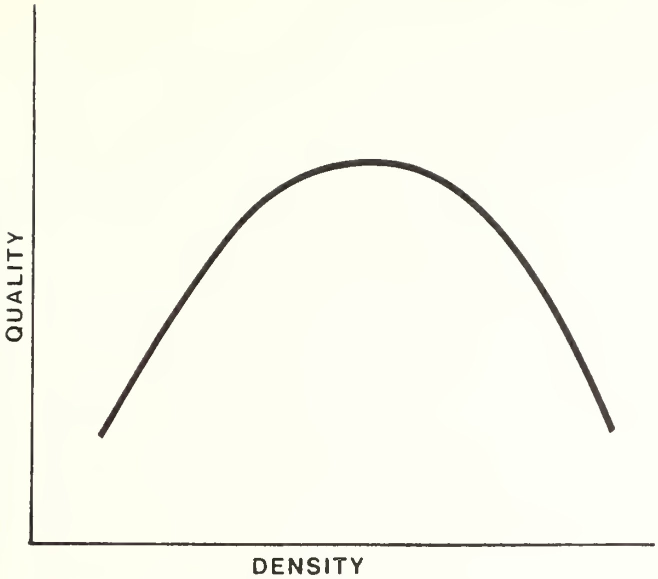

Figure 1—Hypothetical production function for foreground views.

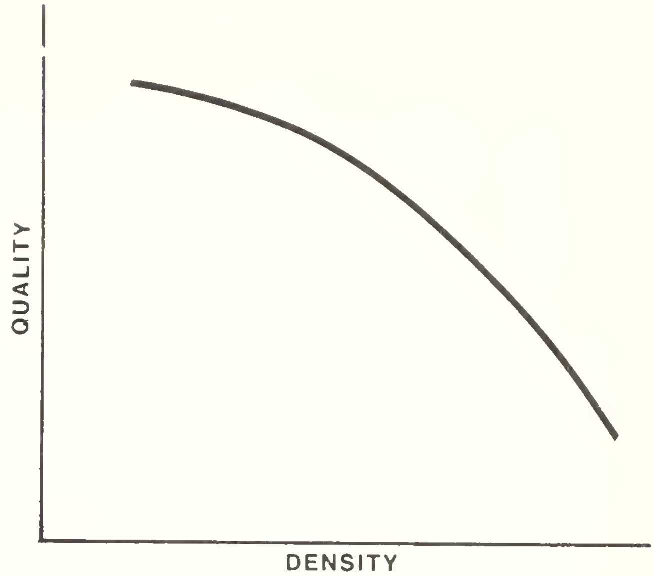

Figure 2—Hypothetical production function for midground views.

site 5 years later with similar results, and in a companion study found that partial harvest with slash removed was preferred to uncut stands. Echelberger (1979) used a semantic differential to evaluate viewer reactions to harvested northern hardwood forest stands rather than direct evaluations of photographs. Viewers preferred selection cutting over clearcutting, and patch clearcuts over strip clearcuts.

While this research trend is helpful to managers in a general sense, it is clear that specific visual quality production functions linking preferences to quality cannot be generated; at best they can be only approximated. Figure 1 shows a hypothetical production function for foreground views. An optimal stand density does probably exist, but such variables as average stem diameter, presence and type of understory vegetation, and season of year reduce the likelihood of researchers providing definitive rules for managers.

Research concerning viewer assessments of visual quality when the observer is located off-site at a distance of one-fourth to 3 miles has not had the same level of attention as near-view research. This is unfortunate because both the Forest Service and Bureau of Land Management visual management systems are primarily directed at management of visual quality in this middle distance range.

Benson and others (1985) and McCool and others (1986) report on a series of studies where cutting units representing each of four VQO's where harvesting is permitted were photographed and then presented to a number of groups for evaluation. These units were randomly selected from all timber sales occurring in the Forest Service Northern Region during 1975-80. The sale areas chosen were limited to mature conifer stands, medium or better stocked, on moderate slopes. In general, the areas selected for study were representative of the most common landscapes harvested and viewed by travelers on forest roads in the Northern Rockies.

Eighteen public and professional groups participated in this study. Each VQO was represented by five cutting units (for the Preservation VQO, uncut areas adjacent to several cutting units were used). Respondents were asked to rate each slide on a scale of 0-9 in terms of scenic quality. Using the Scenic Beauty Estimation method developed by Daniel and Boster (1976), viewer ratings of the scenes were analyzed.

The results indicated, first, that evaluations of scenic quality decrease as more and more modification is visible in the slides. This finding was consistent over nearly all groups included, regardless of attitudes toward timber harvesting. A hypothetic production function for midrange views is suggested in figure 2. Again, specific stand density guidelines cannot be generated. Second, many groups did not differentiate, at least statistically, among all VQO categories, often rating the retention and partial retention scenes similarly. Third, as attitudes toward timber harvesting become less favorable, evaluations of scenic quality tend to decrease, particularly for cutting units in the maximum modification category. These results indicate that environmental groups tend to exhibit the highest normative standards of scenic attractiveness; members of these groups may be more sensitive to modifications of the natural-appearing landscape.

WHAT STAND MANAGEMENT TECHNIQUES CAN BE USED TO ACHIEVE A VISUAL QUALITY OBJECTIVE?

Once an objective is determined, managers must deal with the issue of selecting cost-effective techniques that will ensure it is met. For stands in the immediate foreground, research has focused primarily on the effect of logging residues on visual quality. The presence of slash, stumps, whips, and snags left from logging operations significantly depresses the esthetic value of a site Logging residue may "... extend the [esthetic] recovery period for several decades" (McGee 1970). These results are confirmed in a number of recent studies. Benson (1974) found that removal of logging residues reduces by 50 percent the esthetic loss imposed by a logging operation. Schroeder and Daniel (1981) reported that in southwestern ponderosa pine forests, the amount of downed wood on the site is a strong negative linear correlate of measures of public preference. This finding is supported by earlier work by Daniel and Boster (1976) who found a correlation of −0.87 between the amount of downed wood in a forest scene and scenic quality judgments rendered by the public. Other research—Benson (1982), Arthur (1977), and Kenner and McCool (1985)—also confirms these findings.

Researchers also have examined the impact of prescribed burning on visual preferences. Anderson and others (1982) examined the scenic values of two ponderosa pine stands, both selectively logged, but one burned to remove slash. The burned site resulted in substantially lower scenic attractiveness immediately after the burn compared to the unburned site. However, after a 1-year period, scenic values on the burned site surpassed those on the unburned one. After a 4-year period, scenic values were essentially equal. The indications from this study suggest burning could indeed help mitigate some of the adverse impacts of timber harvests. The immediate effects of burning stimulate growth of grasses and forbs, which may help to rapidly cover skid trails and other scars. Burning might also provide more long-term scenic benefits in areas where a heavy amount of slash has accompanied harvest. Prescribed burning appears to be a useful tool in mitigating the negative effects to scenic quality for near views, as suggested by Mobley (1974):

> In certain timber types such as the fire-climax southern pine, a low intensity prescribed fire can be used to maintain parklike stands, emphasize vegetative-type changes and increase the number and visibility of flowering plants.

Such consequences come about only with careful attention to the objectives of prescribed fire as well as competent execution of the technique.

HOW EFFECTIVE WAS THE TECHNIQUE IN MEETING A PLANNED VISUAL QUALITY OBJECTIVE?

This is an important question. The ultimate test of planning is whether it changes what otherwise would have occurred. Unfortunately, little research has been conducted on the efficacy of visual management planning. Benson and others (1985) reported on a study of Forest Service landscape architects—the individuals with direct responsibility for ensuring that visual quality objectives are identified and met. Landscape architects from three Forest Service Regions (Northern, Intermountain, and Pacific Southwest) were asked to identify the Visual Quality Objective for each of 25 stands, five stands each representing each of the five VQO's in the Forest Service visual management system. Twenty of the 25 stands had been given a specific silvicultural prescription designed to achieve a specific VQO. Five stands had not been treated, and were selected to represent the Preservation VQO where only ecological changes are permitted. Of the 25 areas, the landscape architects' data suggested that two did not meet the planned VQO, and two exceeded the planned VQO. These data suggest that, at least for the areas studied, use of landscape architect expertise can help managers achieve the desired objective.

CONCLUSIONS

We have learned a great deal in the last decade about the sensitivity of forest stands to visual quality considerations. First, in the midrange, natural-appearing landscapes are favored. Timber harvesting techniques that modify the natural-appearing landscape through significant changes in form and line in particular will result in a decrease in visual quality. Road construction that leaves visible cut and fill slopes will also reduce visual quality because of changes in line and color. The more these cut areas are visible, the more the viewing public will react negatively to them. It is probably not enough to explain that such visual effects will decrease over the rotation; the public simply does not accept what it perceives as unnecessary visual intrusions into the natural-appearing landscape. Management actions that retain elements of naturalness will receive much greater favor.

Second, in the immediate foreground, stand managers can enhance scenic values through careful thinning and treatment of logging residues. Thinning tends to produce open and parklike views, and reduces the number of stems, branches, dead trees, etc., on the site. Careful attention to this principle can provide forest visitors with a higher quality experience. This conclusion is tied to removal of logging residues, however. The presence of such residues significantly reduces the visual quality of otherwise acceptable sites. Prescribed burning, with the objective of reducing logging residues and if conducted with sensitivity, can be a cost-effective way of quickly returning positive scenic values to a site.

Research also is beginning to suggest that other factors, such as spacing in relation to tree size, diversity in spacing and species, and ground cover and vegetative regrowth following cutting may significantly affect viewer perceptions of visual quality. The current lack of specific quantitative guidelines for stand managers for these factors does not mean they should be ignored; these factors should be carefully considered when visual quality is a goal for stand management.

While research has told us much about preferences for visual quality and stand management, it still is not specific enough to provide a production function. Although this may be perceived as a problem, the lack of specific production functions rules out reliance on rules generated for specific sites that have been inappropriately generalized to other stands. The lack of production functions does force managers to more explicitly consider the visual objectives for which each stand is managed, the rationale for those objectives, and the techniques used to achieve those objectives.

In the future, the value of the Mountain West's forests for scenic quality is likely to increase substantially. A major industry in the region will center on exporting high-quality recreational and visual opportunities. In many situations, timber values may be subservient to the visual resource. Managing forested landscapes specifically to enhance their contribution to quality recreational and visual experiences will assume a larger proportion of the forest manager's attention. The knowledge base to weave production of wood fiber into visual resource management must be increased in a significant and meaningful way.

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A COMPARISON OF GROWTH MODELS USED IN SIMULATING THE FUTURE FOREST

Ralph R. Johnson

ABSTRACT

Over the past two decades a variety of computer models have been developed for use in predicting forest growth and yield. Developers have designed these programs for use in specific geographic areas, forest types, and stand structures. Models differ in their required input as well as the format, content, and definition of output tables. Models also differ in the mathematical equations used to "grow" and "kill" trees. This paper compares the growth and yield models currently used in the Mountain West. Comparisons are made, not in terms of the actual output values, but rather in terms of the more general operating features of models.

INTRODUCTION

The use of computer models to simulate growth of managed stands has expanded considerably in the last 15 years. The models have evolved rapidly in a time when computers themselves are changing daily. What 5 years ago required a mainframe computer can now be done on a desktop personal computer (PC) in the same length of time. The common use of the PC has placed the burden of software selection on the user. The selection of software is wider than ever, and software is easier to obtain. This also, unfortunately, makes it possible to get a copy of a program which mechanically runs, but produces pure garbage answers. It is the purpose of this paper to compare managed stand simulators used in the Mountain West, so one can make more intelligent decisions on the appropriateness of their use.

MODELS CONSIDERED AND THEIR GENERAL CHARACTERISTICS

A variety of growth and yield simulators are available for the Mountain West. These simulators differ in where they work and how they work. Tables 1, 2, and 3 are a summary of the general features of these models. The labels column in table 1 is merely for convenience; acronyms may not be commonly used. The model type is as described by Munro (1974). Not all software is "free" and in the public domain. I have attempted to show those models that are copywrited.

Model developers, in what appears to be a deeply embedded human instinct, manage to place a great deal of creativity in program control methodology. To simplify model operation, parameters are entered via question and answer sessions. Other models take input only via parameter cards, and woe to the individual who places the residual cutting target in column 6 instead of column 8. There have been successful attempts at placing the user interface (questions and answers) apart from the actual growth model (Arney 1985b; Sleavin 1986). With separation of model and interface, it is easier to batch process growth and yield simulations. Tables 2 and 3 also array some additional features, which I have had occasion to question from time to time, concerning processes that drive off growth and yield outputs.

Table 1—General characteristics of managed stand models used in the Mountain West

Label	Model name	Model type	Proprietary	Front end	Method of input	Primary reference[1]
ECOSIM	ECOSIM	Individual tree, distance independent	No	Yes	Parameter cards	14
LPSIM	LPSIM	Stand	No	No	Interactive	4
PIPO	PIPO	Diameter class	No	No	Interactive	10
PPINE	PPINE	Diameter class	No	Yes	Parameter cards	8
PPSIM	PPSIM	Stand	No	No	Parameter cards	5, 6
BLPROG	PROGNOSIS BLUE MTS	Individual tree, distance independent	No	Yes	Keywords	16, 17
ECPROG	PROGNOSIS EAST CASCADES	Individual tree, distance independent	No	Yes	Keywords	16, 17
EMPROG	PROGNOSIS EAST MONTANA	Individual tree, distance independent	No	Yes	Keywords	[2]17
INPROG	PROGNOSIS INLAND EMPIRE	Individual tree, distance independent	No	Yes	Keywords	17, 18
SOPROG	PROGNOSIS S ORE N CALIF	Individual tree, distance independent	No	Yes	Keywords	9, 17, 18
SIPROG	PROGNOSIS S IDAHO	Individual tree, distance independent	No	Yes	Keywords	16, 17
TEPROG	PROGNOSIS TETON	Individual tree, distance independent	No	Yes	Keywords	[2]17
UTPROG	PROGNOSIS UTAH	Individual tree, distance independent	No	Yes	Keywords	[2]17
RMYLD2	RMYLD2	Stand	No	No	Interactive/ parameter cards	7
RMYLDN	RMYLDNORTH	Stand	No	No	Interactive/ parameter cards	3
INSPS	SPS INLAND EMPIRE	Individual tree, distance independent	Yes	Yes	Keywords	1, 2
BCSPS	SPS BRITISH COLUMBIA	Individual tree, distance independent	Yes	Yes	Keywords	[3]1, 2
WMSPS	SPS WESTERN MONTANA	Individual tree, distance independent	Yes	Yes	Keywords	[4]1, 2
TASS	TASS	Individual tree, distance dependent	Yes	No	Parameter cards	11, 12

[1]Numbers reflect order of references in list.
[2]Personal work by this author.
[3]Personal communication with Kelsey Milner, Champion International Corp., Milltown, MT.
[4]Personal communication with Al Becker, British Columbia Forest Service, Victoria, BC.

Table 2—Summarization of features available for models used in the Mountain West

Feature	Model										
	ECOSIM	LPSIM	PIPO	PPINE	PPSIM	BMPROG	ECPROG	EMPROG	INPROG	SOPROG	SIPROG
Establishes new trees by starting with bare ground	Y	N	Y	Y	N	N	N	N	Y	Y	N
Use in a hypothetical situation[1]	N	N	Y	N	Y	N	N	N	Y	Y	N
Minimum diameter handled by the model (inches)	0.5	1	0.1	1	3	0.1	0.1	0.1	0.1	0.1	0.1
Maximum age	NONE	120	NONE	NONE	182	NONE	NONE	NONE	NONE	NONE	NONE
Minimum age	NONE	NONE	NONE	NONE	15	NONE	NONE	NONE	NONE	NONE	NONE
Handles forest pests	N	N	Y	Y	N	Y	N	Y	Y	Y	Y
"Calibrates" internal functions to local data[2]	N	N	N	N	N	Y	Y	Y	Y	Y	Y
Computing environment[3]	MF	PC	MF/PC	MF	MF	MF	MF	MF	MF/PC	MF	MF
Structures simulated											
even-aged stands	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
two-storied stands	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y
multistoried stands	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y
Merchantability stands[4]											
cubic feet	F	SV	SV	NONE	US	US	US	US	US	US	US
board feet	F	SV	SV	NONE	NONE	US	US	US	US	US	US

[1]The model is easy to use if user has stand and structure conceptually but does not have actual data to start from.
[2]Usually used to make sure the first projection period accretion is similar to actual conditions.
[3]Computing environment: PC—personal computer; MF—mainframe computer.
[4]Merchantability stands: US—user specified; SV—somewhat variable; F—fixed by the program.

Table 3—Summarization of features available for models used in the Mountain West

Feature	TEPROG	UTPROG	RMYLD2	RMYLDN	ECSPS	IDSPS	BCSPS	TASS
	Model							
Establishes new trees by starting with bare ground	Y	Y	N	N	N	N	N	Y
Use in a hypothetical situation[1]	Y	Y	Y	Y	Y	Y	Y	N
Minimum diameter handled by the model (inches)	0.1	0.1	0.1	0.1	2	2	2	0.1
Maximum age	NONE	NONE	NONE	NONE	NONE	NONE	NONE	?
Minimum age	NONE	NONE	10	10	NONE	NONE	NONE	10
Handles forest pests	Y	Y	Y	Y	N	N	N	Y
"Calibrates" internal functions to local data[2]	Y	Y	N	N	N	N	N	N
Computing environment[3]	MF	MF	MF/PC	MF/PC	PC	PC	PC	MF
Structures simulated								
even-age stands	Y	Y	Y	Y	Y	Y	Y	Y
two-storied stands	Y	Y	Y	N	Y	Y	Y	N
multistoried stands	Y	Y	N	N	Y	Y	Y	N
Merchantability stands[4]								
cubic feet	US	US	F	F	US	US	US	SV
board feet	US	US	F	F	US	US	US	SV

[1]The model is easy to use if user has stand and structure conceptually but does not have actual data to start from.
[2]Usually used to make sure the first projection period accretion is similar to actual conditions.
[3]Computing environment: PC—personal computer; MF—mainframe computer.
[4]Merchantability stands: US—user specified; SV—somewhat variable/limited choice; F—fixed by the program.

A GEOGRAPHIC COMPARISON

The Mountain West is a highly diverse area. The likelihood of a model developed for the southern part of the region biologically working in the northern part would seem to me to be small. Individual model types like Prognosis, RMYLD, and SPS actually have variants that were developed only for specific areas. Figures 1-9 illustrate the geographic area of application for the models considered in this paper.

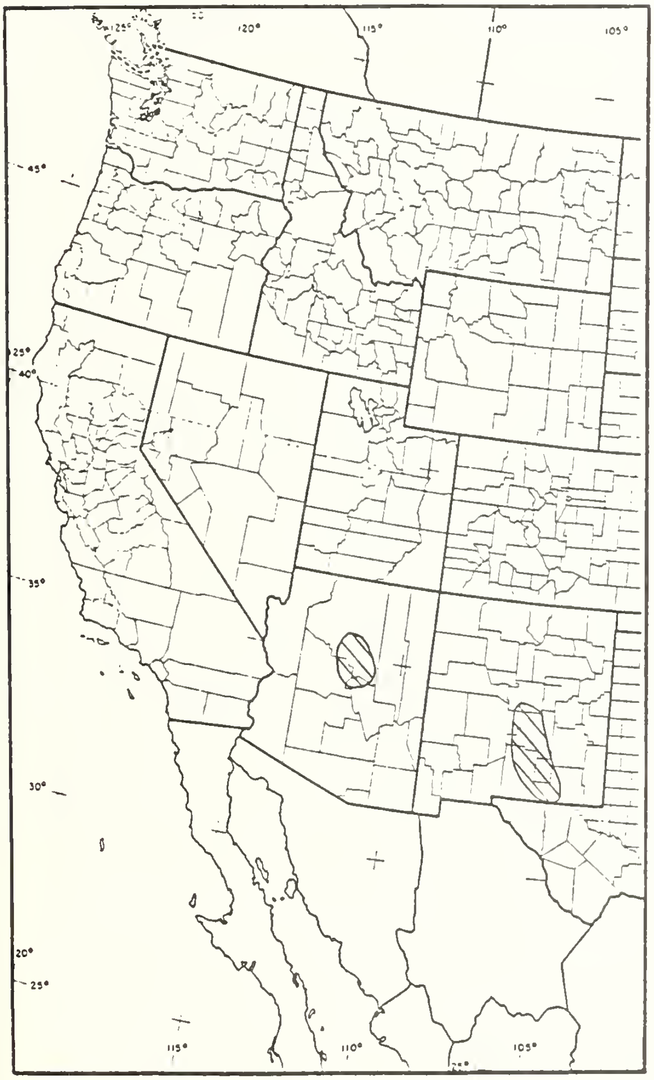

Figure 1—Approximate geographic range for the ECOSIM growth and yield simulator.

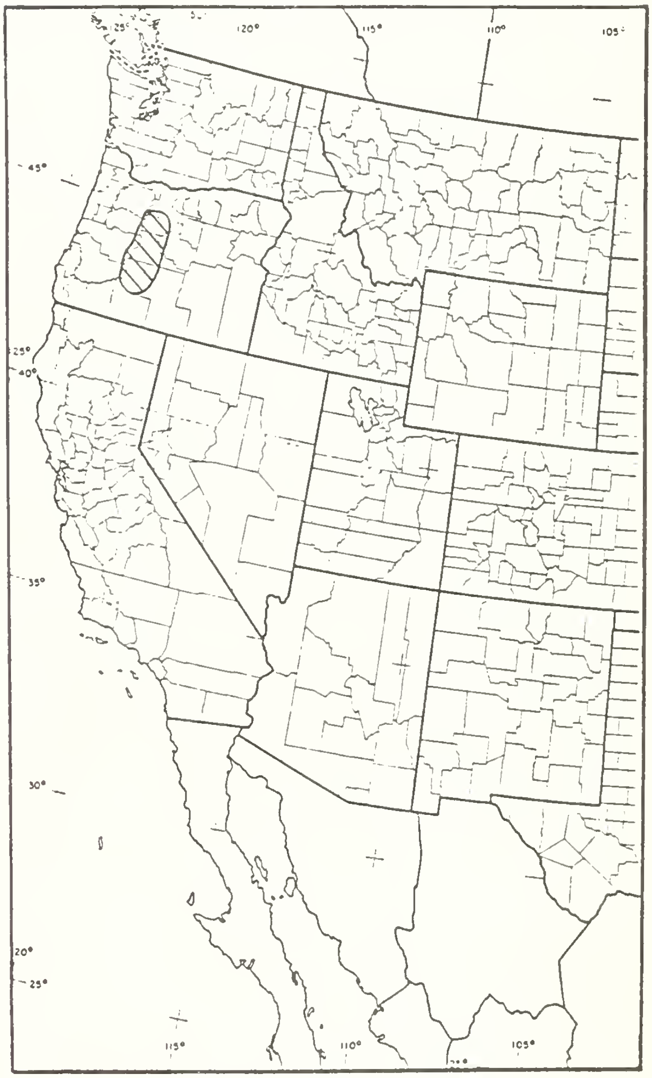

Figure 2—Approximate geographic range for the LPSIM growth and yield simulator.

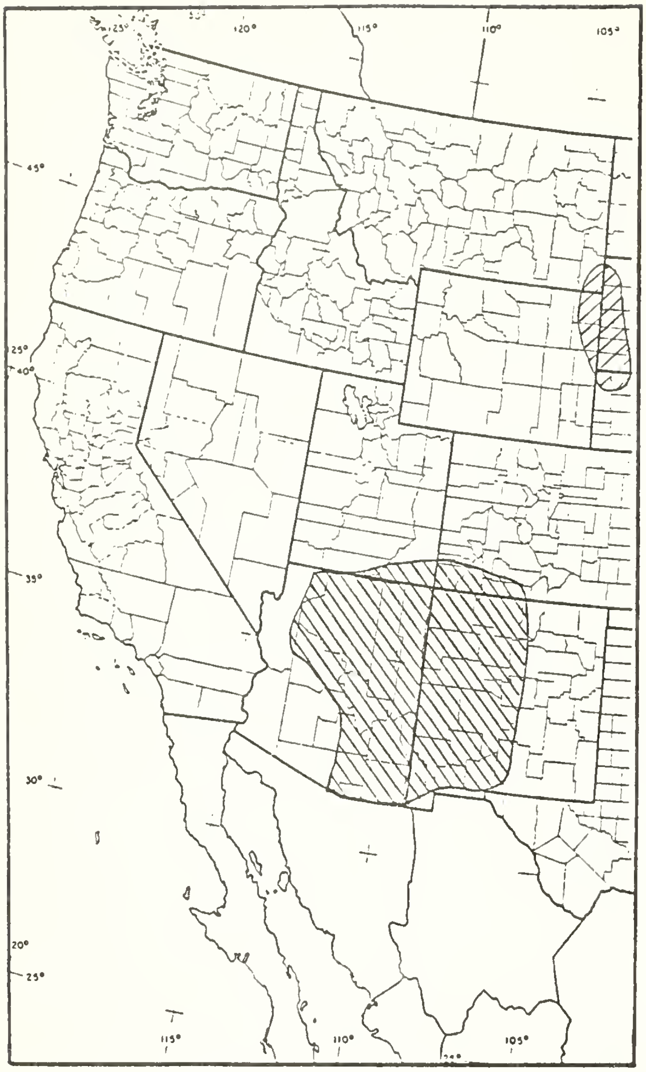

Figure 3—Approximate geographic range for the PIPO growth and yield simulator.

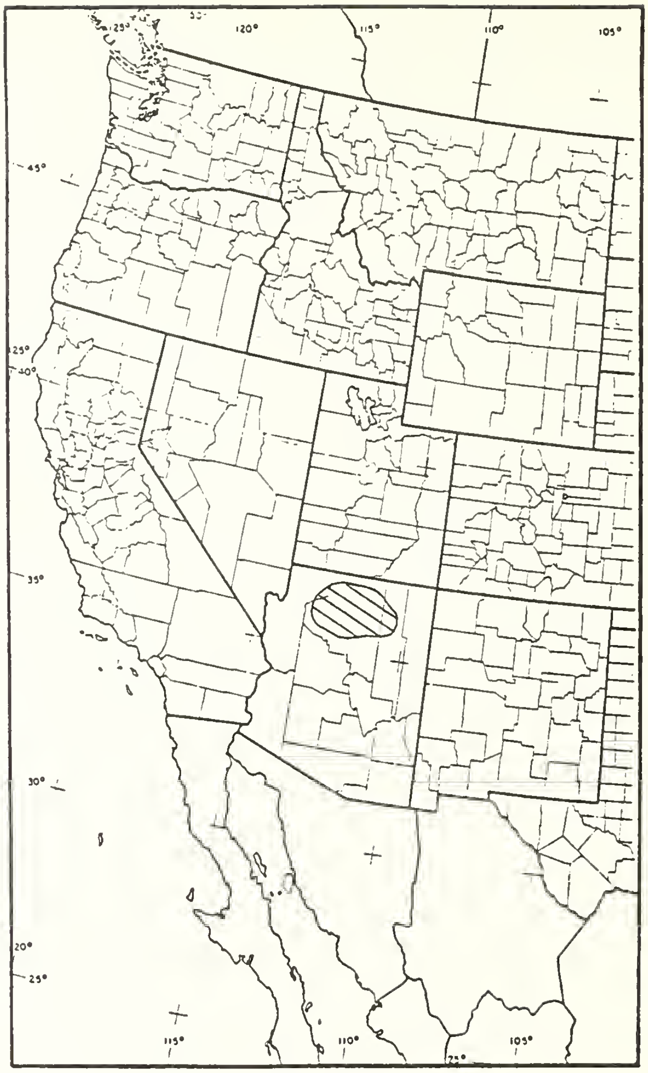

Figure 4—Approximate geographic range for the PPINE growth and yield simulator.

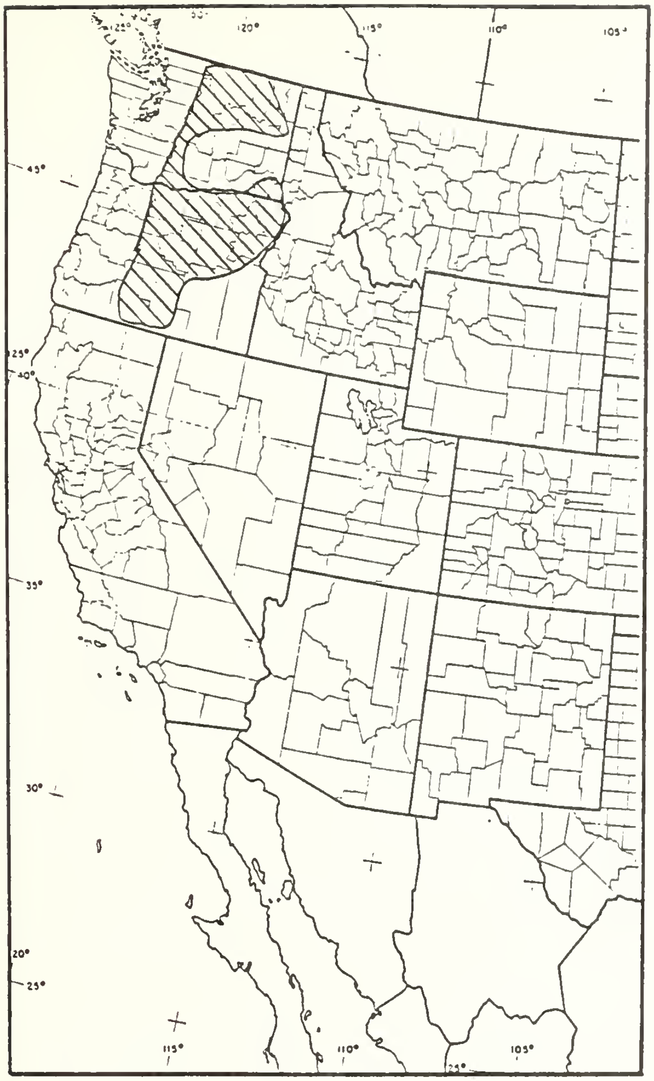

Figure 5—Approximate geographic range for the PPSIM growth and yield simulator.

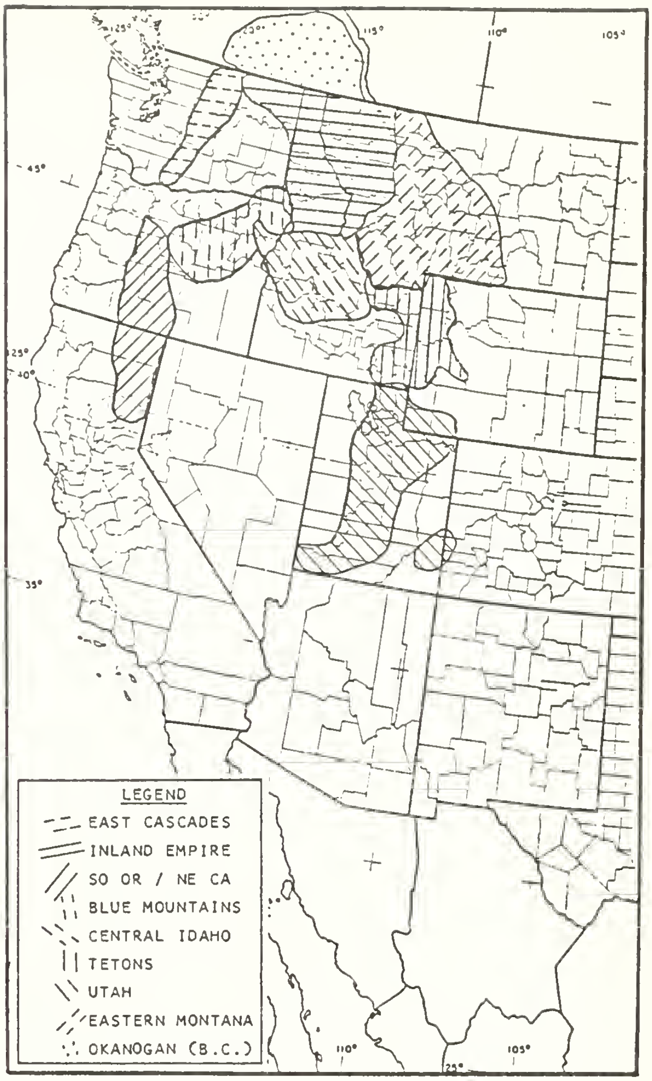

Figure 6—Approximate geographic range for variants of Prognosis in the Inland West.

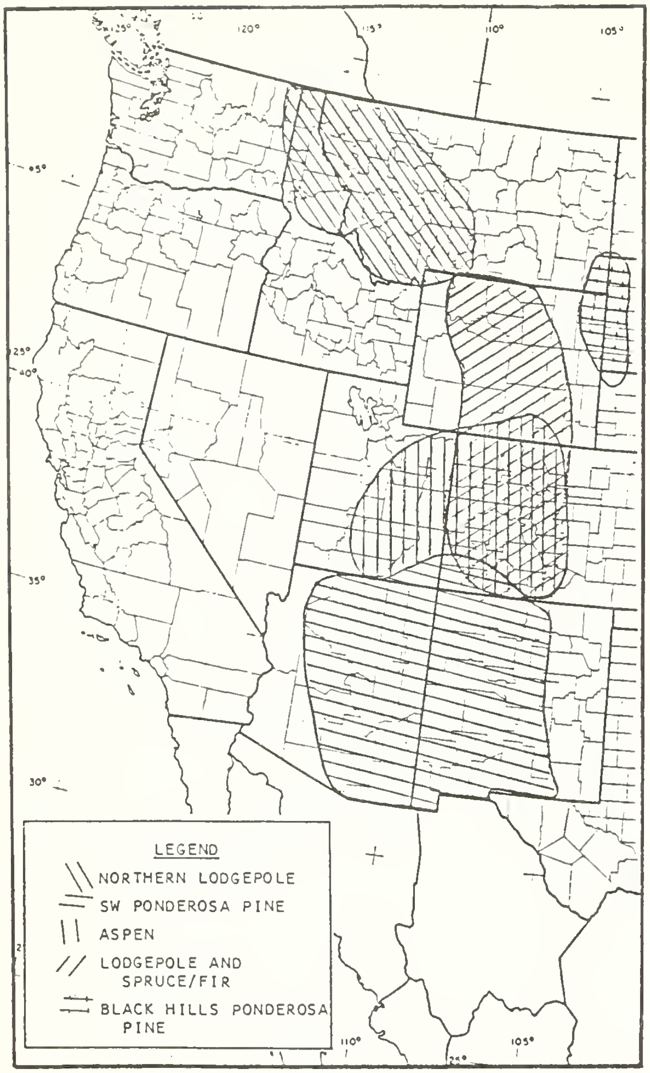

Figure 7—Approximate geographic range for submodels of the RMYLD growth and yield simulator.

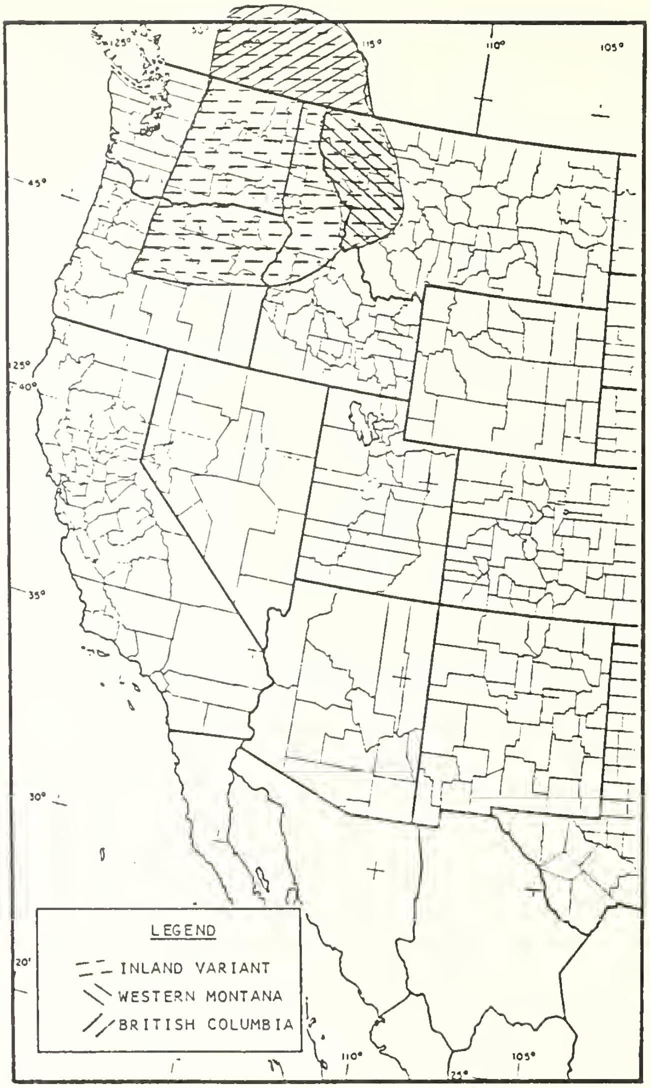

Figure 8—Approximate geographic range of variants of the SPS growth and yield simulator.

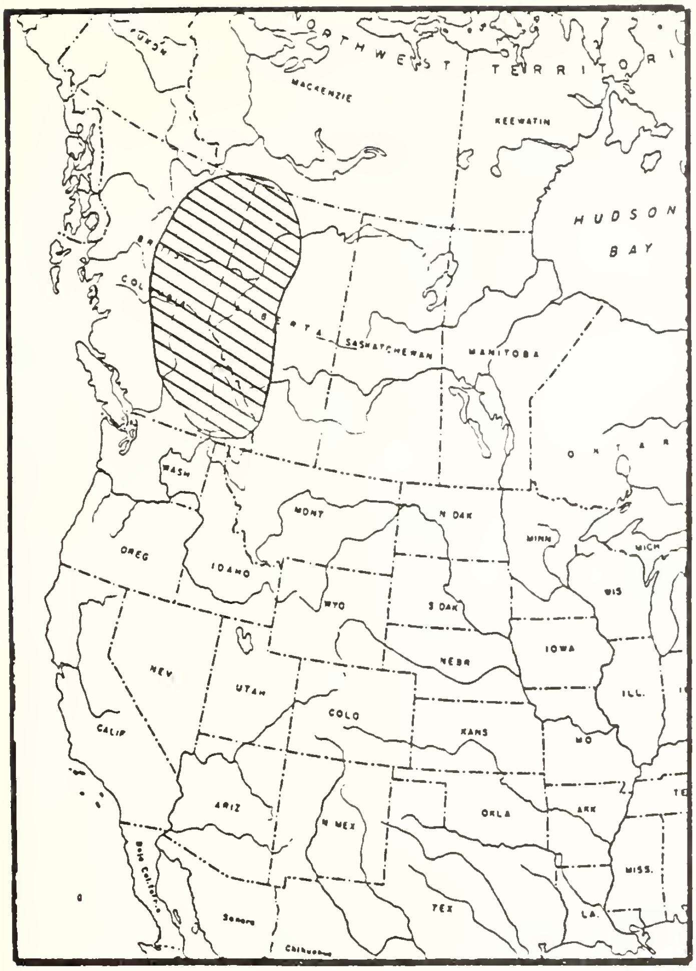

Figure 9—Approximate geographic range for the TASS growth and yield simulator.

A SPECIES COMPARISON

Even though a selected model may be applicable to a particular geographic region, the species of interest may not be accounted for. In general, stand models relate only to a single species, although allowance is made for token amounts of minor species. The individual tree models usually account for a wide variety of species, but keep in mind not all species are equally represented in the data base used to build the model. Some subparts of individual tree models may not have any species specific data behind them and rather draw on findings from another species. One should check the user's manual to make sure the simulator selected will work in your area, on your species, for the kind of analysis you want to do.

Table 4 is a listing of species accounted for by model variant. I have not attempted to rank the strength of how the species is represented in the model.

Table 4—Species occurrence for some selected managed stand simulators

	Tree species[1]																				
Model	WB	WP	LP	PP	JP	SP	P	WL	WRC	DF	AF	WF	GF	RF	NF	WH	MH	ES	J	AS	WS
ECOSIM		*		*						*	*	*						*		*	
LPSIM			*																		
PIPO				*																	
PPINE				*																	
BLPROG			*	*				*		*	*	*	*					*			
ECPROG			*	*				*		*	*	*	*					*			
EMPROG	*		*	*						*	*							*			
INPROG		*	*	*				*	*	*	*	*	*			*	*	*			
SOPROG		*	*	*	*	*				*		*		*	*		*		*		
SIPROG		*	*	*				*		*	*	*	*					*			
TEPROG	*		*							*	*							*			
UTPROG	*		*	*						*	*	*						*		*	
RMYLDSWP				*																	
RMYLDLP			*																		
RMYLDBHP				*																	
RMYLDASP																				*	
RMYLDSF											*							*			
RMYLDN			*																		
INSPS			*	*				*		*			*								
BCSPS			*	*				*		*		*	*								
WMSPS			*	*				*		*											
TASS			*																		*

[1]WP	Western white pine	P	Pinyon pine	AF	Subalpine fir	WH	Western hemlock
WB	Whitebark pine	JF	Jeffrey pine	WF	White fir	MH	Mountain hemlock
SP	Sugar pine	WRC	Western redcedar	GF	Grand fir	AS	Aspen
LP	Lodgepole pine	DF	Douglas-fir (interior)	RF	Red fir	WS	White spruce
PP	Ponderosa pine	J	Juniper	NF	Noble fir		

INPUT VARIABLES USED IN "DRIVING" THE SIMULATOR

The question is often asked, "What kind of data does it take to run this model?" Or, individuals say they cannot run model X because they do not have habitat type. Selection of a particular model may be directed by the kind of data available, or a silviculturist may wish to alter field data collection procedures so the full power of a model might be utilized. Tables 5 through 8 array input variables by model. I have indicated whether the variable is for the stand as a whole or for a point or a tree. I have also indicated whether the variable is mandatory, not used, or optional.

Table 5—Input variables used in selected models used for managed stand simulation in the Mountain West

Tree/point level variables	Model												
	ECOSIM	LPSIM	PIPO	PPINE	PPSIM	BLPROG	ECPROG	EMPROG	INPROG	SOPROG	SIPROG	TEPROG	UTPROG
Point number	[1]-	-	-	-	-	[2]+	+	+	+	+	+	+	+
Tree coordinate	-	-	-	-	-	-	-	-	-	-	-	-	-
Species	[3]*	-	-	-	-	*	*	*	*	*	*	*	*
D.b.h.	*	*	*	*	-	*	*	*	*	*	*	*	*
Diameter growth	-	-	-	-	-	+	+	+	+	+	+	+	+
Height	-	+	+	-	-	+	+	+	+	+	+	+	+
Height growth	-	-	-	-	-	+	+	+	+	+	+	+	+
Tree expansion factor	*	-	-	*	-	+	+	+	+	+	+	+	+
Crown ratio/crown length	-	-	-	-	-	+	+	+	+	+	+	+	+
Crown class	-	-	-	-	-	-	-	-	-	-	-	-	-
Tree status/history	-	-	-	-	-	+	+	+	+	+	+	+	+
Mistletoe rating	-	-	-	-	*	-	-	-	-	*	-	-	-
Top damage	-	-	-	-	-	+	+	+	+	+	+	+	+
Defect	-	-	-	-	-	-	-	-	-	-	-	-	-
Tree product class	-	-	-	-	-	+	+	+	+	+	+	+	+
Slope	-	-	-	-	-	-	-	-	+	-	-	-	-
Aspect	-	-	-	-	-	-	-	-	+	-	-	-	-
Elevation	-	-	-	-	-	-	-	-	+	-	-	-	-
Percent ground cover	-	-	-	-	-	-	-	-	-	-	-	-	-
Brush height	-	-	-	-	-	-	-	-	-	-	-	-	-
Brush species	-	-	-	-	-	-	-	-	-	-	-	-	-
Habitat	-	-	-	-	-	-	-	-	+	-	-	-	-

[1]- not used or relevant.
[2]+ optional.
[3]* mandatory.

Table 6—Input variables used in selected models used for managed stand simulation in the Mountain West

Tree/point level variables	Model					
	RMYLD2	RMYLDN	INSPS	BCSPS	WMSPS	TASS
Point number	[1]-	-	-	-	-	-
Tree coordinate	-	-	-	-	-	[2]*
Species	-	-	*	*	*	-
D.b.h.	-	-	[3]+	+	+	*
Diameter growth	-	-	-	-	-	-
Height	-	-	+	+	+	*
Height growth	-	-	-	-	-	*
Tree expansion factor	-	-	*	*	*	-
Crown ratio/crown length	-	-	+	+	+	*
Crown class	-	-	-	-	-	*
Tree status/history	-	-	-	-	-	-
Mistletoe rating	-	-	-	-	-	-
Top damage	-	-	-	-	-	*
Defect	-	-	-	-	-	-
Tree product class	-	-	-	-	-	-
Slope	-	-	-	-	-	-
Aspect	-	-	-	-	-	-
Elevation	-	-	-	-	-	-
Percent ground cover	-	-	-	-	-	-
Brush height	-	-	-	-	-	-
Brush species	-	-	-	-	-	-
Habitat/ecoclass	-	-	-	-	-	-

[1]- not used or relevant.
[2]* mandatory.
[3]+ optional.

Table 7—Area related input variables used in selected models used for managed stand simulation in the Mountain West

	Model												
Variable	ECOSIM	LPSIM	PIPO	PPINE	PPSIM	BLPROG	ECPROG	EMPROG	INPROG	SOPROG	SIPROG	TEPROG	UTPROG
Location name	[1]*	*	[2]-	*	-	[3]+	+	+	+	+	+	+	+
Location number	-	-	-	-	-	+	+	+	+	+	+	+	+
Stand/location age	-	*	-	+	*	+	+	+	+	+	+	+	+
Site index	*	*	*	*	*	-	-	-	-	*	-	*	*
Site index method	*	-	-	-	-	-	-	-	-	*	-	*	*
Area (acres/ hectares)	-	-	-	-	-	+	+	+	+	+	+	+	+
Stand origin	*	-	+	-	*	-	-	-	-	-	-	-	-
Vegetative type	*	-	-	-	-	-	-	-	-	-	-	-	-
Elevation	-	-	-	-	-	*	*	*	*	*	*	*	*
Slope	*	-	-	-	-	*	*	*	*	*	*	*	*
Aspect	*	-	-	-	-	*	*	*	*	*	*	*	*
Slope position	-	-	-	-	-	-	-	-	-	-	-	-	-
Unit of measure	-	-	-	-	-	-	-	-	-	-	-	-	-
Basal area	-	-	-	-	*	-	-	-	-	-	-	-	-
Trees/acre	-	-	-	-	*	-	-	-	-	-	-	-	-
Quadratic mean diameter	-	-	-	-	*	-	-	-	-	-	-	-	-
Habitat type/ ecoclass	-	-	-	-	-	*	-	*	*	-	*	-	-
Sample design	*	-	-	-	-	*	*	*	*	*	*	*	*

[1]* mandatory.
[2]- not used or relevant.
[3]+ optional.

Table 8—Area related input variables used in selected models used in managed stand simulation for the Mountain West

Variable	Model					
	RMYLD2	RMYLDN	INSPS	BCSPS	WMSPS	TASS
Location name	[1]*	*	[2]-	-	-	-
Location number	-	-	-	-	-	*
Stand/location age	*	*	[3]+	+	+	+
Site index	*	*	*	*	*	*
Site index method	*	*	*	*	*	*
Area (acres/hectares)	-	-	-	-	-	*
Stand origin	-	-	+	+	+	-
Vegetative type	*	*	-	-	-	*
Elevation	-	-	-	-	-	-
Slope	-	-	-	-	-	-
Aspect	-	-	-	-	-	-
Slope position	-	-	-	-	-	-
Unit of measure	*	*	-	-	-	-
Basal area	*	*	-	-	-	-
Trees/acre	*	*	+	+	+	-
Quadratic mean diameter	*	*	+	+	+	-
Habitat type/ecoclass	-	-	-	-	-	-

[1]* mandatory.
[2]- not used or relevant.
[3]+ optional.

OUTPUT INFORMATION

The need to produce unique output displays must be as ingrained as the need to be creative in program control, for virtually every author has a different way of arraying output. It takes a bit of adjustment to pick up an output sheet and figure out what is on it. Some tables even require special training to interpret them. Stand models generally cannot produce tree level detail, so the stand models usually have a subset of possible output variables. In tables 9 through 12, I have arrayed variables of mensurational interest by model variant. These variables may appear in only one standard table, may appear in all tables, or may only be available through a special feature. If the variable was observable, it shows as such in tables 9 through 12. In other words, you may have to hunt awhile to find them.

Table 9—Information available on output displays for selected models used in managed stand simulation in the Mountain West

	Model										
	ECOSIM	LPSIM	PIPO	PPINE	PPSIM	BLPROG	ECPROG	EMPROG	INPROG	SOPROG	SIPROG
Starting inventory conditions	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Periodic report of the inventory[1]	US	1Y	US	5Y	US	10/US	10/US	10/US	10/US	10/US	10/US
Removals	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
List of trees or diameter classes	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
After treatment conditions	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
Cumulative summary	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
Economic link	N	Y	N	N	N	Y	Y	Y	Y	Y	Y

[1]1Y—every year
10—every 10 years
5Y—every 5 years
US—user specified intervals.

Table 10—Information available on output displays for selected managed stand simulators used in the Mountain West

Information	Model						
	UTPROG	RMYLD2	RMYLDN	INSPS	BCSPS	WMSPS	TASS
Starting inventory conditions	Y	Y	Y	Y	Y	Y	Y
Periodic report of the inventory[1]	10/US	10/US	10/US	5/US	5/US	5/US	US
Removals	Y	Y	Y	Y	Y	Y	Y
List of trees or diameter classes	Y	N	N	Y	Y	Y	Y
After treatment conditions	Y	Y	Y	Y	Y	Y	?
Cumulative summary	Y	Y	Y	Y	Y	Y	Y
Economic link	Y	N	N	Y	Y	Y	N

[1]10—every 10 years
5—every 5 years
US—user specified intervals.

Table 11—Values displayed in the output tables for selected managed stand simulators used in the Mountain West

Item	Model											
	ECOSIM	LPSIM	PIPO	PPINE	PPSIM	BLPROG	ECPROG	EMPROG	INPROG	SOPROG	SIPROG	TEPROG
Stand identification	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y
Stand age	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
Stand density index	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y
Basal area	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
Trees per acre	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Crown competition factor	N	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y
Total cubic volume	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Merchantable cubic volume	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Special products	Y	N	Y	N	N	N	N	N	N	N	N	N
Scribner volume	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y
International volume	N	Y	N	N	N	N	N	N	N	N	N	N
Quadratic mean diameter	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Projection interval	N	N	Y	N	N	Y	Y	Y	Y	Y	Y	Y
Top height	N	Y	I	N	Y	Y	Y	Y	Y	Y	Y	Y
Footnote explaining merchantability limit[1]	Y	Y	Y	N/A	Y	Y	Y	Y	Y	Y	Y	Y
Accretion in table	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y
Mortality	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
Mean annual increment	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y

[1]I—indirectly via a special feature.

Table 12—Values displayed in selected managed stand simulators used in the Mountain West

Item	Model						
	UTPROG	RMYLD2	RMYLDN	INSPS	BCSPS	WMSPS	TASS
Stand identification	Y	Y	Y	Y	Y	Y	Y
Stand age	Y	Y	Y	Y	Y	Y	Y
Date/year	Y	N	N	N	N	N	N
Stand density index	Y	N	N	N	N	N	N
Basal area	Y	Y	Y	Y	Y	Y	Y
Trees per acre	Y	Y	Y	Y	Y	Y	Y
Crown competition factor	Y	N	N	Y	Y	Y	Y
Total cubic volume	Y	Y	Y	Y	Y	Y	Y
Merchantable cubic volume	Y	Y	Y	Y	Y	Y	Y
Special products	N	Y	Y	Y	Y	Y	Y
Scribner volume	Y	Y	Y	Y	Y	Y	Y
International volume	N	N	N	N	N	N	Y
Quadratic mean diameter	Y	Y	Y	Y	Y	Y	Y
Projection interval	Y	N	N	N	N	N	N
Top height	Y	Y	Y	Y	Y	Y	Y
Footnote explaining merchantability limits[1]	I	Y	Y	Y	Y	Y	I
Accretion in table	Y	N	N	Y	Y	Y	N
Mortality	Y	N	N	N	N	N	Y
Mean annual increment	Y	Y	Y	Y	Y	Y	Y

[1]I—available via a special feature.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from W. [Bill] Young)—While I would never believe this story, one of your USFS "buddies" said that you told your lengthy "shaggy dog" house building story so that time constraints would mean that you would not have to address the vacuum for a model to project uneven management growth and yield models. What models can be used for uneven management of dry belt Douglas-fir?

A.—Because of the necessity of bringing new trees into the simulation only Prognosis can be easily used at the present time. SPS is capable of simulating uneven size management; however, one needs to bring trees in at about 2 inches d.b.h.

Q. (from Ernie Collard)—Will your paper, published in the proceedings, cover the advantages and disadvantages of each model as they relate to your criteria of what the model should produce?

A.—No. I did not attempt to make a qualitative judgment on each model.

Q. (from George Howe)—Nance's work suggests that models for unimproved southern pine stands may not be appropriate for improved stands. Is Prognosis appropriate for improved stands of Northern Rocky Mountain conifers?

A.—For use of blister rust resistant stock of western white pine, the model will undoubtedly overpredict mortality. For improved tree growth rates, the Prognosis allows for internal adjustment by the user to increase rates. If the use of improved stock not only results in faster growth but higher possible stocking, the model can be tuned to reflect the adjustment resulting for improved stock. There are no automation-embedded features one can invoke.

PEST MODELS FOR THE INLAND MOUNTAIN WEST

Bov B. Eav
Michael A. Marsden

ABSTRACT

Computer-based simulation models are increasingly being used to support forest resource planning and management. Forest pest models that have been linked to a forest growth and yield system and are applicable in the Inland Mountain West are the Douglas-fir tussock moth, mountain pine beetle, western spruce budworm, dwarf mistletoe, and root disease models.

A suggested approach for incorporating pest models into the forest planning process consists of the following steps: risk rating of analysis areas and individual stands within each area; selection of management alternatives; projection of pest-host response under each alternative; and submission of resulting growth and yield data into an optimization model such as FORPLAN.

INTRODUCTION

As the advantages of computer-based models become better understood, more and more managers are using them. For example, forest growth and yield simulation models have been successfully applied both to the development of individual stand prescriptions and forest plans.

Forest simulation models are valuable as planning tools because they permit studies of the consequences of choice without actually having to commit valuable resources to an experiment or having to wait many years to observe the outcomes. Simulation experiments are seen as more convenient, relatively less expensive, and without risks compared to experimentations in the real world. Pest models need to be better and more frequently used in resource planning and other management activities.

One method of integrating forest pest impact considerations into the resource planning process is to provide resource managers with the capability and competence to simulate the growth of infested or diseased forest stands under various management scenarios employing different strategies. Relevant forest simulation models have been developed over the past few years.

This paper reviews available forest pest simulation models applicable to the Inland Mountain West. Two scenarios for using forest pest models in the resource planning process will also be proposed.

FOREST PEST MODELS FOR THE INLAND MOUNTAIN WEST

In the past decade various forest insect and disease simulation models have been developed to assist pest management specialists and resource planners in their decision-making process. Three insect pest and two disease models for the Inland Mountain West are currently available or being installed at the Fort Collins Computer Center (FCCC).

Insect Pest Models

Douglas-fir Tussock Moth Model(DFTM)—The Douglas-fir tussock moth (*Orgyia pseudotsugata*) was the first insect to be modeled and linked to a forest growth and yield system. DFTM is not just an index of the population level or tree damage; it simulates actual population dynamics of the tussock moth.

The purposes of the model are "to provide an explicit perspective for research and study of the population" and "to make knowledge of the tussock moth system available to the manager so that this knowledge can be used without the manager first becoming a tussock moth expert" (Overton and Colbert 1978).

The simulation model is actually a combination of two models: the Stand Prognosis Model (Stage 1973) and the DFTM Outbreak Model (Overton and Colbert 1978). The DFTM Outbreak Model simulates the insect population dynamics and resulting defoliation during a tussock moth outbreak. The Stand Prognosis Model, referred to earlier as the Prognosis Model, is an individual tree-based stand model designed to simulate the development of the mixed-species even- and uneven-aged stands commonly found in the Northern Rocky Mountains.

The combined Prognosis/DFTM model has been used to assess the likely consequences of both silvicultural treatments and tussock moth control activities for stands in the Northern Rocky Mountains (Bousfield and others 1984; Stoszek and Mika 1984).

Mountain Pine Beetle Model—Coupled with the Stand Prognosis Model (Stage 1973), the mountain pine beetle model (Crookston 1979) is a tool for predicting lodgepole pine (*Pinus contorta*) stand growth and development for stands infested with mountain pine beetle (*Dendroctonus ponderosae* Hopkins).

The Mountain Pine Beetle Model as it is maintained at the FCCC actually contains two models: the Cole model (no population dynamics) and the Burnell model (with population dynamics).

The Cole model predicts lodgepole pine mortality rate as a function of density of live trees in a diameter class, density of trees killed the previous year, and a diameter class dependent constant. It is designed to give estimates of losses to unmanaged stands.

The Burnell model simulates beetle population dynamics and predicts stand growth and damage due to the mountain pine beetle. The model can be triggered by user's request or by probabilistic approach where the model is called when the calculated probability of outbreak is greater than a random number or a specified probability level. The probability of outbreak is a function of crown competition factor and the proportion of basal area in lodgepole pine. This model can be used to evaluate various stand management alternatives. An example of how the evaluation can be performed is given in Crookston (1979).

Western Spruce Budworm Model—Development of the Budworm Model is a major objective of the western component of the Canada/United States Spruce Budworm Program (CANUSA-West), a 7-year research and development program of the Forest Service, U.S. Department of Agriculture and the Canadian Forestry Service. The model integrates CANUSA-sponsored research results and was designed to allow scientists to identify critical factors that affect budworm population dynamics, and allow resource managers to evaluate the effects of budworm defoliation on stand growth and yield (Colbert and others 1983). The Budworm Model can be used in any one of four modes:

—As a stand-alone model, it predicts budworm population dynamics, effects on host foliage, and their interactions based on site, stand, foliage, and weather conditions.

—As a damage model, it works with the Prognosis growth and yield model to convert budworm defoliation estimates into impacts on stand growth and mortality.

—Linked to the Stand Prognosis Model, it can be used to make long-term projections of budworm population dynamics, defoliation, and effects on stand growth, one stand at a time.

—In the near future the Parallel Processing-Budworm Model will allow long-term projections of budworm population dynamics, defoliation, and effects on stand growth and yields for hundreds of stands simultaneously.

The Budworm Model simulates budworm effects on five host species: Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), white fir (*Abies concolor*), subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*). It is available on the Univac computer at the FCCC.

Disease Models

Dwarf Mistletoe—The effects of dwarf mistletoe on lodgepole and ponderosa (*Pinus ponderosa*) pines are included in the stand growth model for these species, RMYLD (Edminster 1978). This model simulates the effects of dwarf mistletoe (*Arceuthobium americana* Nutt. ex Engelm. in Gray) on lodgepole pine even-aged stands in Colorado and Wyoming. It also simulates the effects of dwarf mistletoe (*A. vaginatum* [H.B.K.] Eichler ssp. *cryptopodum* Hawksworth & Wiens) on ponderosa pine even-aged and two-storied stands in Colorado, Arizona, and New Mexico.

Volume reduction due to dwarf mistletoe has been modeled for the central Oregon plateau (Schmitt and Wiitala 1983). This reduction is calculated on a stand volume basis with capacity to project the volume through time.

In the south-central Oregon/northeastern California variant of Prognosis (SORNEC), the effect of dwarf mistletoe is included for eight conifer species: western white pine (*Pinus monticola* Dougl.), Engelmann spruce, Douglas-fir, white fir, mountain hemlock (*Tsuga mertensiana* [Bong] Carr.), lodgepole pine, red fir (*Abies magnifica* A. Murr.), and ponderosa pine (Johnson and others 1986).

Root Disease Model—Root disease is a major pest problem in the forests of the Inland Mountain West. A simulation model has been developed for two major root disease species: *Armillaria* and *Phellinus*.

The Root Disease Model is linked to the Prognosis Stand Model and is designed to work with existing forest inventories. It simulates the possible outcomes of silvicultural prescriptions and root disease control activities for stands where root disease is known to occur. The model can be used to evaluate the effects of stand management for long-term planning (Sutherland and McNamee 1986).

The basic components of the model include the relative susceptibilities of trees to infection, resistance of trees to death resulting from root disease attack, disease-related growth reduction, decay of infected root systems, and life span of root disease pathogens. Because trees weakened by root disease are subject to attack by pine beetles or bark beetles and windthrow, the model also simulates the impact of these agents.

PEST MODELS IN THE PLANNING PROCESS

Procedures and guidelines for incorporating pest simulation models into forest management planning and decision-making processes have been provided by numerous authors (Bousfield and others 1984; Stage 1975; Stage and Long 1976; Stage and others 1986; USDA 1978; Waters and Cowling 1976; White 1986; Marsden 1984). We are reviewing only a few recently suggested and demonstrated procedures here.

A demonstration of a methodology for incorporating economic impact evaluation of the Douglas-fir tussock moth on forest management objectives and for assessing the economic efficiency of alternative pest management strategies was conducted by Bousfield and others (1984) in two National Forests (Clearwater and Malheur). This study selected areas that have historically been subjected to tussock moth infestation to submit to the Douglas-fir Tussock Moth Model simulation. Figure 1 shows the procedures used in the study. The approach followed by this study differs only slightly from the current forest planning practice. The modification is in linking the pest simulation model to the growth and yield model (fig. 1).

Stage and others (1986) recently suggested a procedure for preparing forest management plans that include pests. Their approach keys on the use of a multistand model that "permits interaction between stands and between the different resource response models." Their guidelines for including pests in forest planning are: (1) analysis units

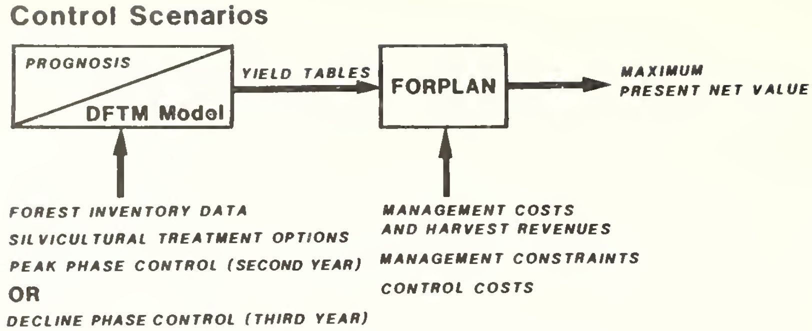

Figure 1—Analysis procedures for DFTM outbreak and control scenarios used by Bousfield and others (1984).

should be contiguous aggregates of stands, (2) yield streams should be estimated for analysis areas by scenario with regard to spatial relationships between stands within analysis units, and (3) FORPLAN Version 2 should be used to select scenarios for analysis units.

The use of multistand models in the overall pest impact assessment and pest control planning is included in the Integrated Pest Impact Assessment System (IPIAS) being developed by the Methods Application Group of Forest Pest Management and various cooperators (White 1986). IPIAS can be used in conjunction with current forest planning tools and procedures to ensure that pest impacts and pest management considerations are integral parts of the planning process. Figure 2 illustrates how IPIAS might be used in forest planning. IPIAS, however, requires the availability of a geographic information data base that may not be available at most National Forests. Also, the high resolution inherent in IPIAS may be too cumbersome for forestwide analysis.

In most National Forests such detailed analyses of the entire forest are required only for high-value or high-concern areas. For those areas where either a geographic information system does not exist or the details provided by IPIAS are not required, we propose the following procedures for integration of pest impacts into the planning process (fig. 3):

Step 1. While defining analysis areas, recognize vegetation's susceptibility to forest pests and its response to pest management practices.

Step 2. Devise sampling scheme to select stands to represent each analysis area.

Step 3. Submit each analysis area to risk rating systems for the appropriate pest. A risk rating system determines an index to the susceptibility to a pest for an analysis area, or the probability that an analysis area will be infested by the particular pest. Risk rating systems for both eastern and western spruce budworms, for example, are described

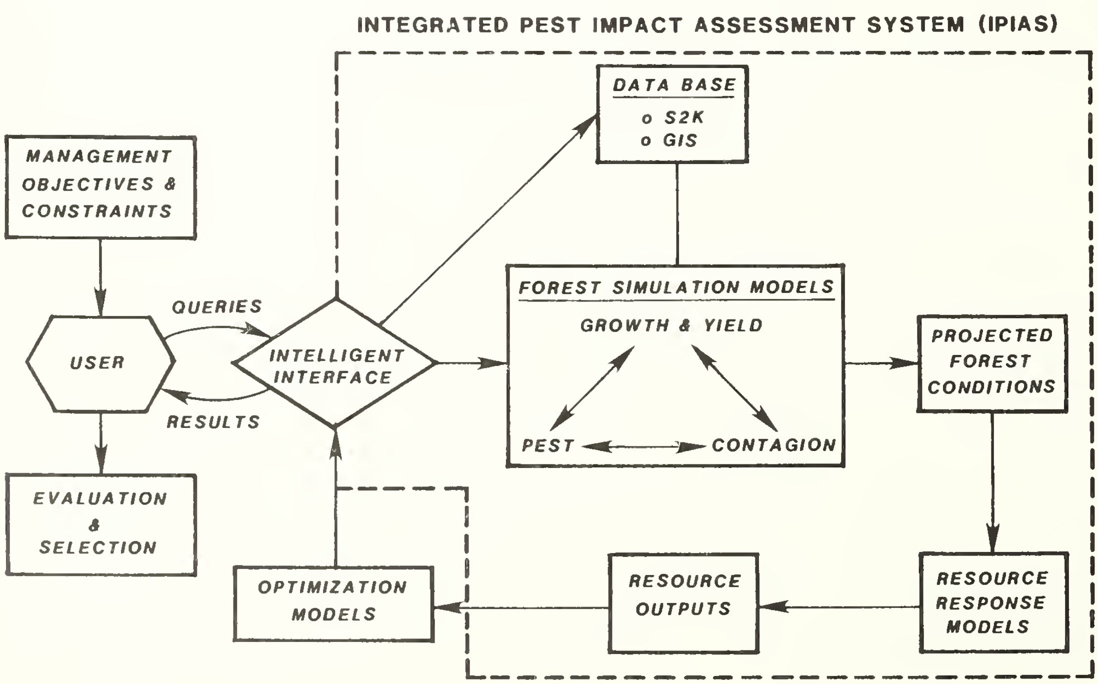

Figure 2—Diagram showing the concept for using the Integrated Pest Impact Assessment System in forest planning (adapted from White 1986).

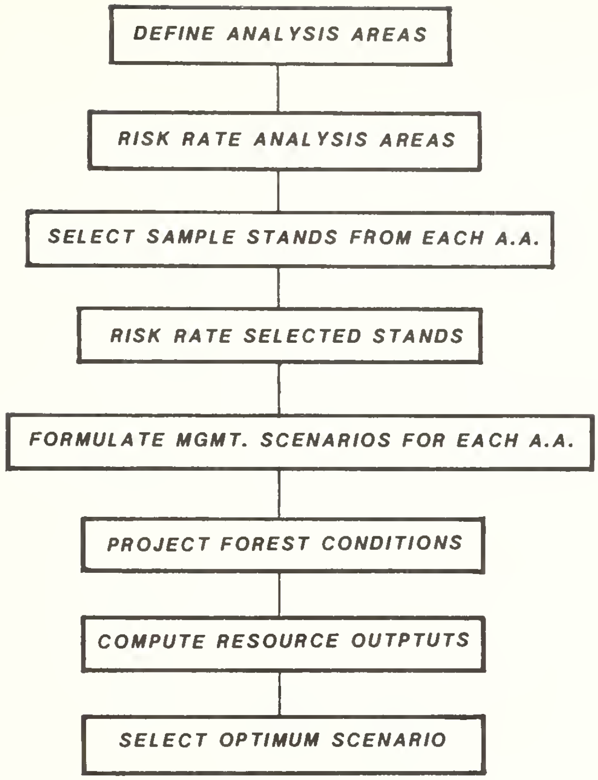

Figure 3—Proposed procedures for integrating pest impacts in forest planning.

in Witter and others (1984), Carlson and others (1985), and Marsden and others (1986).

Step 4. Submit sampled stands within each high risk analysis area to a risk rating system for the pest(s). Conditional probability that a stand will be infested helps determine whether or not simulating for the pest is necessary. This step may be automatically performed in some pest models.

Step 5. In defining management scenarios for each analysis area, include those scenarios containing silvicultural treatments or control measures for minimizing pest impacts.

Step 6. Just as in current practice, project forest conditions resulting from all scenarios.

Step 7. Use forest conditions to compute resource outputs through socio-economic models for input into the chosen optimization model. These procedures may undergo refinements as our efforts to develop easy-to-use delivery systems for pest models progress.

CONCLUSIONS

Management planning for future forests will most likely require the use of simulation models. Realistic predictions can be obtained only if pests' and other destructive agents' impacts are accounted for. The procedures outlined in this paper are designed to integrate pest impacts into the planning process. Projects being conducted by the Methods Application Group of Forest Pest Management, within the Forest Service, are intended to automate most required tasks into easy-to-use pest model delivery systems.

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SESSION 3.

The Practice

Orville E. Engelby
Session Coordinator

The first two sections of this proceedings covered the resource opportunities in young forests of the Mountain West and the analysis tools for diagnoses. They laid the groundwork for this section, which deals with the "doing" part—the practice of silviculture. The purpose of this section is to provide state-of-the-art information about the response of most of the major tree species and forests to various cultural practices. Six categories are used to describe the practices including: (1) physiological response to cultural practices, (2) stand density effects on growth and yield of the major species, (3) fertilization effects on tree and stand growth of most of the major species, (4) genetic implications and potential, (5) interaction of cultural treatments with damaging agents, and (6) various methods that can be used to implement cultural treatments.

With the objective of "providing a legacy of quality forests for future generations," this section goes a long way in telling managers how to accomplish that objective.

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GENETIC CONSIDERATIONS FOR CULTURE OF IMMATURE STANDS

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Lauren Fins

ABSTRACT

Considerable, though often overlooked, opportunities for genetic improvement are available through use of intermediate stand treatments. To take advantage of these opportunities, it is important to understand and correctly apply principles of selection and genetic gain. Selection intensity provides the leverage for improvement. Because selection intensities are much lower for cultural treatments than for breeding programs, the amount of gain achieved will be lower, but still important. Of the cultural operations likely to be applied (thinning, timber stand improvement, brush control, fertilization), thinning offers the greatest opportunity for genetic improvement. Early thinnings present more opportunities than later thinnings, and a series of thinnings is better than a single thinning. In terms of potential for genetic upgrading, the formal thinning methods could be ranked: low > crown > mechanical > selection.

Predicting the effects of cultural treatment on stand genetics can sometimes be done through modifying predictive models. In most cases, lack of information regarding the effect of competition, cultural treatments, mixes of genotypes, and time responses prevent immediate modification of these models.

INTRODUCTION

Forest genetic principles are often perceived as applying only to artificial regeneration programs. However, intermediate stand treatments can also affect the genetic quality of the remaining stand. Both positive and negative results are possible. By conducting stand culture with conscious efforts toward improving genetic structure, gains in many commercially important tree characteristics may be obtained. By ignoring or dismissing the importance of genetic considerations in stand culture, opportunities for improving important traits are forgone, or worse, degradation may occur. In this paper we review genetic principles applicable to intermediate stand treatments, demonstrate how these apply to various culture operations, and suggest how these fit within the context of management planning.

Opportunities

The primary tool used to accomplish cultural objectives in established stands is cutting (Smith 1986). The choice of trees retained or removed represents an artificial selection pressure that can be eugenic or dysgenic. In contrast to tree improvement programs directed at producing planting stock, the genetic impacts of stand culture are immediate. Furthermore, with treatments (such as thinning) applied serially over the rotation continual upgrading is possible (Zobel and Talbert 1984).

There are two other compelling reasons for applying tree improvement principles to stand culture. It is a very good way to develop improved phenotypes for natural regeneration in the next rotation, and it represents low-cost tree improvement. Opportunities for genetic improvement exist in naturally regenerated stands, in plantations derived from ordinary planting stock, and even in plantations established with genetically improved stock. Dense, even-aged natural stands provide a good opportunity for upgrading if no previous dysgenic cutting has occurred (van Buijtenen and others 1981). In plantations, culling poor-performing phenotypes can improve average stand performance. With plantations of genetically improved stock, thinning and other cultural treatments are necessary to allow maximum expression of genetic potential. Also, additional gains can be obtained as a result of further selection (James 1979).

To take advantage of genetic opportunities in stand culture, it is important to understand and correctly apply principles of selection and genetic gain.

CONCEPTS OF SELECTION AND GENETIC GAIN

In applying intermediate cutting operations, a decision must be reached regarding which trees will be retained in the stand. This can be based on a single characteristic or a group of characteristics, each weighted by its importance. Quantitative characteristics that are the usual focus of genetic improvement (such as, height, diameter, and volume) tend to be distributed normally within a stand. To achieve improvement in any such characteristic, we select within the population the trees that have higher values for that trait. By leaving the selected individuals in the stand and removing the others, we attempt to shift the mean of the population to the right (fig. 1). The difference in the mean value of the original population and that of the selected population is known as the selection differential (SD). Selection can also be negative if the remaining population has a lower mean value than the original population (fig. 1).

Genetic gain in the trait of interest is defined as the product of the selection differential and heritability (h^2):

$$\text{Gain} = \text{SD}^*h^2$$

Heritability is the proportion of variation in a population that has a genetic base. It is a measure of the strength of genetic control over a characteristic. Values of h^2 for most characteristics of interest are less than 0.50 (van Buijtenen and others 1981). If the selected trees will not be used for natural regeneration in the next rotation, heritability is unimportant. Gain in such cases is then equivalent to

Washington State University Agriculture Research Center Scientific Paper SP 7667.

selection differential, at least to the extent that differences are retained during the course of the rotation.

Within finite limits, the selection differential is controlled by selection intensity. Selection intensity refers to the proportion of the population that is selected. For a finite population size (for example, a stand), the smaller the ratio of trees selected to the total population (the greater the selection intensity), the greater the selection differential, and thus the greater the gain. For example, the selection differential would be greater if the best 1 in 100 trees were selected compared with the best 10 of 100 (fig. 2), because the mean of the former would be greater than the mean of the latter.

Large selection intensities can be used in dense, even-aged stands of natural regeneration, especially with a series of thinnings leading to a natural regeneration cut. Selection intensity, and therefore selection differential, would depend on the type of thinning and the type of regeneration cut. For example, in a young stand with an initial density of 15,000 trees per hectare (6,000 trees per acre), a series of thinnings leading to regeneration with a seed-tree cut might result in an overall selection intensity of 1:1250 (assuming 12 trees/ha were retained as seed trees).

Families in plantations established with genetically improved stock have already been subjected to selection

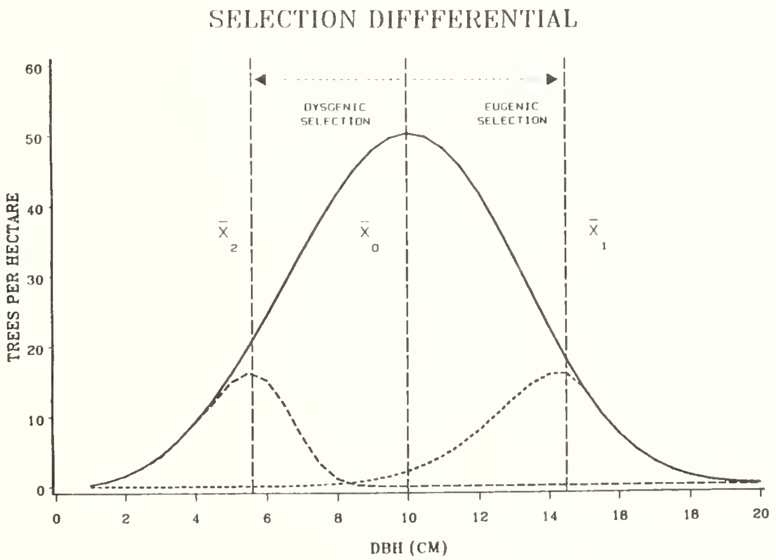

Figure 1—Hypothetical distribution of tree diameters in an even-aged stand before and after selection. Difference in means of the two populations is the selection differential. X_0 = mean of original population; X_1 = mean of eugenically selected population; X_2 = mean of dysgenically selected population. After van Buijtenen and others 1981.

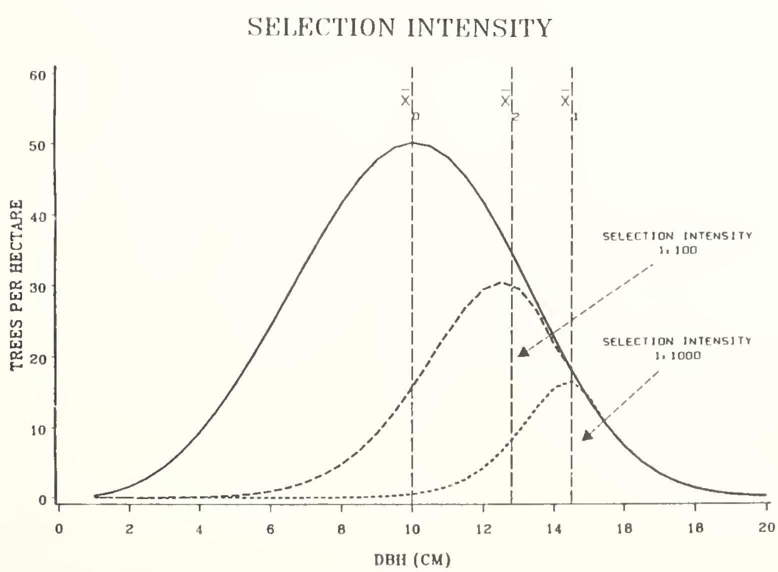

Figure 2—Effect of varying selection intensities on selection differential. X_0 = mean of original population; X_1 = mean for selection intensity of 1:1000; X_2 = mean for selection intensity of 1:100.

and may be outperforming their parent populations. Nonetheless, additional selection in the course of cultural work widens the original selection differential and will boost average performance (James 1979). A series of thinnings allows roguing whole families that are not performing as expected based on earlier, juvenile assessments, as well as selections within families, to retain the best of the best.

Applying selection principles in mixed or uneven-aged stands is much more difficult. Age, competitive influences during the course of development, and other environmental factors invalidate direct comparisons. In these types of stands, a regression selection technique is more appropriate (Zobel and Talbert 1984).

Estimation of Genetic Gains

Gain estimates are usually made for individual traits, although managers may be interested in several traits. Cultural treatments have been most frequently directed toward enhanced diameter and height growth. When selections are made to improve more than one trait, a weighting system should be applied that associates the gain expected with a relative value placed on the trait (van Buijtenen and others 1981). For example:

TOTAL SCORE = G1W1 + G2W2 + G3W3 . . .

where:

G1 = expected gain in trait 1

W1 = relative importance assigned to trait 1

G2 = expected gain in trait 2

W2 = relative importance assigned to trait 2

continued through as many traits as desired.

Since all traits may not be weighted the same, nor will expected gains be the same, this allows a compromise ideotype to be described for development of marking guides. Weightings may be economic or based on other criteria.

CULTURAL CONSIDERATIONS

Three main categories of cultural treatments are likely to be applied to the forests of the Inland Mountain West: thinning, timber stand improvement, and fertilization. Genetic gains from these treatments will be less than those possible with tree improvement programs aimed at production of planting stock because selection intensities in cultural treatments are much lower. Gains will also vary with the treatment and how it is applied. Nevertheless, the gains obtained can be important.

Thinning

Thinning, and particularly a series of thinnings over an entire rotation, offers considerable potential for upgrading or downgrading the genetic resource (James 1979; Wilusz and Giertych 1974). A high selection intensity is possible with some kinds of thinning, but the degree of impact will depend on: (1) timing of the first and subsequent thinnings, (2) intensity of thinning, and (3) choice of trees to cut and leave. Because natural selection enforces mortality functions (and the choice of trees is likely to be different than managers would make for economic reasons), more choices for artificial selection will be available earlier in the rotation than later. Densities are higher, and thus there is more opportunity for selections. However, a thinning done too early is not likely to affect genetic change if the treatment occurs before the trees have had sufficient opportunity to express their genetic differences. Because thinning offers such a high degree of selection intensity, retaining better phenotypes can substantially improve genetic quality. Conversely, thinning that leaves the poorest trees can considerably lower genetic quality.

Thinning is most often done to improve diameter growth and, therefore, volume production. For this reason, size considerations will prevail in the following paragraphs. It is important to recognize, however, that other quality traits can be selected for simultaneously or alone, depending on the objectives of thinning.

Environmental stresses occurring in overstocked stands are normally sufficient to mask expression of full genetic potential, whether from selected natural regeneration or a plantation of genetically improved stock. A major advantage of thinning is that it allows greater expression of the genetic potential of the selected crop trees.

A major problem in selecting trees in young stands comes from not knowing if characteristics exhibited will be retained through the rotation, or at least until the next stand entry; we do not know the strength of the juvenile/mature correlations. This provides genetic justification for delaying the first thinning until there is a clear basis for selecting potential crop trees by characteristic(s) of interest.

Geometric Thinning—Geometric thinning (Smith 1986), formerly known as mechanical thinning, removes trees on the basis of some predetermined pattern or spacing. "Mechanical" referred to the mechanistic way trees were selected and not to the way in which they are removed. There are several ways in which geometric thinnings can be applied, resulting in different degrees of genetic gain.

One of the earliest cultural practices applied to overstocked, naturally regenerated stands is spacing thinning. Indeed, this may be the only culture the stand gets during the entire rotation. With spacing thinning, trees at fixed intervals are selected for retention and all others cut (Smith 1986). Densities may be reduced to rotation spacing, or some intermediate level of stocking may be retained that would allow for one or more future stand entries. In most cases, postthinning stocking is considerably reduced. From a genetic standpoint, very high selection intensities are possible, depending on how individual tree selections are made. Normally, a set of criteria (including species, size, and vigor) for retaining a tree is developed that allows relative ranking. Growth rate, form, apparent disease resistance, and other characteristics could easily be incorporated into that set. If trees are selected only on the basis of species and spacing, selection would be essentially random with regard to genetic quality, resulting in little if any gain.

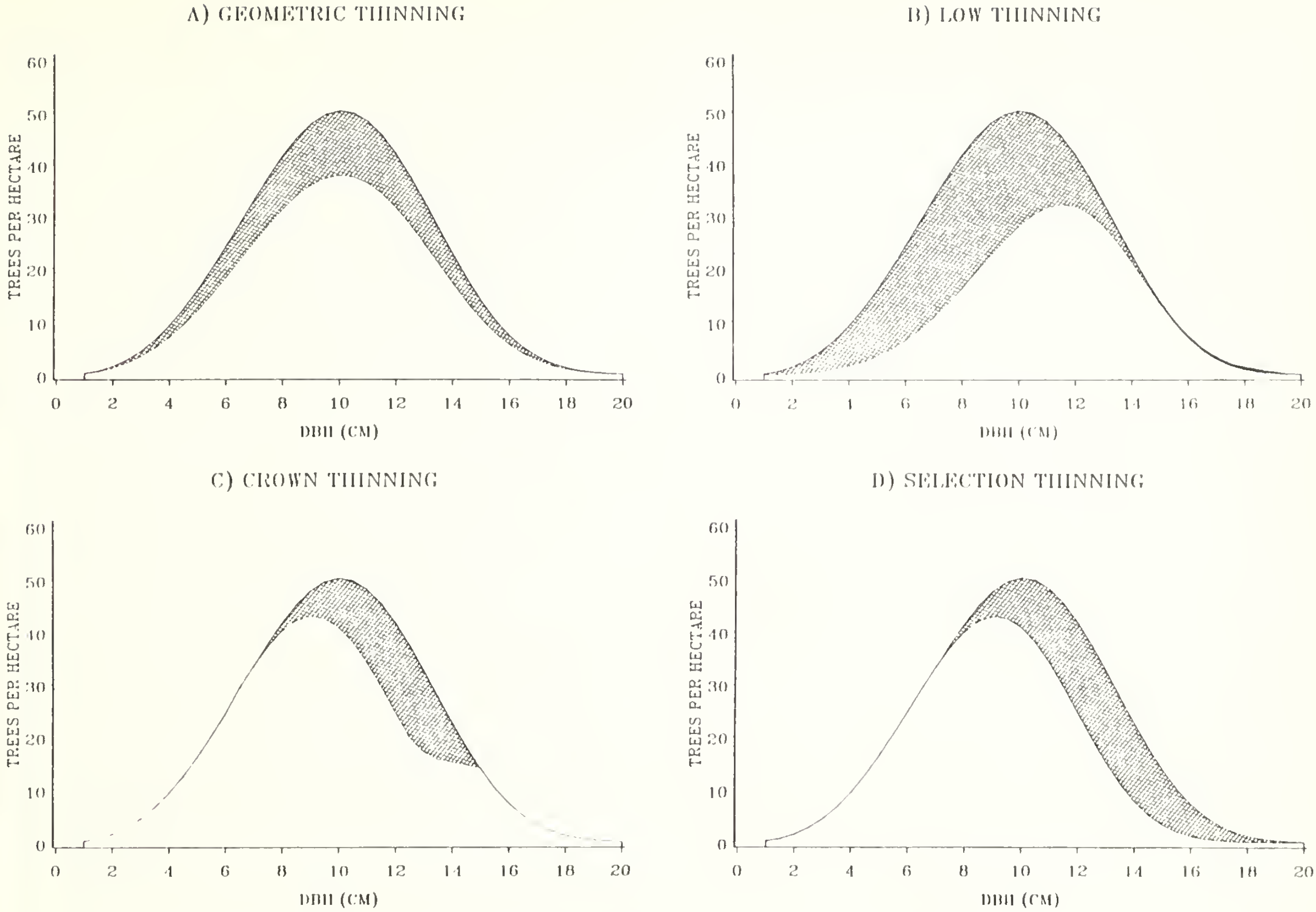

Figure 3—Diameter distributions in an even-aged stand before and after the type of thinning indicated. Cross-hatched area indicates portion of the diameter distribution removed. Note potential impacts on selection differential. Redrawn from Smith 1986.

Strip and row thinning are two other types of geometric thinning. Strip thinnings, using a bulldozer or other swathing device (such as a Hydroaxe) are commonly applied to very high density, naturally regenerated stands of lodgepole and ponderosa pine where removing individual stems would be impractical and expensive. Row thinnings, most commonly applied to plantations where trees are planted on uniform spacing, might remove every third row. In both cases selections are randomly applied resulting in neither genetic improvement, nor genetic degradation (fig. 3A).

Low Thinning—In low thinnings, trees are removed from the lowest crown classes first. With heavier grades, there is a progression into the intermediate and upper crown classes. Figure 3B shows a hypothetical diameter distribution before and after such a thinning. The potential for shifting the mean immediately and substantially to the right is evident. Since this type of thinning eliminates the poorer competitors, there is good potential for upgrading the genetic quality of the residual stand, particularly with heavier thinnings that remove trees in the higher crown classes. The great advantage of this type of thinning is that the trees to be removed are easily identified. Trees in the upper crown classes that display superior growth are likely to continue to do so (Smith 1986). Thus, at least for growth characteristics, it is easy to make eugenic selections. Dysgenic selections are less likely to occur.

Crown Thinning—Crown thinning removes trees preferentially from the middle and upper diameter and crown classes to stimulate growth of trees in the same classes. In strict application, intermediate and suppressed trees remain; these seemingly offer no serious competition.

From a genetic standpoint, several potential problems can be identified with this method. It can easily be argued (Zobel and Talbert 1984) that trees left in the lower crown classes are the poorer competitors and genetically inferior. If these trees do not occupy an excessive amount of stand space or die during the rotation, there is potential for significant genetic upgrading in the dominant crown classes. However, if these trees survive, the potential negative impact on average stand performance could be substantial (fig. 3C). Worse, if the stand is to be regenerated naturally at the end of the rotation, these trees could contribute seed, serving to lower genetic quality in the next rotation. Furthermore, since the focus is on removal of larger material, there is some potential for high-grading and, as a result, dysgenic selection. Careful, vigorous control should be exercised to avoid genetic abuses.

Selection Thinning—With selection thinning, dominant trees are removed to stimulate growth of the lower crown and diameter classes. The largest trees are removed to eliminate coarse dominants that occupy an inordinate amount of growing space (Smith 1986). This is the thinning method most likely to lead to high-grading and has clear dysgenic tendencies (fig. 3D).

Selection thinning is somewhat unique among the methods so far discussed. Although it may be intended to have an extremely positive effect on quality characteristics, unless carefully monitored, it is unfortunately more likely to lead to genetic degradation.

Free Thinning—Free thinning is sometimes recognized as a unique thinning method. In fact it is a technique that does not strictly adhere to any one of the methods described above, but combines those methods to release the best potential crop tree. Thus it is subject to various advantages and disadvantages described for each of the methods.

Timber Stand Improvement (TSI)

Improvement cutting is conducted in stands that are past the sapling stage to remove trees of undesirable form, age, species, or condition from the main canopy (Smith 1986). TSI work may be the earliest of operations conducted in stands coming under management for the first time and has particular application to stands that have been high-graded in the past. The intent with TSI cutting is to set the stage for later thinnings or reproduction cuttings.

In concept, TSI cutting is similar to selection thinning with regard to genetic impacts. Positive and substantial gain can be obtained for quality characteristics, but there may be a negative selection with regard to size.

Fertilization

Fertilization may be a viable cultural practice for some species and on some sites in the Inland Mountain West (see other papers in this proceedings). Genetically, the best that can be done is to select genotypes for planting that have been tested for fertilizer response. By thinning over the rotation, trees with better response characteristics can be further selected and favored when the stand is marked for cutting. To some extent this may also prove effective for naturally regenerated stands, but a series of fertilizer applications over the rotation would be required to make best use of the selected genotypes.

MANAGEMENT PLANNING CONSIDERATIONS

Management decisions for stand treatment or series of treatments in the Inland Mountain West should be made only after careful consideration of alternatives. To aid in this decision-making process, yield prediction models such as PROGNOSIS (Stage 1973), RMYLD (Edminster 1978), DFSIM (Curtis and others 1981), and SPS (Arney 1984) have been developed. These models generally allow imposition of various cultural regimens such as thinning and fertilization. A few of them make provisions for insect and disease influences (Nance and others 1983, 1985; Wykoff and others 1982).

The increased use of genetically improved planting stock and cultural treatments to upgrade genetic composition necessitates modification of the models to allow assessment of yield changes resulting from such practices. Such modifications have been made for a loblolly pine model (Nance 1982; Nance and Bey 1979; Nance and Wells 1981a). PROGNOSIS has been used to estimate tree improvement program impacts (Howe and Raetig 1985), but with some reservation (G. E. Howe, 1986 personal communication). An added benefit is the ability to use economic models, such as CHEAPO (Medema and Hatch 1979), to conduct concomitant financial analysis. The major problem is in quantifying biological differences resulting from genetic improvement in such a way that they can be used in yield projection systems (Nance and Bey 1979).

Modeling can be used in at least three ways: (1) to compare improved tree yields with woods-run stock under various cultural regimes; (2) to compare yields between single-family and multifamily plantings of improved stock (Nance 1982) under various cultural regimes; and (3) to define cultural regimes to optimize yields from improved stock. To do this requires information that may or may not be currently available from genetic testing. For example, using stock with a known increase in height growth may be tantamount to increasing site index. Thus, a model might be adjusted by simple changes to the input for site index (Nance and Wells 1981b).

Most model modifications will, however, be much more complicated and require long-term genetic test information to be accurate. Progeny tests, from which gain information is assessed, are normally grown under minimum competition to maximize genetic differences. We know competition affects performance but we don't know the magnitude of these impacts in genetic tests. Similarly, we need information concerning performance of genetically improved stock under various thinning and fertilization regimes. Also, various mixtures of families can be expected to perform differently in a plantation. There is a need to quantify these effects (see Nance 1982; Nance and others 1983).

Modeling the impacts of genetic improvement is a difficult task for several reasons. Most estimates of gain are based on early performance in progeny tests, but those estimates may not accurately predict performance of older trees. Gain predictions based on single-tree or small plot estimates do not necessarily reflect performance on a standwide basis. Nor do we know the impact of genetic improvements on the shape of the growth curve, with and without cultural treatments. One can conceive of several types of scenarios (fig. 4), each resulting in substantially different yields at different ages. Consider the added complexity if different families within a genetically improved plantation exhibited a similar range in growth curves.

Although it is obvious we need to account for genetic impacts in growth and yield prediction systems, it is not so obvious how to do it. Certainly we will not have all the

YIELDS FOR NORMAL
AND IMPROVED POPULATIONS

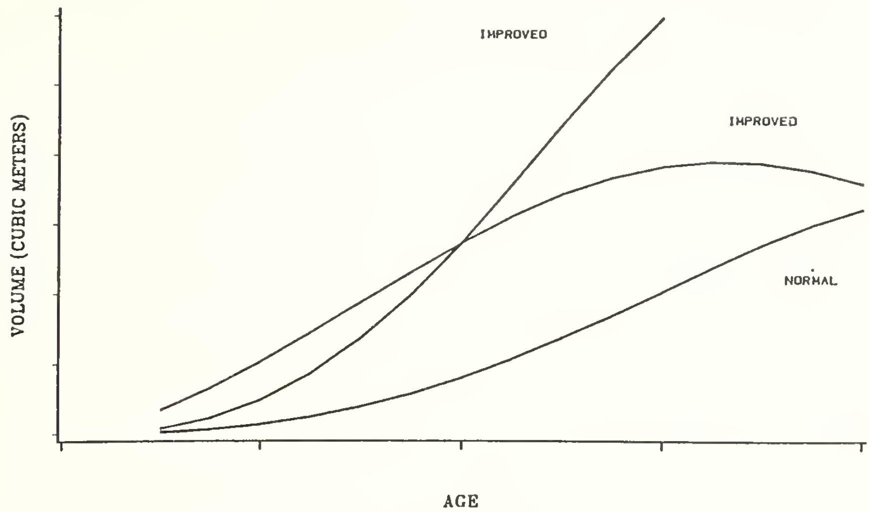

Figure 4—Hypothetical yield curves for different populations of the same species. Two plantations are derived from selected and progeny-tested planting stock. The third plantation would derive from an equivalent woods-run seedlot.

information required to accurately model the interactive effects of genetic improvement and cultural treatments for some time. But neither do we have all the data concerning these interactions for natural stands or plantations of woods-run stock. Yet we must model what we can because it is an improvement over windshield silviculture. What should be clear is the folly of making broad and sweeping management decisions based on single-point estimates.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Robert Pfister)—What percentage of growth increase reported in thinning studies might be attributed to genetic selection rather than simply growing space? Could you take a guess?

A.—Our best response to your question is to refer you to the paper by Wilusz and Giertuch (1974) cited in our reference section.

Q. (from Bill Peterson)—In operational tree improvement programs we tend to select for dominant crown positions within a stand. What about the potential for higher yields with selection of codominants ("crop tree" ideotype) in other words, consider the social structure of stands versus individuals?

A.—Thats a good question, but we don't know the answer. This is a study that must be done.

Q. (from Anonymous)—What's the best criteria for determining leave tree selections when thinning a 15- to 20-year-old plantation of rust resistant white pine that also contains natural white pine, to obtain greatest return on investment in rust resistant white pine?

A.—Primarily the amount of infection. However, if the stand has not been infected, it may be a low risk stand and thus it may not be important to retain rust resistant white pine.

Q. (from Chuck Wierman)—Your discussion of genetic selection in thinning seemed to deal only with even-aged stands. Is there dysgenic selection occurring by removing large trees in uneven-aged natural stands?

A.—If the stands are truly uneven-aged and not just uneven-sized, you will be harvesting the oldest trees, and not really conducting dysgenic selection. However, within the class of oldest trees, always removing the largest ones may be slightly dysgenic as these would likely be the fastest growing trees and removed from the system faster.

Q. (from David Crampton)—How can you determine during a thinning operation that what you are selecting for is genotypic and not a response of a genotype to a particular environment within the pretreated stand?

A.—You can't be sure. These types of experiments are still to be done. However, some nursery/plantation evidence does show that very superior spruce seedlings in the nursery continued to be superior in a plantation for at least 7 years.

Q. (from Anonymous)—Concerns thinning in a plantation of "improved" stock. a. Is there a problem that "selected trees" end up being those that are mostly from the same genotypes (parents) thereby reducing genetic variability of the stand? b. Related to this, what about any problems with selected seed trees at regeneration time being too related (inbreeding?) and problems again with reduction in stand genetic variability? Do we really care whether a particular individual stand within a forest has genetic variability?

A.—a. If you begin with enough families and maintain good stocking, you may bias the remaining genotype composition to some degree, but you would not be able to reduce the genetic base to just one or two families. For example, if you begin with 20 families equally represented and stocked at 600/acre, then reduced the stocking to 150/acre, you would have a minimum of five families left. But more likely there would be a greater number of families represented, although they would not be equally distributed.

b. Evidence suggests that with natural regeneration, highly inbred individuals do not compete well with outcrossed ones. We know, however, that there is almost always a certain level of inbreeding in natural stands. We care about genetic variability in the longterm and over many acres.

GROWTH OF PONDEROSA PINE THINNED TO DIFFERENT STOCKING LEVELS IN THE WESTERN UNITED STATES

William W. Oliver
Carleton B. Edminster

ABSTRACT

Growth of ponderosa pine was studied by the western Forest and Range Experiment Stations of the USDA Forest Service in response to increasing demands for better and more precise estimates of yields possible through intensive management. We summarized results of 15 to 20 years of growth after thinning each of five stands to a wide range of stocking levels. The stands—two in the Black Hills of South Dakota, and one each in northern Arizona, central Oregon, and northern California—ranged in size from small saplings to large poles and in age from about 20 to 90 years. Within the fundamental constraints of site quality, thinning influenced growth markedly and, on the better sites, stands were more responsive to manipulation than they were on poorer sites. Only the most general conclusions are possible; nevertheless, results at every installation demonstrated the marked decline in volume production and, conversely, the rapid attainment of merchantable-sized material at low residual stand densities.

INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) is one of the most widely distributed pines in the Western United States. Within this vast area of contrasting soils and climate, many studies of thinning in even-aged stands of ponderosa pine have been conducted over the years (Gaines and Kotok 1954; Mowat 1953; Myers 1958). In general, results from these early studies were similar to those found from thinning most pure even-aged stands, in that diameter growth was greater in lightly stocked than in heavily stocked plots. But other results seemed contradictory. Sometimes total cubic-foot volume production increased with increasing stand density and sometimes it did not. Results from studies conducted in one part of the range seemed to have limited use in another part. Dissimilar experimental designs and measurements that were incomplete or based on specific products further restricted comparability. Also, these early studies did not test the low reserve densities that may be desired for today's multiresource management.

Growth information was needed over a wide range of stand and site conditions, and with a minimum of operational restrictions, to provide useful guides for a variety of management objectives. To fill this need three western Forest and Range Experiment Stations of the U.S. Department of Agriculture, Forest Service, cooperated through the use of a common study plan (Myers 1967). This paper reports 15- to 20-year results of this West-wide study. It describes some of the relationships between stand growth and the stand attributes of basal area, mean diameter, and site.

ORIGINAL STUDY PLAN

Five areas within the range of ponderosa pine in the Western United States were arbitrarily selected for study and assigned to the participating Experiment Stations (fig. 1). These five "provinces" differ in many respects. Physiography ranges from the uplift of the Black Hills of South Dakota to the Coconino Plateau of Arizona, the Cascade Range of Oregon, and Sierra Nevada of California. Two varieties of ponderosa pine are recognized (*P. ponderosa* var. *ponderosa* and var. *scopulorum*). Some provinces are without summer precipitation; other provinces receive most of their annual precipitation during the growing season.

Within each province, four tree-size classes in even-aged stands from small saplings to large poles, as available, were to be sampled. To be sampled within each size class were areas of low, medium, and high site quality for that province.

The initial plan specified that each study installation consist of three replicates of six arbitrarily selected plots thinned to six different stand densities. Plots were to be at least 0.25 to 0.5 acre with 20-ft isolation strips for small saplings, and 0.5 to 1.0 acre with 30-ft isolation strips for the larger size classes.

One plot in each replicate was to be thinned to the density considered best for that site index, based on past experience. Two or three plots were to be thinned to lower, and two or three plots to higher stand densities. The highest stand density was chosen such that the production of merchantable material would be reduced below that of lower densities. And the lowest density level was chosen such that cubic-foot volume production would be lower than that at higher densities.

Stand densities to be retained after thinning were specified as a series of growing stock levels (GSL's) (Myers 1967). These levels were defined by relationships between basal area and average stand diameter. Numerical designation of the level assigned to a plot was the basal area per acre that would remain after thinning when mean stand diameter was 10 inches or more. Stands with trees smaller than 10 inches when thinned would contain residual basal areas that were less than the designated GSL.

Thinning was to be from below, primarily, the smallest trees and rough dominants being removed. Each

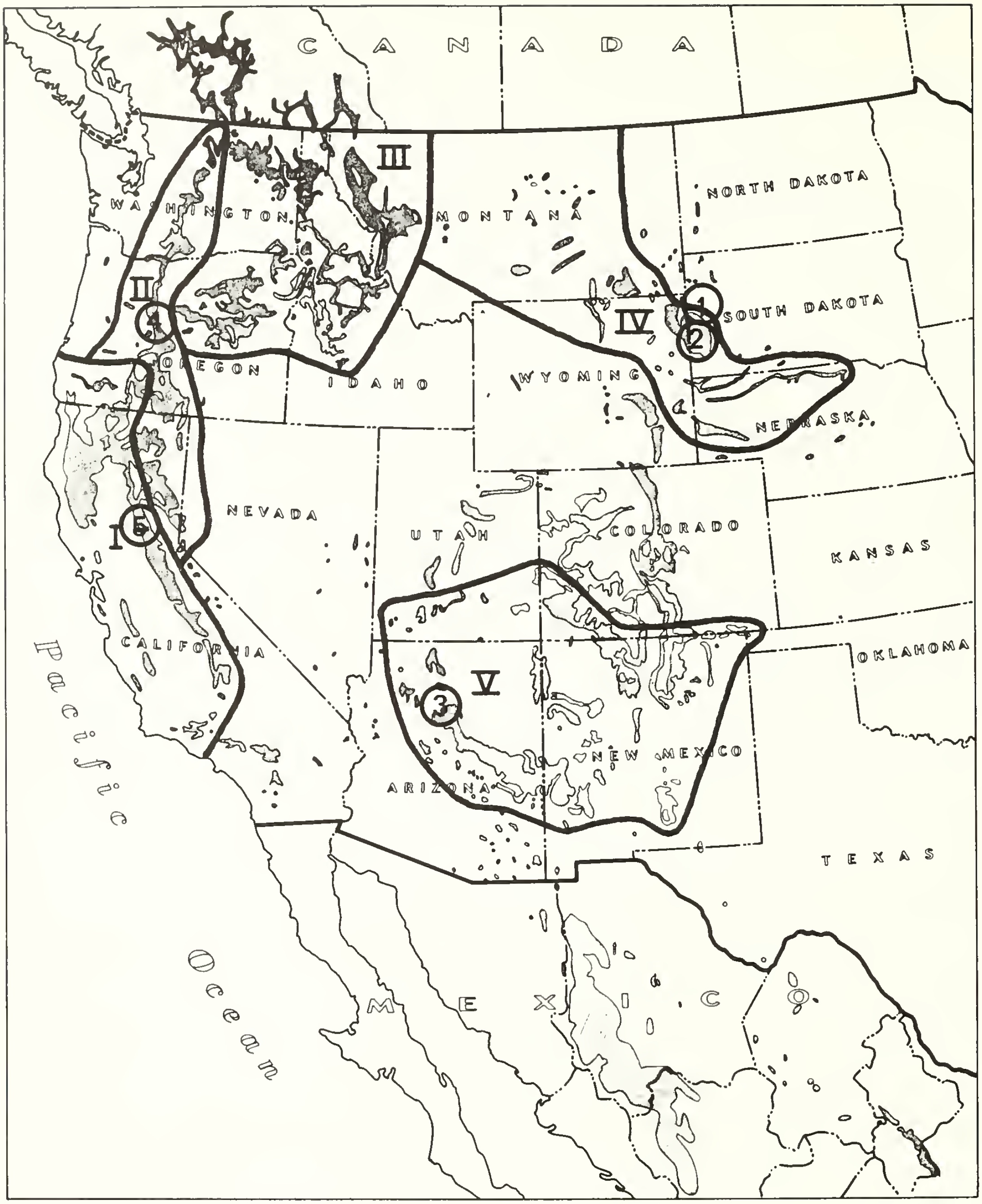

Figure 1—Province boundaries (Roman numerals) and installation locations (Arabic numerals) for study of levels of ponderosa pine growing stock. (1) Black Hills saplings, (2) Black Hills poles, (3) Taylor Woods, (4) Lookout Mountain, (5) Elliot Ranch (map of botanical range of ponderosa pine from Curtis and Lynch 1957).

installation was scheduled to run for 20 years, with measurements at 5-year intervals. At the end of 10 years, plots were to be rethinned to the specified GSL's.

Before the growing season following initial thinning, all trees were to be tagged, described by crown class, and measured for diameter at breast height (d.b.h.) to the nearest 0.1 inch. Tree damage and diseases were to be noted. Various sampling schemes could be used to select trees for total height and height to the living crown, measured to the nearest 1 ft, and total stem volume when measured by optical dendrometer. All measurements were to be repeated on the same trees after each 5-year period.

THE INSTALLATIONS

The study as envisioned was ambitious, requiring prodigious amounts of land, labor, and money. Cooperators experienced difficulty both in finding large enough areas of uniform site and stand conditions, and in allocating sufficient resources to sample but a few of the province/size/site combinations. Although many fewer than planned, the four installations established in naturally regenerated stands and one in a plantation (Elliot Ranch) nearly spanned the geographic range of ponderosa pine (fig. 1). Characteristics of the installations are summarized in table 1.

The five installations were established in general conformance with the plan except those at Elliot Ranch and Lookout Mountain. At Elliot Ranch only five GSL's were tested because of limited stand area, and plots were rethinned to prescribed GSL's at 5- rather than at 10-year intervals because of rapid growth. At Lookout Mountain height to the living crown was not measured. Remarkably, all installations have been maintained, many for as long as 20 years. Detailed descriptions of the installations and measurements taken at Taylor Woods (Ronco and others 1985), Lookout Mountain (Barrett 1983), and Elliot Ranch (Oliver 1979) are available. Measurement standards and procedures followed at the Black Hills installations were similar to those described by Ronco and others (1985) for Taylor Woods.

ANALYSIS

Mean tree and stand characteristics for each plot at each measurement were calculated as follows:

- D.b.h.—quadratic mean diameter at breast height
- Total height—calculated for tree of mean diameter by using measured tree heights in each plot or treatment in an equation relating total height to d.b.h.
- Basal area—square feet per acre
- Percent live crown—calculated as 100 [(total height - height to live crown)/total height]
- Total volume—cubic-foot volume inside bark from ground line to tip, estimated for each tree from gross volume equations for the Black Hills (Myers 1964) and for Taylor Woods (Hann and Bare 1978). At Lookout Mountain and Elliot Ranch where an optical dendrometer was used, equations relating volume to d.b.h. were calculated separately for each treatment.

Linear regressions of 5-year periodic annual increments (PAI's) for treatment means of diameter, height, and basal area and total volume per acre were used to describe trends. For percent live crown, the equation was based on that characteristic at the end of the period. Independent variables were stand basal area and mean d.b.h. at the beginning of the period, site index, and several of their transformations. Although stand treatment was based on GSL, stand basal area was used in modeling because of variations in stand diameter and marking practices among plots assigned similar GSL's at Taylor Woods (Ronco and others 1985). We did not attempt to analyze merchantable volume production because utilization standards varied widely among installations.

Selection of independent variables was by conventional stepwise regression with coefficients calculated by ordinary least squares. Criteria for selecting variables or their transformations that best explained the variation in PAI's were these: the statistics F, coefficient of determination (R^2), and standard error (S); those with fewest terms; and those that were consistent with known biological relationships. The synthesis of these criteria necessarily caused the choice of variables to be partially subjective.

The calculated variances are underestimates of the actual amounts. The chief reasons are that we used treatment means for each period in this summary analysis rather than plot means. We did not account for serial correlations within installations caused by repeated measurements. For the height and volume equations, measurements were not uniform among the installations. Furthermore, because only one installation usually was available for analysis within each province/site quality combination, the influence of province (or location or stand history among other influences) could not be separated from the influence of site quality.

Table 1—Installations in the West-wide levels-of-growing-stock study for even-aged ponderosa pine

Province	Name	Year installed	Site index[1]	Size class	Growing stock levels	5-year periods analyzed
IV	Black Hills	1964	57	large saplings	20,40,60,80,100,120	4
IV	Black Hills	1964	57	small poles	20,40,60,80,100,120	4
V	Taylor Woods	1962	62	small poles	30,60,80,100,120,150	4
II	Lookout Mt.	1966	92	large poles	30,60,80,100,120,150	3
I	Elliot Ranch	1970	140	large poles	40,70,100,130,160	3

[1]Meyer 1938.

RESULTS AND DISCUSSION

Diameter

Periodic annual diameter growth was strongly correlated with site index and stand basal area, and less so with mean d.b.h. (fig. 2A). Growth increased exponentially as site index increased. This curvilinear form fit the data better than the linear form, but we suspected this may have been an artifact of the data. The installation at Elliot Ranch with the highest site index was the youngest by 20 years, and was expected to grow more rapidly in diameter than would older stands. Nevertheless, when the stepwise re-gression procedure was run on the data without Elliot Ranch, exponential site index was still a better fit than was linear site index. Exponential site index alone explained 43 percent of the observed variation in diameter growth. As expected, diameter growth declined curvilinearly as reserve stand basal area increased. This commonly reported relationship, which explained an additional 28 percent of the variation, was strong at every installation.

Treatments with larger trees tended to grow more rapidly in diameter than treatments with smaller trees. Although the variation explained by mean d.b.h. (an additional 4 percent) was less than it was for site index and stand basal area, mean d.b.h. was significant. The resulting equation was:

$$PAI\ DBH = 0.3135 + 0.0965 \exp(SI/100) - 0.0994 \ln BA + 0.0102\, DBH$$

$$R^2 = 0.749$$

$$SEE = 0.1 \text{ inch}$$

where

$PAI\ DBH$ = periodic annual increment of d.b.h. in inches

exp = base of natural logarithms

SI = site index (Meyer 1938) in feet at 100 years total age

ln = natural logarithm

BA = stand basal area at the beginning of the period in square feet per acre

DBH = quadratic mean stand d.b.h. at the beginning of the period in inches

R^2 = coefficient of determination

SEE = standard error of the estimate.

Height

Site index was the overwhelming influence on periodic annual height growth of the average tree. The relationship

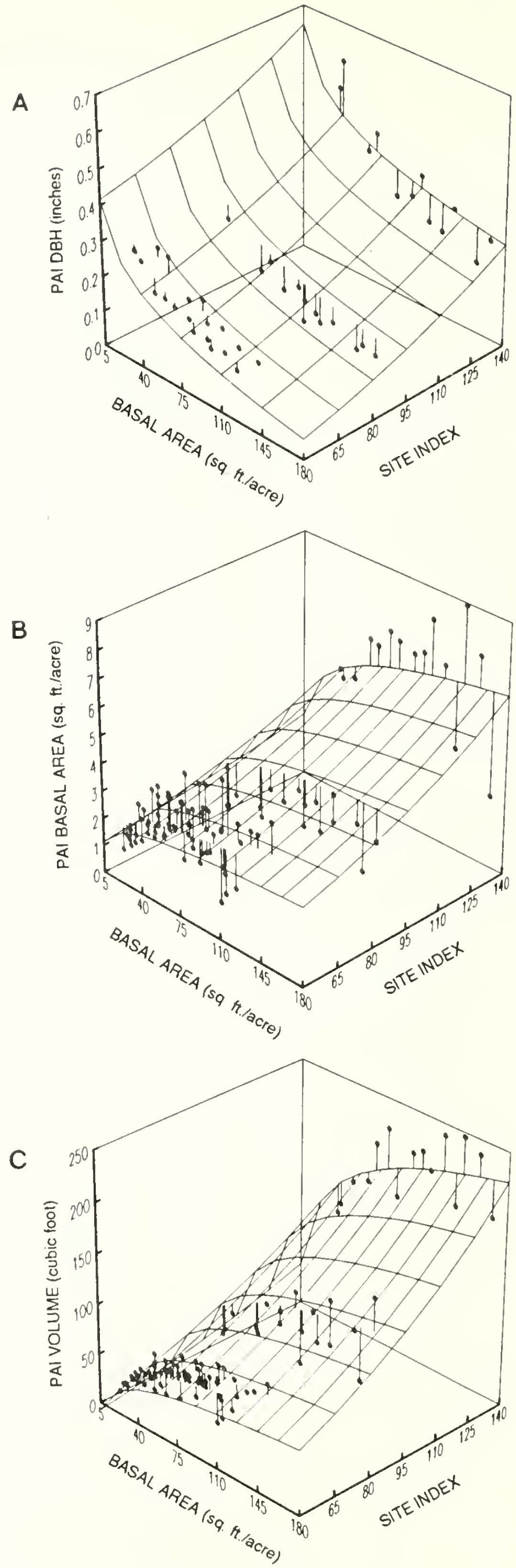

Figure 2—Stand density and site index were related to periodic annual increments (PAI) of (A) diameter and (B) basal area for stands10 inches in diameter, and (C) volume of even-aged ponderosa pine.

was curvilinear and positive, and explained 93 percent of the variation observed across all installations. Additional variation could be explained by mean stand d.b.h. and basal area at the Elliot Ranch installation only. We expected that, within an installation, plots with more basal area would tend to have smaller trees, on the average, and less growth in mean height than would plots with less basal area. Only at Elliot Ranch was this expectation borne out, probably because of the much more rapid height growth in this young, high-site plantation than was found in the other installations. Although the additional variation explained by mean stand d.b.h. and basal area was small (about 2 percent), these variables were included to make the equation for the combined data more generally applicable:

$$PAI\ HT = -0.6731 + 0.6329\ \exp(SI/100) + 0.0348\ DBH - 0.0016\ BA$$

$$R^2 = 0.942$$

$$SEE = 0.1 \text{ foot}$$

where

PAI HT = periodic annual growth in total height in feet.

A more intriguing and important question, however, is whether stand density influenced the height growth of dominant or future crop trees. We could not answer this question because we restricted analysis to treatment averages only.

Basal Area

Net periodic annual basal area growth was related significantly with site index and to a lesser extent with stand basal area. Both relationships were positive and curvilinear (fig. 2B); PAI basal area increased exponentially with increasing site index and logarithmically with stand basal area. Basal area growth differences were larger among stand density treatments in installations on better sites than they were in installations on poorer sites. Thus, the cross product of the transformed variables of site index and reserve stand basal area seemed to fit the combined data:

$$PAI\ BA = 1.4884 + 0.3742\ \ln BA\ [\exp(SI/100)] - 0.2404\ DBH$$

$$R^2 = 0.683$$

$$SEE = 0.9 \text{ ft}^2 \text{ per acre}$$

where

PAI BA = net periodic annual basal area increment in square feet per acre.

Mean stand diameter was related, significantly, with PAI basal area, explaining an additional 11 percent of the observed variation. Stands with larger mean diameters tended to grow more slowly in basal area than stands with smaller mean diameters. This negative relationship is to be expected from this data set because plots in all installations were rethinned at least once (twice at Elliot Ranch). Thinning from below raised the mean stand diameter, more so when thinning to low reserve stand basal areas. Trees in plots with low basal areas grew faster in diameter. Hence, plots with low reserve stand basal areas, which grew less basal area, tended to have larger mean diameters than plots with high reserve basal areas.

Total Volume

Similar to PAI basal area, PAI total cubic-foot volume was strongly related to site index and somewhat less to stand basal area. The relationship was positive and curvilinear for both variables (fig. 2C). Again similar to PAI basal area, stand basal area exerted a greater influence on PAI volume on better sites than it did on poorer sites. As a result the cross product of exponential site index and the logarithm of reserve stand basal area described the observed variation in volume growth:

$$PAI\ \text{Volume} = -40.4050 + 12.4336\ \ln BA\ [\exp(SI/100)]$$

$$R^2 = 0.904$$

$$SEE = 16.9 \text{ ft}^3 \text{ per acre}$$

where

PAI Volume = net periodic annual increment in total stem volume from ground to tip inside bark in cubic feet per acre.

Mean stand diameter was a significant variable. And, similar to its relationship to PAI basal area, was negatively correlated. But in this case, its contribution to explained variation was of no practical importance—less than 1 percent.

After plots were rethinned back to the prescribed GSL's, volume production tended to be lower than it was during the period after initial thinning. Mortality after the second thinning tended to reduce volume production, especially at the higher GSL's at Elliot Ranch and the Black Hills pole-size stands. However, at lower GSL's where mortality was insignificant, production was lower as well. This decline in PAI volume with time was expected because stands at all installations had passed the culmination of period annual increment (Meyer 1938).

Percent Live Crown

The proportion of a tree's total height in living crown is recognized as an indication of its competitive position within the stand and its ability to grow. Percent live crown would be expected, therefore, to be related to stand basal area. Because percent live crown changes slowly in response to changes in stand density, most investigators studying short-term thinning response report no change in percent live crown. We found no relationship between percent live crown and stand basal area for the first 5 years after initial thinning, and only a weak relationship for the first 10 years. Only after 10 years did the relationship to stand basal area become strong.

To describe the influence of stand basal area on percent live crown, we included only the 15- and 20-year measurements and expressed percent live crown as that existing at the end of those measurement periods. We found percent live crown to be strongly correlated with stand basal area. As basal area increased percent live crown decreased, rapidly at first and then more slowly throughout the range of stand basal areas tested. This curvilinear relationship can be described adequately with the equation:

$$PLC = 92.138 - 7.673 \ln BA$$

$$R^2 = 0.545$$

$$SEE = 4.0 \text{ percent}$$

where

PLC = mean proportion of the trees' total height in living crown expressed as a percentage.

Stepwise regression analysis of the combined data indicated a strong influence of site index. It was not included in the above equation, however, because its influence appears to be an artifact of the data. No live crown measurements were recorded at Lookout Mountain—the installation of intermediate site quality. For a given stand density, live crowns averaged 8 percent higher at the Elliot Ranch plantation (site index 140) than crowns in the natural stands in the Black Hills and at Taylor Woods (average site index 60). But this difference might be the result of differing stand origins, or differences in any number of other stand and tree attributes, as well as differing site indexes.

CONCLUSIONS

The reader is cautioned not to draw firm conclusions from the results obtained from the combined data. The data obtained from each installation are of uniformly high quality, and results and conclusions drawn from them are sound. In combining the data, however, we assumed that treatment response differences among installations were caused by site quality differences. Even though this assumption enabled us to produce models that behaved according to accepted biological theory, we suspect that the factors we combined under the variable of site index, which are discussed below, had some measurable effect.

The five installations were scattered over a vast geographic area of contrasting soils and climate, and included two varieties of ponderosa pine (*P. ponderosa* var. *ponderosa* and var. *scopulorum*). Some of the genetic differences may have affected wood production. The five installations did not sample equally the range in site indexes—three installations were on about site index 60, one on site index 92, and one on site index 140. And, finally, sampling schemes, particularly for height and volume, differed among the installations.

Nevertheless, what we called site index seemed to perform credibly in integrating and explaining these immense and complex differences. A contributing reason for the good performance of site index may have been that stockability was not a problem. All installations were chosen on sites capable of the productivity estimated by Meyer (1938). Of the transformations tested, exponential site index, which from experience would be expected to fit the data well, was, in fact, the best fit of those transformations we tested.

Despite thinning to a wide range of stand densities from open-grown to densities high enough to jeopardize stand health, observed growth differences were correlated best by exponential site index. It, alone, explained from 43 percent for PAI d.b.h. to a high of 93 percent for PAI height. The axiom that productivity of the site is the key factor underlying growth is supported by these results.

Within the fundamental constraints of site quality, thinning influenced markedly all the growth measures we examined. For production of basal area and volume the relationship was curvilinear and, on better sites, stands were more responsive to thinning than they were on poorer sites. These relationships were in accordance with our expectations.

Considering our small sample, all conclusions must be considered tentative, and conclusions about long-term stand performance could be especially misleading. Stand age is known to have a strong effect on stand density-growth relationships. Several conclusions about intermediate management of even-aged stands are possible, however. The volume-growth relationship (fig. 2C) demonstrates the significant decline in production with the low residual stand densities often required to meet multiresource management constraints. For instance, stands with site index 60 grew only 43 ft^3 per acre of volume annually when thinned heavily to 40 ft^2 of basal area per acre, whereas, 66 ft^3 could be achieved if these stands were thinned to 110 ft^2. Comparison growth rates for stands on site index 140 land were 145 ft^3 (thinned to 40 ft^2/acre) and 197 ft^3 (thinned to 110 ft^2/acre). Conversely, the diameter growth relationship (fig. 2A) demonstrates that if a goal of management is to produce merchantable-sized material rapidly, then lower residual stand densities are desirable. Computing diameter growth for the same sites and stand densities as above, we found that 5-inch d.b.h. stands grew 0.10-inch faster in diameter when thinned heavily than when thinned to a moderate density, regardless of site quality. At the lower site indexes, more than one precommercial thinning was required for the higher reserve densities. This points to longer thinning intervals and, perhaps, to the desirability of lower reserve stand densities, at least for initial thinnings.

As originally conceived with all the size/site/province combinations sampled, this study could have provided the data for constructing variable density yield tables. Today's growth and yield computer programs offer versatility impossible to achieve from static tables and, if based on temporary sample plots in existing stands, are cheaper and faster to construct, as well. We know of no substitute, however, for remeasurement data from planned treatment response trials such as these five installations provide. These data are invaluable for precise estimates of biological relationships and for validating computer simulated growth predictions for a given set of conditions and treatments.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Carl Beyerhelm)—Open-grown ponderosa pine often are shorter and fatter than adjacent trees grown with competition. This indicates that height growth benefits from competition. How do you square this with your contention that height growth is not related to stand density?

A.—Contrary to appearances, intertree competition has not been found to stimulate height growth of conifers. Rather, competing trees maintain a fairly constant height growth at the expense of diameter growth, thus giving the appearance of being taller than trees of the same age in the open. Only when stands are extremely dense (higher than densities found in "normal" yield tables) can height growth be affected. If this were not so, the site index concept for measuring site productivity would not work.

Q. (from Carl Beyerhelm and Bill Coburn)—At what stand density level can one expect the best "value" growth of ponderosa pine, given that the more open spacings encourage branch retention and hence grade reduction?

A.—I don't believe that stand density management is an effective method of improving the value of ponderosa pine logs. The species does not readily shed dead branches. And branch diameters are noticeably reduced only at spacings so close that merchantable volume production is sacrificed (spacings of 6 by 6 ft in one study). Probably pruning, interest in which has picked up lately, is the only answer, and then only in intensively managed stands on good sites.

THINNING LODGEPOLE PINE: A RESEARCH REVIEW

Wayne D. Johnstone
Dennis M. Cole

ABSTRACT

Judicious stand density control is essential to the successful management of the lodgepole pine resource of the Mountain West. This paper presents a capsule review of previous thinning research, and briefly discusses recently available methods for identifying treatment opportunities and for predicting the response to various stand management regimes.

INTRODUCTION

Long considered a "weed species," lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) is now of major commercial importance in the Mountain West. Lodgepole pine is perhaps the most ubiquitous and widely distributed tree species in the interior Northwest, occurring in a variety of successional stages and growing under a wide variety of edaphic and climatic conditions. Because of the economic importance and wide geographic distribution of lodgepole pine, three recent symposia have been devoted to the species and its management (Baumgartner 1975; Murray 1983; Baumgartner and others 1985).

Natural stands of lodgepole pine, which commonly regenerate following wildfire, are frequently overly dense. Similarly, second-growth stands that regenerate following logging and scarification or prescribed fire often reestablish in excessively dense clumps. Even when lodgepole pine is planted (or thinned at a very early age), ingress of pine seedlings may result in denser stand conditions than desirable. Lodgepole pine does not thin itself well naturally and, regardless of site quality, dense stands tend to remain dense (fig. 1) despite heavy mortality (Smithers 1961). Unless remedied, excessive stand density will repress tree and stand growth and result in yields well below the productive capacity of the site. Because of its paramount importance to successful forest management, stand density control was a topic of considerable discussion at the aforementioned lodgepole pine symposia. Our purpose in this paper is to present a capsule review of these earlier findings. Readers wishing a more comprehensive discussion should consult the original reports.

A REVIEW OF THINNING RESEARCH

Thinning research on lodgepole pine has a long and varied history. The first tests of thinning were established in Wyoming in 1909 and expanded throughout Wyoming and Colorado between 1911 and 1933 (Alexander 1956). In Canada, the earliest studies were initiated in British Columbia in 1921 (Clark 1957) and in Alberta in 1937 (Smithers 1957). Over the last 30 years, several researchers (Alexander 1956, 1960, 1965; Barrett 1961; Dahms 1967, 1971a, 1971b, 1971c, 1973; Daniel and Barnes 1959; Johnstone 1981a, 1981b, 1982a, 1982b, 1983; Smithers 1957, 1961) have studied the response of

Figure 1—Overly dense stands of lodgepole pine typically result from wildfires or following logging and scarification of sites. Such stands tend to stagnate, as shown with this 90-year-old stand, and will produce few if any usable wood products unless thinned much earlier in the life of the stand.

lodgepole pine to selective thinning. Their results have been reviewed and summarized by Cole (1975) and Johnstone (1985). Review of these past studies leads to the following general conclusions about the selective thinning of lodgepole pine:

1. Younger trees respond better than older trees.
2. The largest growth response will occur in the larger dominant and codominant trees.
3. Individual tree response generally increases with increased thinning intensity (fig. 2).
4. Thinning can significantly enhance the future merchantable yield and value of dense stands (fig. 3).
5. For a given thinning intensity, the larger absolute growth response will occur on higher productivity sites (fig. 4A) and the larger relative response will occur on lower productivity sites (fig. 4B).
6. Thinning may substantially alter the risks associated with managing lodgepole pine.

The extensive area requiring treatment and the often high unit-area costs associated with selective hand-

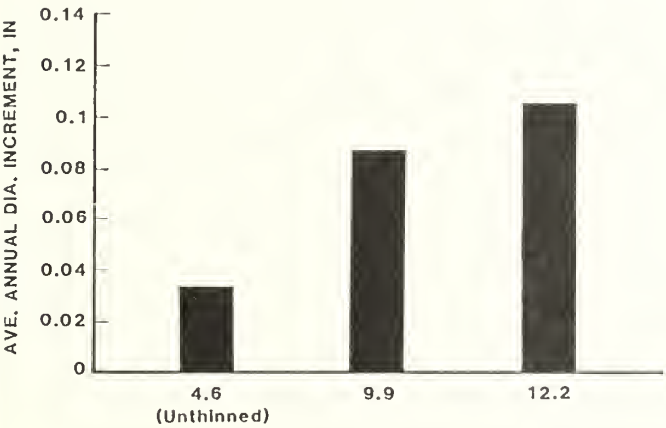

Figure 2—Effect of thinning intensity on average annual diameter increment in inches in the first 22 years after thinning, Medicine Bow National Forest, WY (after Alexander 1960).

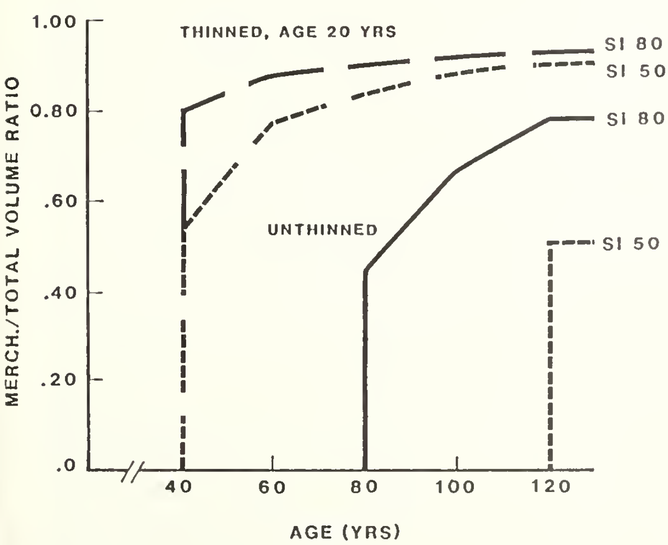

Figure 3—Effect on merchantable/total volume ratio, of thinning and not thinning lodgepole pine on high (SI_{100} = 80 ft) and low (SI_{100} = 50 ft) site indices in Idaho and Montana (from Cole and Edminster 1985).

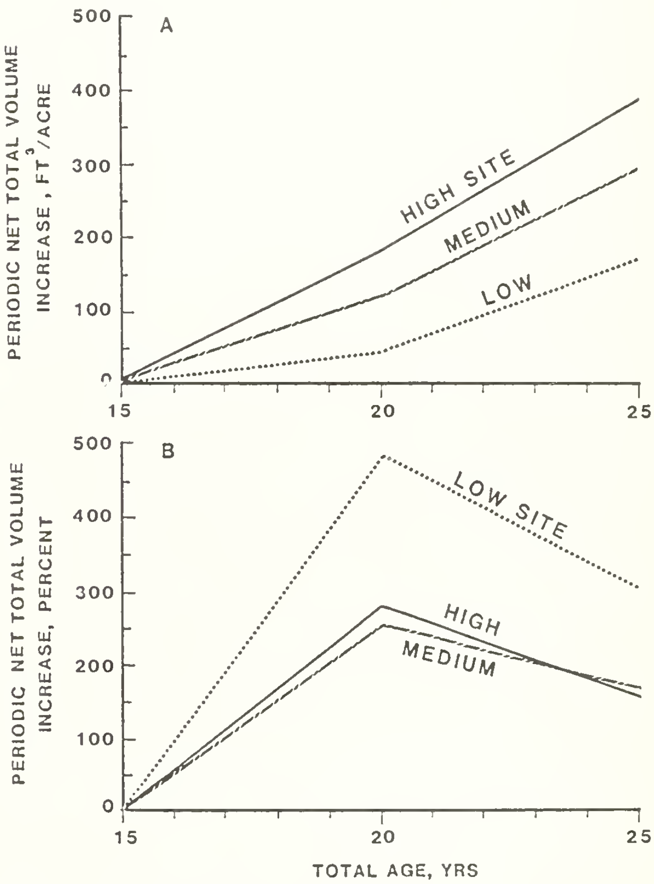

Figure 4—Absolute (A) and percentage (B) increase in net total cubic stand volume, from 15 to 20 and 20 to 25 years of age, of lodgepole pine thinned to a spacing of 7.4 ft (2.25 m) on low-, medium-, and high-quality sites in Alberta (after Johnstone 1983).

thinning of dense lodgepole pine in the Mountain West have stimulated the search for alternative, low-cost thinning methods. Examples of this are studies of full-tree thinning and chipping (Montana Forest and Conservation Experiment Station 1986a) and steep terrain thinning with cable yarders (Montana Forest and Conservation Experiment Station 1986b).

Early research on chemical thinning was initiated by Crossley (1956) in 1949, but this treatment has not been widely used in operational practice, largely because of concerns about chemicals in the environment.

In the early 1950's, Crossley (1952) also initiated research on mechanically strip-thinning lodgepole pine, especially extremely dense stands. Since then a number of studies both in Canada (Bella 1972; Bella and DeFranceschi 1977, 1982; Herring 1979, 1981) and in the United States (Lotan 1967; Lynch 1973; Tackle and Shearer 1959) have tested a variety of treatment designs and equipment. Concerns about the survival of low branches in the cut strips, damage to edge trees in the residual strips, and— owing to the lack of crop-tree selection—substantially lower growth responses than result from selective hand-thinning, have limited the application of strip-thinning. Of considerable current interest is a combination of mechanical strip-thinning followed by selective hand-thinning within the residual strips, but the success of this method depends on the development of equipment that effectively and carefully thins narrow strips. Success in developing such equipment could allow mechanical thinning with right-angle strips to create spaced residual blocks of trees for selective hand-thinning, as suggested by Cole (1975).

PREDICTING THE RESPONSE TO THINNING

Despite a limited and fragmented research data base, several computerized stand development models (Dahms 1983; Goudie and Mitchell 1982; Myers 1967; Wykoff and others 1982) are presently available that simulate a variety of stand management regimes for lodgepole pine. At the most recent lodgepole pine symposium, Cole and Edminster (1985), using the LPMIST subroutine (Myers and others 1971) in conjunction with the RMYLD computer model (Edminster 1978), examined the yield consequences of alternative thinning regimes (including a variety of thinning intensities and frequencies) for a range of age, site, and stand density conditions. The results of their simulations agreed well with previous research observations. Cole and Edminster (1985) concluded that:

1. The determination of some "optimum" density necessarily involves a tradeoff between tree size and stand volume objectives, and this optimum density will vary depending on site quality.
2. Merchantable cubic volume production per unit area is maximized at relatively high stand densities and substantially declines when managed stand density is reduced.
3. For most management considerations, cutting cycles of 30 years seem most feasible.

Two recent research developments have occurred that will assist forest planners and field foresters in rationalizing their thinning and stocking control decisions. Cole (1986) has developed a regression model for estimating the basal area growth response of dominant and codominant trees on the edges of clearings as a function of pre-clearing stand parameters. Although not a predictor of growth after thinning, the method allows managers to determine the relative order of expected thinning response among a number of unmanaged lodgepole pine stands being considered for thinning. This provides a basis for setting thinning priorities among stands.

Another recent development is density management diagrams for lodgepole pine. Based on the -3/2 self-thinning rule, these diagrams are graphical presentations of the dimensional relationships between mean tree size and stand density. The first lodgepole pine diagrams were published by Flewelling and Drew (1985). Long and coworkers have recently published a more comprehensive one for the species (Long 1985; Long and McCarter 1985; McCarter and Long 1986). These diagrams provide a simple, visual comparison of the tradeoffs between individual tree size and stand volume for various management regimes being considered for a stand. When used in conjunction with appropriate site index estimates, these diagrams also can provide reasonable short-term approximations of the growth and yield of these regimes. In a test of one thinning regime, McCarter and Long (1986) reported a difference of less than 1 percent when the diagram-based estimate was compared to an estimate based upon RMYLD (Edminster 1978). However, like other forms of stand development models, density management diagrams are limited by the data on which they are based. McCarter and Long's (1986) diagram for lodgepole pine was based on very few data from stands having over 2,000 stems per acre (4,942 per hectare) or having mean stand diameters of 3.0 inches (7.6 cm) or less. Further development and refinement of management diagrams for lodgepole pine depend on the availability of expanded data sets, including validation data from managed stands. A detailed discussion of the construction and use of stand management diagrams is presented separately (Long, this proceedings).

CONCLUDING COMMENTS

Judicious stand culture is critical to the successful management of lodgepole pine in the Mountain West. Thinning allows the forest manager to maintain or enhance the health, vigor, and productivity of stands and control the rotation, yield, and value of the future crop. Despite a long history, our thinning research data base for lodgepole pine is limited and fragmented. In addition to maintaining and remeasuring our existing studies, we need to expand and refine our thinning research. As management of lodgepole pine intensifies, we must improve our ability to identify and assess the risks associated with management activities and improve our fundamental understanding of tree growth and stand dynamics. Computer simulation models, a method for determining the order of expected thinning response among stands, and density management diagrams are now available to help forest managers identify and rationalize site-specific stand management alternatives. Further refinements and improvements in these tools will depend, to a large extent, on the availability of a high-quality, long-term growth and yield data base, particularly for managed stands.

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WESTERN LARCH AND SPACE: THINNING TO OPTIMIZE GROWTH

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ABSTRACT

Space determines the future of many organisms, and western larch is one of them. Larch is an important pioneer species in the Inland Mountain West of the United States and Canada, well adapted to regenerating sites disturbed by fire, harvesting, or other activities. This paper summarizes information on how space allotted to larch trees affects growth response at very early as well as intermediate ages. Western larch benefits greatly when given adequate space to grow. Spacing is most effective in very young stands. Diameter is most responsive and is directly related to intensity of thinning, but height response is more variable and less conclusive. Basal area increases rapidly to about age 40, slows, and levels off after age 100, and it is related to stand density. Cubic volume yield is relatively constant over a wide range of density, but merchantable volume is generally increased by thinning.

INTRODUCTION

This paper addresses how space allotted to western larch (*Larix occidentalis* Nutt.) in the forests affects its development from early in life through the intermediate ages.

The story is not yet totally in for evaluating larch space needs, but it is more complete than that of many of its associates in the Inland Mountain West. This is due primarily to several long-term studies established in the Northern Rockies of the United States and southern Canada and east of the Cascades in the Pacific Northwest.

This paper discusses the response of western larch to cultural practices in two segments—the first covers young stands when effects of age and previous density are not pronounced, and the second covers intermediate age stands where recovery from previous stand conditions plays a more important role.

SPECIES CHARACTERISTICS

Western larch is the largest of three species of *Larix* indigenous to North America and is the only North American *Larix* that has seen significant management activity in young and intermediate age stands. *Larix* species in other parts of the world, particularly in Europe and Japan, have been managed far more intensively than *Larix* in North America.

Western larch forests are characterized by several factors very important in the selection of stand management practices. Perhaps most important are the propensity of larch to overstock under a wide range of site and management conditions and its extreme shade intolerance. Also important is the fact that even though larch generally predominates in western larch forests it seldom occurs as single-species stands. Because of its intolerance to shade, larch grows in even-aged stands. Its primary associates are often the same age but appear younger because they are usually smaller. Larch's rapid juvenile growth, its ability to sustain growth even at older ages, and its propensity to grow on relatively productive sites are also key factors in larch management (Schmidt and others 1976).

Western larch is one of the fastest growing species in interior western forests; its height growth exceeds that of most of its associates during the first 90 years (Deitschman and Green 1965). Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) sometimes grows slightly faster than larch in the early years, but falls behind by age 60. Western white pine (*Pinus monticola* Dougl. ex D. Don), however, may be taller than larch by age 90.

For the first several decades in a Montana study, larch and lodgepole grew at about twice the rate of their common associates Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), subalpine fir, (*Abies lasiocarpa* [Hook.] Nutt.), and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) (Cole and Schmidt 1986; Schmidt 1969). In an unmanaged stand in northern Idaho, both larch and lodgepole pine grew in height at the same rate, which was three to four times faster than the rate of western white pine, western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and western redcedar (*Thuja plicata* Donn ex D. Don) (Deitschman and Pfister 1973). In thinned stands, larch and white pine grew at about the same rate, even though larch was discriminated against in the original thinning. Another study in eastern Oregon compared growth rates of larch with those of the more shade-tolerant Engelmann spruce (Seidel 1984). At age 20, the average diameter and height of the larch were about double those of spruce, and the stand was developing into a stratified, two-storied stand even though both species were the same age. To maintain its vigor, larch must maintain a dominant position in the stand. If overtopped because of intertree competition or insect attacks on its terminal leaders, its highly shade-intolerant crowns can deteriorate rapidly.

Dwarf mistletoe (*Arceuthobium laricis* [Piper] St. John), western spruce budworm (*Choristoneura occidentalis* Freeman), and the larch casebearer (*Coleophora laricella* Hbn.) are the most important pests of immature larch (Denton 1979; Fellin and Schmidt 1967; Pierce 1960; Schmidt and Fellin 1973). They are all related to stand density but play a relatively modest role in the overall management of larch forests.

EFFECTS OF STAND AND SITE CONDITIONS ON TREE AND STAND GROWTH

Stand and site conditions on any given area normally dictate silvicultural options available to meet resource management objectives (Schmidt and others 1983). Insect and disease conditions sometimes require modification of silvicultural plans and objectives, but, in general, young larch is less susceptible to insects and disease than most of its associated species.

Because of the nature of most of the available data and because cultural practices often vary by stand age, the following sections will deal separately with young and intermediate age stands.

Stand Establishment Influences

Prescribed burning or scarification are commonly used to prepare sites for regenerating western larch forests. When site preparation is properly coordinated with good seed crops, natural regeneration of western larch and its associates is generally assured (Shearer 1981). Without site preparation, there is little assurance that larch will be adequately represented in the new stand. Variations in site preparations, seed crops, and weather largely dictate composition and density of the new stand. These same factors influence stand development for as long as two decades. For example, Haig and others (1941) found in Idaho that 2-year-old larch seedlings grew twice as fast in height on burned seedbeds as on bare mineral or duff-covered soil nearby. A study in Montana showed this early advantage persisting up to age 17, with height growth nearly a third more on burned than on scarified treatments, but the residual effects of site preparation on height growth largely disappeared by age 20 (Schmidt 1969).

What may be good for establishment and initial development is not necessarily good for long-term development. Heavy site preparation can prepare such a favorable seedbed that far too many seedlings become established and compete with each other, reducing their average growth and increasing mortality (Cole and Schmidt 1986).

This early overstocking can have a marked influence on crown development, diameter, and height of western larch. Even as early as 9 years old, dominant larch grew twice as fast in diameter, a third faster in height, and maintained longer, fuller crowns in stands with 5,000 stems/acre than they did in stands with 35,000 (12,350 and 86,450/ha) (Schmidt 1966).

Response to Spacings in Young Stands

Most of the information in this section will come from the first 20 years of a long-term spacing study installed in 7- and 9-year-old western larch at four locations in western Montana in 1961 (Schmidt 1978, 1980). Two sets of plots were located at Coram Experimental Forest in the Flathead National Forest, one set at Cottonwood Lakes in the Lolo National Forest, and another set at Pinkham Creek in the Kootenai National Forest.

Initially, these young stands were thinned to densities ranging from about 110 to 2,720 trees/acre (272 to 6,718/ha). Most of these results will concentrate on evaluating stocking ranging from 200 to 1,740 trees/acre (494 to 4,298/ha). Unthinned controls with 15,000+ trees/acre (37,050/ha) at Coram provide a good example of the effects of "doing nothing." The trees of most interest are the crop trees—those trees that are normally featured in larch forest management. In this case, the 200 largest trees/acre (494/ha) are considered the crop trees.

Crown Development—Western larch crowns are highly intolerant of shade and as a result are very sensitive to stand density. Since crowns are the production factory of the tree, they serve as good monitors of vigor and growth. Sensitivity to shade results in relatively consistent crown shapes with the upper portion a long-tapered cone upward from the widest part of the crown and the lower portion a relatively short-tapered and inverted cone.

Crown Length—Crop trees in thinned stands retain surprisingly long crowns because their rapid height growth extends crowns upward faster than they are declining at the lower portion of the tree. This is most apparent in the more open-grown stands, moderately so in the medium-stocked stands, and much less so in the unthinned stands (Schmidt 1980). Crown ratios (length of crown as a percent of total height) reflect more closely what is happening in crown development in relation to the whole tree. For example, absolute crown lengths and crown ratios of crop trees at age 29 on the study area at Coram Experimental Forest averaged as follows:

Trees per acre	Absolute crown length		Crown ratio
	Feet	*Meters*	*Percent of total height*
Unthinned	14	4.3	50
1,740	21	6.4	62
890	26	7.9	72
680	27	8.2	77
360	32	9.8	86
200	35	10.7	90

Obviously, stand density strongly affected both absolute length and crown ratio.

Age is also important in crown development. For example, crop trees on this same study area in the plots with 200 trees/acre (494/ha) showed absolute crown lengths and ratios changing over time as follows:

Age	Absolute crown length		Crown ratio
	Feet	*Meters*	*Percent of total height*
9	6	1.8	91
14	14	4.3	99
19	20	6.1	94
24	29	8.8	93
29	35	10.7	90

In this case, increased age resulted in little change in crown ratios but substantial increases in absolute crown length.

Crown Width—Crown width of young larch is even more strongly related to stand density than crown length

(Schmidt 1980). Shading from above and the side apparently limits the outward growth of the branches. For example, in terms of absolute crown width, trees in stands with 1,740 trees/acre (4,298/ha) at age 19 average about 75 percent of the width of trees in stands with 200 trees/acre (494/ha). By age 29, they average only about 50 percent of those in the stands with 200 trees/acre (494/ha).

Comparisons of average crown widths with tree spacing help explain the relative decline in crown width of denser stands compared to more open-grown stands (fig. 1). As shown in this figure, average crown widths of the 19-year-old stands at Coram had not exceeded the average distance between trees in the stand density ranges of 200 to 1,740 trees/acre (494 to 4,298/ha) (Schmidt 1980). However, by age 29, average space allotted to each tree started limiting the crown widths at the confluence of the average crown width curve and the average tree spacing curve. This occurred at about 1,000 trees/acre (2,470/ha). This evaluation is based on perfect tree spacing and uniform tree sizes, neither of which are the rule. Thus, in reality, some trees have excess crown space while others experience side crowding.

Crown Configuration—As stand density affects crown length and width, crown configurations also change (Schmidt 1978). Height to the widest part of the crown changes by moving upward rapidly with age and to a lesser extent with density (Schmidt 1980).

Unthinned forest conditions produce the smallest crowns and the most different crown configurations of potential crop trees (fig. 2). Although differences between stand densities are readily apparent in crown configuration, the extreme stand densities in the unthinned stands make the effects of early thinning much more vivid.

The general configuration of open-grown crop trees (200 trees per acre [494/ha]) remains much the same between ages 9 and 29 (fig. 3). However, the ratio of length to width (length/width) changes from about 2.5 at age 9 to 3.0 at age 19 and 3.2 at age 29.

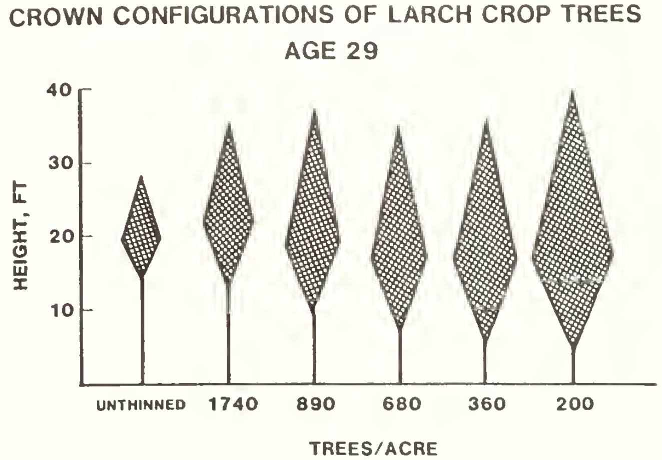

Figure 2—Crown configurations of average 29-year-old larch after growing at specific stand densities for 20 years.

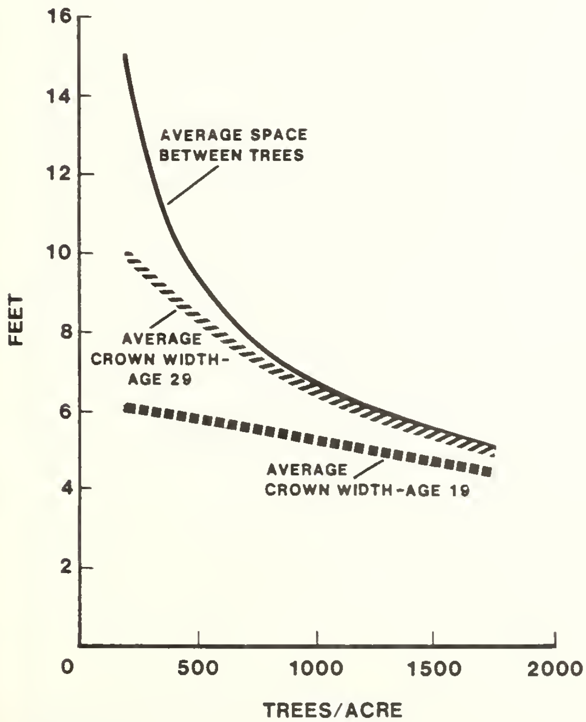

Figure 1—Relationship of average crown widths to average space between trees of larch growing under a range of stand densities.

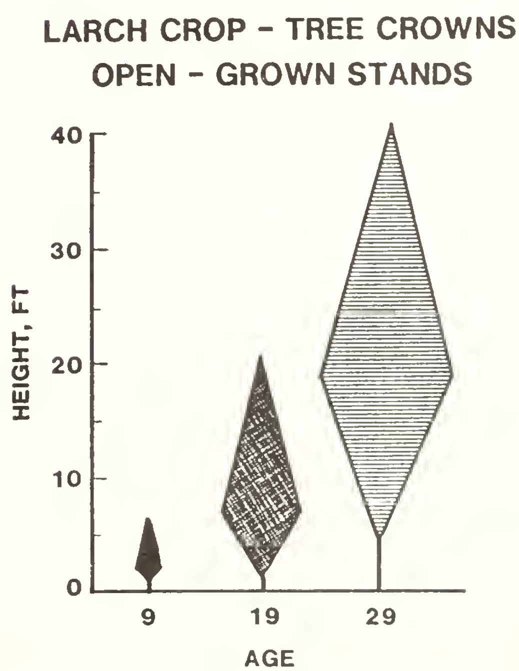

Figure 3—Crown configurations of average open-grown larch (200 trees/acre [494/ha]) at ages 9, 19, and 29.

Diameter—Diameter is characteristically the tree dimension most sensitive to stand density, and this holds true with young western larch (fig. 4). Diameters of larch crop trees at age 29 averaged 6.4 inches (16.3 cm) in the Coram stands with 200 trees/acre (494/ha), more than twice the size of their counterparts in unthinned stands. Differences were readily apparent at age 19 and earlier, becoming more pronounced as the stands grew older and more fully occupied the site. In general, diameter growth was a continuum along the stand density gradient.

The same general diameter-density relationship holds true for all trees as well as for crop trees, but the differences for all trees are more pronounced between stand densities (fig. 5). For example, at age 19, crop trees at Coram averaged 1.3 times larger at stand densities of 200 than at 1,740 trees/acre (494 and 4,298/ha); but when all trees are compared, they average 1.6 times larger, respectively. At age 29, crop trees averaged 1.5 times larger at stand densities of 200 than at 1,740 trees/acre (494 and 4,298/ha), but with all trees the average is 2.0 times larger, respectively.

Height—Larch crop trees in the study at Coram Experimental Forest exceeded expected height growth, described by site index curves (Schmidt and others 1976), in all of the thinned stands regardless of reserve density (fig. 6). For example, expected height for the site was 30 ft (9.2 m) at age 29, but crop trees in the thinned stands averaged 37 ft (11.3 m) or 23 percent greater than expected. This approaches height growth rates expected on site indices of 80 ft (24.4 m). Meanwhile, potential crop trees in the unthinned stands averaged only 28 ft (8.5 m), under par for the expected rate described by site index curves. If height growth in the thinned stands is truly reflecting height growth potential, crop trees in the unthinned stand are about 14 percent below potential at age 19 and 24

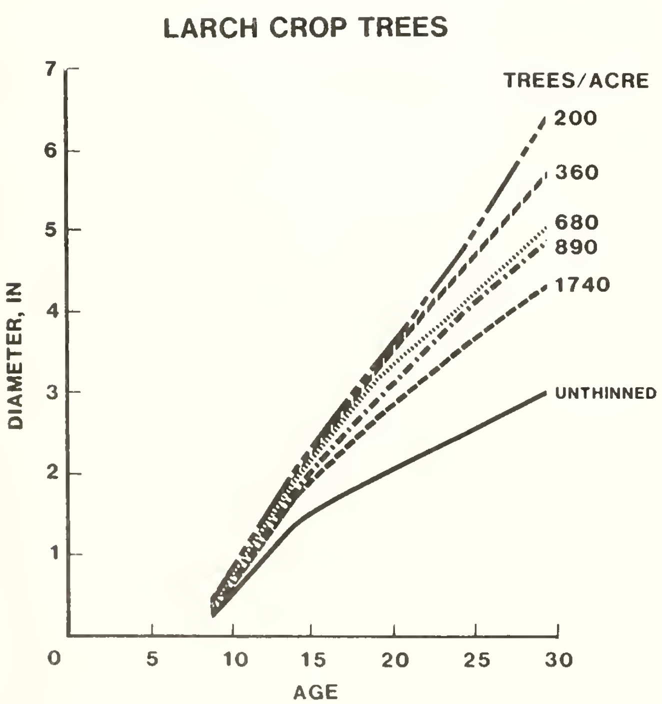

Figure 4—Average diameter at breast height (DBH) of larch crop trees (200 largest trees/acre [494/ha]) growing at specific stand densities from age 9 to 29.

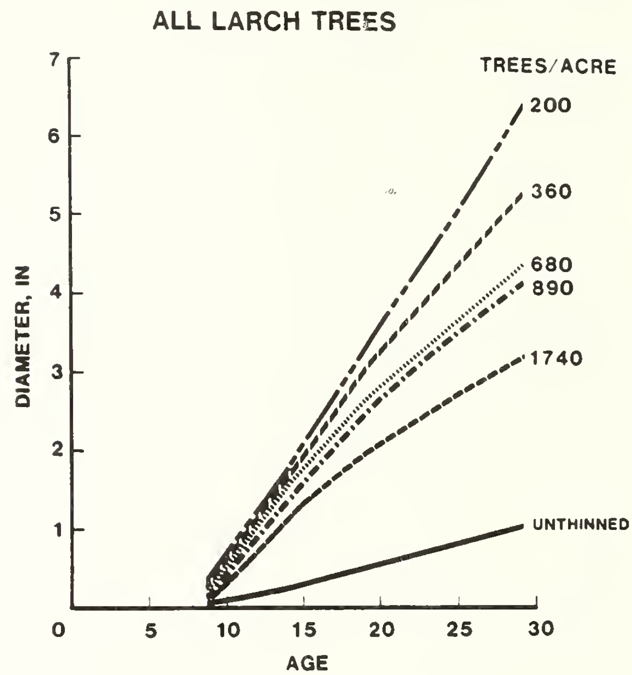

Figure 5—Average diameter at breast height (DBH) of all trees in larch stands that were growing at specific stand densities from age 9 to 29.

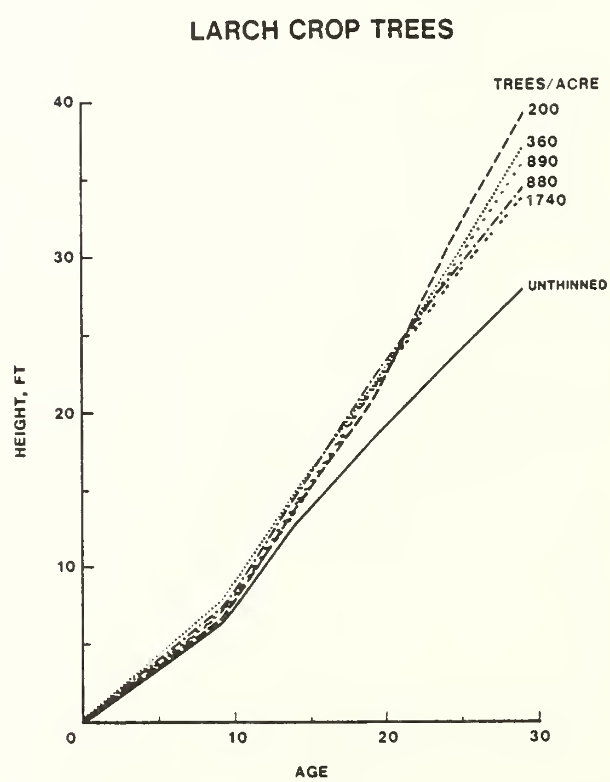

Figure 6—Average height of larch crop trees (200 largest trees/acre [494/ha]) growing at specific stand densities from age 9 to 29.

percent below at age 29. This trend would indicate an even greater disparity in the future.

These figures suggest that either the site index curves are not realistic at younger ages, that this was an above average period of growth, or that the original site evaluations were very conservative. Most importantly, it says that any level of thinning relieves height growth suppression of crop trees in heavily overstocked stands of young larch.

Basal Area and Volume—Basal area per unit area is a function of tree diameter and stand density and is a commonly used measure of stocking, particularly in stands older than those discussed in this section. Young larch stands with the most trees most fully occupied the site and carried the most basal area. Thinned stands with 1,740 trees/acre (4,298/ha) at Coram had 100 ft^2/acre (22.9 m^2/ha) of basal area by age 29, those with 200 trees/acre (494/ha) had 45 ft^2 (10.3 m^2/ha), and stands with intermediate numbers had proportionate basal area stocking (fig. 7). Interestingly, the unthinned stand showed net periodic basal area growth declining while all the thinned stands were sharply increasing in basal area at age 29.

In relation to normal fully stocked larch forests (Cummings 1937; Schmidt and others 1976), all of the thinned and unthinned stands are less than fully stocked, with the most heavily stocked stand (1,740 trees/acre [4,298/ha]) 23 percent under and the stand with 200 trees/acre (494/ha) 65 percent under normality, respectively.

Cubic-foot volume is a function of height, diameter, and density. As such it probably serves as the best overall indicator of the effects of stand density in the long term. We don't normally think of cubic volume as utilizable at this age and size, but the values nevertheless serve as an indicator of practical stocking levels to meet growth objectives.

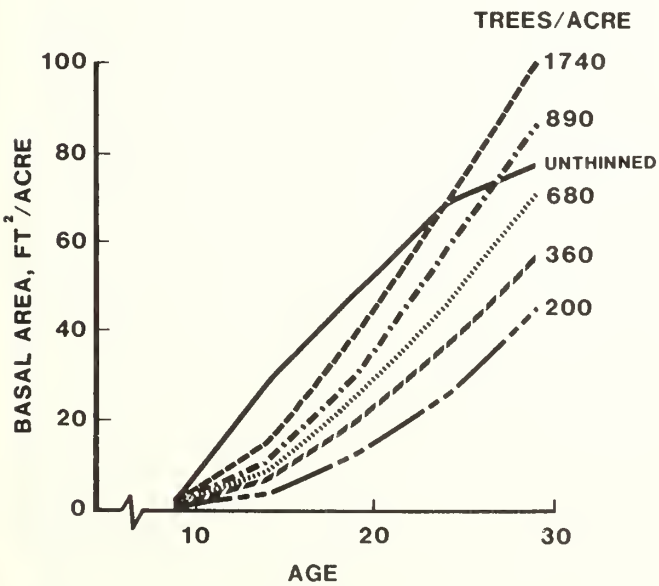

Figure 7—Basal area per acre of western larch growing at specific stand densities from age 9 to 29.

The vast majority of the cubic-foot volume increment at Coram is accounted for by less than 1,000 trees/acre (2,470/ha) in the first two decades after stands were thinned at age 9 (fig. 8). For the decade from age 9 to 19, trees in excess of 1,000/acre (2,470/ha) account for only about 10 percent of the potential growth on the site. In the age period 19 to 29, trees in excess of 1,000/acre (2,470/ha) contribute only 5 percent additional growth while those in excess of 800/acre (1,976/ha) contribute 10 percent additional growth. Thus, fewer and fewer trees are needed to capture the cubic-foot growth potential as the stand ages.

Mortality—Mortality in young unthinned larch forests is quite heavy due to severe intertree competition for light and water (fig. 9). Tree numbers on unthinned Coram Experimental Forest plots declined more than a third from age 9 to 29 but, as evidenced by growth figures, densities are still far too great for good stand development. The sharp decline appears to portend accelerated mortality in these stands. Nearly all of the mortality in the unthinned stands was due to suppression and is actually a benefit to the long-term development of the stand.

Mortality in thinned stands is generally not desirable. For the age period 9 to 29, relatively few trees died in the thinned areas at the four locations used for the larch spacing study (table 1). Percent mortality is about the same in the two age periods 9 to 19 and 19 to 29 with an average overall of about 0.3 percent annually in the thinned stands.

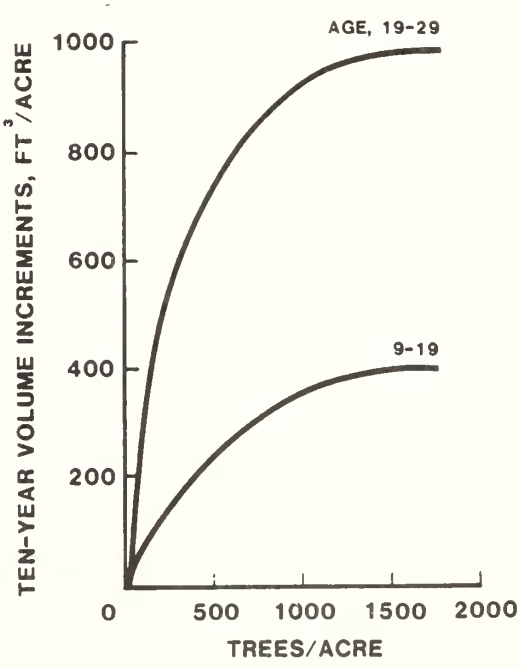

Figure 8—Ten-year cubic-foot volume increment of larch from ages 9 to 19 and 19 to 29 growing under a range of stand densities.

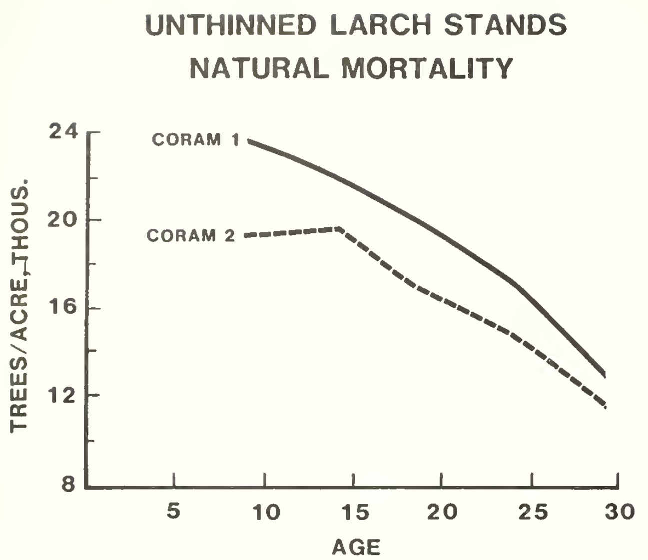

Figure 9—Natural attrition in number of trees of unthinned larch stands from ages 9 to 29.

Table 1—Mortality of young western larch in all the thinned stands of the larch spacing study from age 9 to 29

Location	Mortality of larch: Age period 9 to 19	19 to 29	9 to 29	Average annual rate
	Percent of stand			
Coram 1	5	7	12	0.6
Coram 2	1	1	2	.1
Cottonwood	1	1	2	.1
Pinkham	4	5	9	.4

Causes of mortality in thinned areas are related to location and stand density. Causes of mortality assessed at four locations of the larch spacing study were as follows:

Cause of mortality	Total mortality
	Percent
Snow related	26
Disease	13
Suppression	8
Insects	5
Man-caused	3
Animal	1
Unidentified	44

Snow accounts for the largest percentage of mortality that can be reasonably well identified, and most of this was on an area of heavy snowpack at Pinkham in the Kootenai National Forest. Here, small seedlings in the denser plots often went down en masse under heavy snow turned to ice. However, a heavy snow in June damaged many larch at Coram but did not result in much mortality at age 13—the trees recovered remarkably well (Schmidt and Schmidt 1979).

Disease-caused mortality was concentrated primarily at Cottonwood in the Lolo National Forest and was classified as shoot blight (*Encoeliopsis laricina* [Ettlinger] Groves). Although not identified specifically on the other areas, disease mortality usually followed injury from snow or insects. Larch engraver (*Scolytus laricis* Blkm.) accounted for most of the insect mortality. Even though budworm damaged many trees, particularly at Cottonwood, no mortality was attributed to budworm alone. Animal damage was primarily due to bear (*Ursus* spp.) and has been increasing, particularly in the more open-grown stands.

Response to Thinning in Intermediate-Age Stands

Although sapling stands should have the highest priority for thinning, older pole-sized stands also show significant response to thinning if trees are vigorous with live crown ratios of at least 40 percent and not heavily infected with dwarf mistletoe. Studies in intermediate-age stands have been carried out primarily in western Montana and central Oregon.

Diameter—Diameter growth of even-aged larch stands is significantly increased by thinning and is directly related to the intensity of thinning (Seidel 1971, 1975, 1977, 1980, 1982). For example, diameter growth in a stand thinned at age 33 in eastern Oregon increased from 0.11 inch (0.28 cm) per year on the high-density plots to 0.36 inch (0.91 cm) on the low-density plots during the first 5 years after uniform thinning from below. Crop tree thinning of a 50-year-old larch stand in Montana also resulted in a prompt and significant increase in diameter growth (Roe and Schmidt 1965), but over a 25-year period the diameter increase of thinned crop trees was less than 1 percent greater than that of crop trees in unthinned plots (Cole 1984). Crop tree thinnings in older stands generally are not desirable because removing a limited number of trees around crop trees does not reduce stand density sufficiently to maintain adequate diameter growth. Diameter growth response within a stand appears to increase with initial tree size. Therefore uniform thinnings from below, favoring dominant and codominant trees, to stocking levels meeting the size and rotation objectives of the land manager are recommended.

In addition to increasing the rate of diameter growth, thinning increases the specific gravity of trees in pole-sized stands (Lowery and Schmidt 1967). Thus, thinned trees are not only larger than unthinned trees but they also have superior wood density and strength properties.

Height—In contrast to the consistent increases in diameter growth resulting from thinning reported in the literature, the height growth response to thinning is more variable and less conclusive. The variability of results probably is related to age, site quality, and initial stocking level of the stands. For example, in a heavily overstocked 30-year-old stand in Montana, height growth was 48 percent greater in thinned plots than in unthinned (Roe and Schmidt 1965). Thinning, however, had no effect on height growth in a moderately stocked 50-year-old Montana stand (Roe and Schmidt 1965) or in a moderately stocked 33-year-old Oregon stand (Seidel 1977). Generally, land managers can expect height growth rates of about 0.8 to 1.5 ft (0.24 to 0.46 m) per year in thinned pole-sized stands on medium to good sites (site index 50 to 80 ft [15 to 24 m]). This is about the same rate of growth as found for average dominant and codominant larch in normal fully stocked stands (Schmidt and others 1976).

Basal Area—In normal stands, basal area rises rapidly up to about age 40, slows, and then nearly levels off after age 100. From age 20 to 40, the net basal area of site index 80 stands increases at an average rate of about 4.7 ft^2/acre (1.08 m^2/ha) per year; from age 40 to 100 years the increase is 1.6 ft^2/acre (0.37 m^2/ha) per year, and from age 100 to 200 years growth slows to only 0.4 ft^2/acre (0.09 m^2/ha) annually (Schmidt and others 1976). Thinning studies in intermediate age stands show that basal area growth rates increase with residual stand density and decline with increasing stand age (Seidel 1980, 1982). Although net basal area increment increases as stand density rises, the growth rate is relatively constant over a fairly wide range of stand densities from about 70 to 160 ft^2 of basal area per acre (16.07 to 36.74 m^2/ha). Basal area growth rates from 1.5 to 5.0 ft^2/acre (0.34 to 1.15 m^2/ha) per year are typical over a range of stand densities from 40 to 160 ft^2 of basal area/acre (9.18 to 36.74 m^2/ha) in site index 80 stands from ages 30 to 70.

Volume—Total net volume production in normal stands varies widely depending on site quality. Cubic volume yields at 140 years range from about 7,400 ft^3/acre (518 m^3/ha) in site index 50 stands to 14,000 ft^3/acre (980 m^3/ha) at site index 80. Board-foot volumes (International one-fourth inch) range from 35,000 to 93,000 bd ft/acre at the same age and site indices (Schmidt and others 1976). Culmination of mean annual increment in these stands occurs at about 70 years in terms of cubic feet and at more than 140 years in terms of board feet.

Similar to basal area response, total cubic volume growth rates increase with residual stand density but appear to reach a plateau at basal area levels greater than about 110 ft^2/acre (25.3 m^2/ha). Although significantly smaller and slower growing trees are found at high stand densities, the considerably greater numbers of trees at these densities result in higher total cubic volume growth rates. In the 33-year-old Oregon pole stand referred to previously, total annual gross cubic volume increment ranged from 64 ft^3/acre (4.5 m^3/ha) at the lowest density level (26 ft^2/acre [6 m^2/ha] of basal area) to 136 ft^3/acre (9.5 m^3/ha) at the highest level (110 ft^2/acre [25 m^2/ha]) during the first 5 years after the initial thinning (Seidel 1982).

Although periodic total cubic volume increment increases with stand density, the results of larch thinning studies in pole-sized stands support the theory that total cubic volume yield is relatively constant over a wide range of basal area (70 to 160 ft^2/acre [16.07 to 36.74 m^2/ha]) and that thinning can reduce, but not increase, this level of production. The relationship between cubic volume yield and stand density appears to depend on the age at which thinnings are begun. When thinning is begun at an early age (10-20 years), cubic volume yield should increase with stand density. In contrast, if thinning is delayed until stands are pole-sized (30-50 years), volume yield is more uniform over a range of stand densities because the large initial volume, extracted from stands thinned to low densities, tends to offset the reduced growth at these densities. Although total cubic volume yield can be reduced by thinning, there is also evidence that merchantable or usable volume can be increased by thinning (Seidel 1982). By increasing growth of the residual trees, thinning transfers the growth potential of the site to fewer, larger, and more valuable trees. It also reduces mortality due to competition and salvages merchantable mortality in older stands.

In addition to increasing usable volume, thinning can also result in greater economic benefits because of the greater value of larger trees and the products obtained from large trees and because of the lower harvesting and milling costs, per unit volume, associated with larger trees (Schweitzer 1975).

Thinning Priorities and Intensity

Generally in any given management unit there are more stands in need of thinning than there are funds to do the job. Therefore, it is necessary to allocate available funds to stands most likely to benefit from thinning. Important criteria for setting priorities follow:

1. Stand Age. Seedling and sapling stands about 15 years old should have the highest priority for thinning.
2. Site Index. Thinning of stands on better sites should yield greater returns.
3. Stocking. Stands to be thinned should be overstocked, but extremely dense stands may be too costly to thin. Young stands having from about 1,000 to 25,000 trees/acre (2,470 to 61,750/ha) are good candidates for thinning. Any remaining overstory should be removed before thinning.
4. Dwarf Mistletoe. Stands free of mistletoe have the highest priority, but mistletoe control can be accomplished in lightly infected stands through thinning.
5. Growth. Overstocked stands where actual growth is much less than potential should be considered for thinning. A method of evaluating the performance of larch stands based on present diameter and past 10-year diameter growth is available to rank stands for thinning needs (Schmidt and others 1976).

Thinning intensity depends on many factors. These include (1) rotation age, (2) expected growth rate, (3) present and future markets for small trees, (4) risk of damage to the stand, (5) schedule of future thinnings, and (6) multiple use considerations. The most important factor affecting the intensity of precommercial thinnings is the manager's estimate of a minimum tree size (d.b.h.) that will be merchantable in the future. By leaving a high stand density, the silviculturist is assuming that smaller trees will provide a commercial thinning in the future; conversely, leaving a stand of low density implies that larger trees are needed for a commercial thinning or that the stand will not be rethinned before final harvest. In other words, the larger the trees needed for a commercial thinning, the fewer should be left after the precommercial thinning. Obviously, it is not possible to maximize both diameter growth per tree and volume growth per acre because maximum diameter growth occurs at low stand densities while high densities result in maximum total volume (fig. 10) (Seidel 1977).

After a stand has reached merchantable size, goals usually are to utilize mortality and maintain adequate volume and diameter growth. Determination of appropriate stand density in merchantable stands can be accomplished using the stocking level curves for larch prepared by Cochran (1985) (fig. 11). These curves show that acceptable stocking levels encompass a wide range of stand densities depending on management objectives. Therefore it is not critical to maintain an exact stand density at any time in the rotation. The important point is to thin the stand sufficiently when young to prevent excessive competition which results in smaller crowns, loss of vigor, reduced growth, and greater mortality.

Simulation models such as the Stand Prognosis Model (Wykoff and others 1982) can assist the forest manager in predicting stand response to various thinning prescriptions for a variety of sites, plant communities, and stand ages.

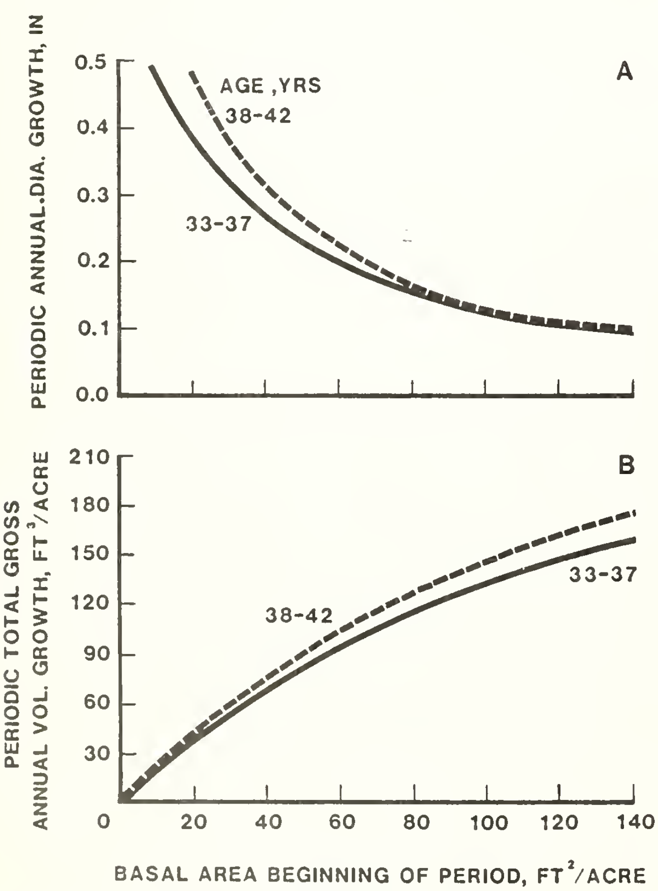

Figure 10—Periodic annual growth of 33-year-old western larch by density level (basal area) and growth period, site index 80 ft (24 m) at 50 years: A, Diameter growth (adapted from Seidel 1977, fig. 3); B, Cubic volume growth (adapted from Seidel 1977, fig. 8).

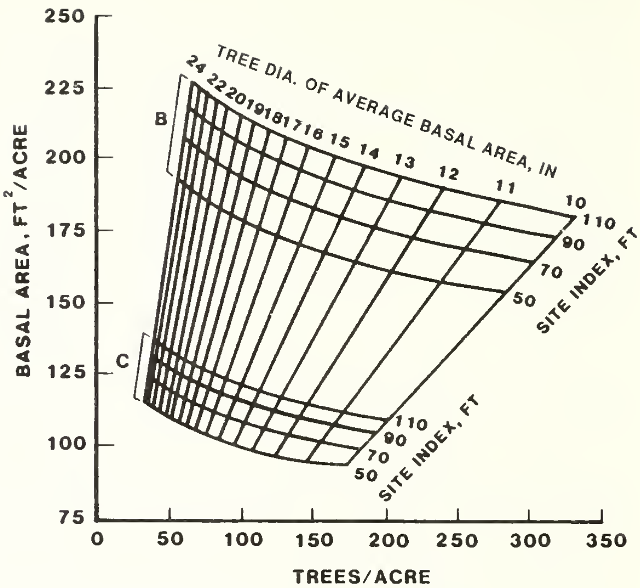

Figure 11—Stocking level curves for larch. The "B" lines represent 75 percent of normal stocking, and the "C" lines represent 45 percent of normal stocking. Stands should be managed so that they are at the "B" level for a commercial entry. Commercial thinnings should be from below and should reduce stocking to the "C" level. (From Cochran 1985, fig. 2.)

SUMMARY AND CONCLUSIONS

Western larch benefits greatly from early thinning because it relieves overstocking competition and allows larch to capitalize on its rapid juvenile growth. Thinning dense seedling and sapling stands transfers growth to fewer rapidly growing trees thus maintaining good vigor and crown development, increasing resistance to wind, snow, and insects, and permitting more uniform diameter growth. Judicious thinning regimes can result in shorter rotations and increased merchantable yields as well as other benefits such as increased water yields and greater forage production. Stocking level curves and simulation models are available to assist the land manager in planning thinning schedules.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Robbin Boyce)—With pre-treatment stand densities having an effect on diameter growth response after thinning, at what age and stand density level will thinning be of limited benefit for producing sawlogs?

A.—I wish we could unequivocally answer that question, and so would lots of other people. In addition to age and stand density, several other factors such as site quality, crown length, and current growth rate help provide a better handle on what to expect in growth response after thinning. A number of the publications referenced in this paper do provide some benchmark values for answering this question, but we know of no thinning studies that span the entire range of site, age, density, and other conditions that can provide a definitive answer for this question. Schmidt, Shearer, and Roe (1976) developed a method of evaluating growth performance of western larch. It compares actual with potential growth—by age, site index, and ecological habitat type—to determine relative growth performance of trees and stands. This helps determine the need for thinning. Unfortunately, it does not specifically tell you how well trees will respond under this whole range of conditions.

Q. (from Barry Coles)—Is there any indication that bear damage is on the increase in young larch stands? Is it related to thinning? Do you have any suggestions for prevention or mitigation of bear damage?

A.—I know of no definitive data that tell us if bear damage is increasing in young larch stands. However, in all likelihood, bear damage has increased in absolute terms, but probably remained about the same percentagewise. The fact is, we have far more 15- to 35-year-old larch stands, that are highly susceptible to this type of damage, than we had in the past. Young stands that came about as a result of increased harvest cutting since the early 50's are beginning to dominate the landscape. Bear damage is most pronounced on the largest most vigorous trees in thinned western larch stands. Coincidentally, larch has likely been the most rigorously cultured species in the Northern Rockies. Thus, stand conditions are very favorable and there is a relatively high population of bear in these forests.

Bark stripping appears to be a learned behavior passed from sow to cub. This occurs in the spring when wood sugar levels are high and bear have high energy demands.

At this time, I know of no economically and biologically feasible method of dealing with this problem. An "Animal Damage" symposium, dealing with a number of problems of this type, is being sponsored by Washington State University at Spokane, Washington, March 1987.

Q. (from Ken W. Weaver)—What is the predominant site preparation treatment on larch sites in Montana—prescribed burning or scarification—and why?

A.—Piling and burning with accompanying scarification is the most frequently used site preparation method. The most common explanation given to me by land managers is that, even though they prefer prescribed burning, favorable prescribed burning time "windows" are too short and infrequent to keep up with site preparation needs. However, prescribed burning is still used a lot and it has many desirable features, not only for preparing seedbeds but for enhancing subsequent stand development.

INFLUENCE OF STAND DENSITY ON DEVELOPMENT OF WESTERN WHITE PINE, REDCEDAR, HEMLOCK, AND GRAND FIR IN THE NORTHERN ROCKY MOUNTAINS

Russell T. Graham

ABSTRACT

Western white pine, western redcedar, western hemlock and grand fir occupy the most productive sites of the Northern Rocky Mountains. Blister rust-resistant seedlings are usually used to establish western white pine. Because of disease and frost susceptibility, grand fir is planted sparingly. Western hemlock and western redcedar are seldom planted, but regenerate naturally, often creating overly dense stands. Stand densities do not appreciably affect tree growth during the first 10 years of stand development. By 30 years of age stands should be at or near the desired stocking. Depending on site, stand condition, and management objectives, cleaning densities between 400 and 900 trees per acre (988/ha to 2,224/ha) are desired with spacings of 10 ft by 10 ft (3.05 m by 3.05 m) optimum. Thinnings accelerate diameter growth of crop trees, but stand yields are not usually increased compared to well-stocked unthinned stands.

INTRODUCTION

The concept that tree spacing influences stand development has been recognized since the 15th century when thinning prescriptions were first prepared for the city forests of Zurich, Switzerland. Thinning was practiced in central Europe during the middle 1850's. Thinning research was started in Scandinavia around 1900 (Robinson 1970). Thinning studies in eastern white pine (*Pinus strobus* L.) started in the northeastern United States in 1910; similar studies began in 1914 on western white pine (*Pinus monticola* Dougl. ex D. Don) in northern Idaho. Because of the mixed species stands that occur in northern Idaho, this research also included western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), and grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.). These studies, and numerous others, confirmed that (within limits) tree growth increases as individual tree spacing increases (Evert 1971).

Western white pine, western redcedar, western hemlock, and grand fir generally occupy the most productive sites in the Northern Rocky Mountains including parts of northern Idaho, and contiguous portions of Washington, Montana, and British Columbia (Haig 1932). Stands containing western white pine occur in other areas, but they reach their best development in this region. It is not uncommon for stands containing a mix of these species to have over 50,000 bd ft to the acre and grow over 250 ft^3 per acre per year (17.5 m^3/ha/yr).

The area is characterized by precipitous topography, with mixed species stands occurring on all aspects and slopes. Elevations range from 1,500 to 6,000 ft (457 to 1,829 m) (Graham and others 1983). The climate is highly variable, characterized by dry summers with wet falls and winters. Most precipitation occurs in the form of snow. Total precipitation ranges from 28 to 60 inches (711 to 1,524 mm). The growing season averages between 60 and 160 days (Haig and others 1941). Because of this diversity, the ecosystems in which western white pine and associates grow tend to be very complex (see Daubenmire and Daubenmire 1968; Haig and others 1941).

Western white pine is moderately shade tolerant while western hemlock, western redcedar, and grand fir are shade tolerant (Minore 1979). Western white pine is always seral, western hemlock always climax. Grand fir and western redcedar are either seral or climax, depending on the particular site. Because of this range in shade tolerance, stands containing these species are highly diverse with a wide range of stand densities possible.

Western white pine trees have clean boles with minimum taper and narrow, short crowns compared to the other species over a wide range of stand densities. White pine blister rust (*Cronartium ribicola* Fisch.) is the most damaging disease of western white pine. Mountain pine beetle (*Dendroctonus ponderosae* Hopkins) can also cause considerable damage in mature stands.

Depending on stand conditions, western redcedar is usually extremely long-lived with long, dense crowns (Minore 1983). The boles are usually tapered; fluted trunks are the norm on mature trees. Branches are retained except in overly dense stands. Western redcedar can be severely damaged by *Phellinus weirii* (Murr.) Gilbertson and *Armillaria* spp. but is somewhat resistant to bole-rotting organisms. Western redcedar is susceptible to cold injury and snow damage. Sun scald can be damaging, especially on trees with large amounts of shade-formed foliage.

Dominant and codominant western hemlock and grand fir usually have long, wide crowns and tapered boles. Natural pruning is minimal unless the stand is extremely dense where trees with poor crowns develop. Western hemlock and grand fir have heavy crowns (Minore 1979) making them susceptible to snow damage when sapling and pole sized. Several insects and diseases attack grand fir and western hemlock, but *Armillaria* spp., *Phellinus* spp., *Echinodontium tinctorium* (E. & E.), and *Heterobasidion annosum* (Fr.) Bref. are particularly troublesome. Similar to western redcedar, both species are susceptible to winter injury and sun scalding.

STAND ESTABLISHMENT

In western redcedar and western hemlock habitat types, regeneration is usually more than adequate. However, species mix is seldom optimum. On northerly facing slopes western hemlock, western redcedar, and grand fir usually regenerate profusely even with shrub competition. In the hemlock habitat types, stands containing 50,000 stems per acre (123,550/ha) are not uncommon. They are usually composed primarily of western redcedar and western hemlock but often have a good complement of grand fir and Douglas-fir (Haig and others 1941; Wellner 1946). In natural stands, western larch and blister rust-resistant western white pine are often absent.

On southerly exposures or on high-elevation sites in the subalpine fir and grand fir habitat series, shrub competition, intense solar radiation, animals, and cold damage can decrease regeneration success (Boyd 1969; Foiles and Curtis 1973). On such sites stocking is often inadequate and lodgepole pine, western larch, Douglas-fir, or ponderosa pine are preferred.

Because of white pine blister rust, artificial regeneration of resistant western white pine is preferred. Western redcedar and grand fir are planted sparingly, but during the 1950's and 1960's grand fir was planted in place of western white pine. Because of grand fir's susceptibility to cold injury, insects, and diseases, successful artificial regeneration has been highly variable.

EARLY STAND DENSITIES

Seedlings

From a practical point of view, high seedling densities do not appear to adversely affect the development of dominant western white pine (fig. 1). Helmers (1948) showed that, 9 years after sowing, the taller trees were growing in seed spots (approximately 1 ft^2 [30.5 cm^2]) that had the most trees. He also showed that tree diameters decreased as seedling density increased, but the differences among the diameters were less than 0.2 inch (5 mm). Early growth of Engelmann spruce (Helmers 1948) also appears to be minimally impacted by tree densities, indicating that western redcedar, western hemlock, and grand fir seedlings may also develop satisfactorily over a wide range of densities.

Saplings

During the early 1900's several large fires burned in northern Idaho preparing extensive areas for both natural

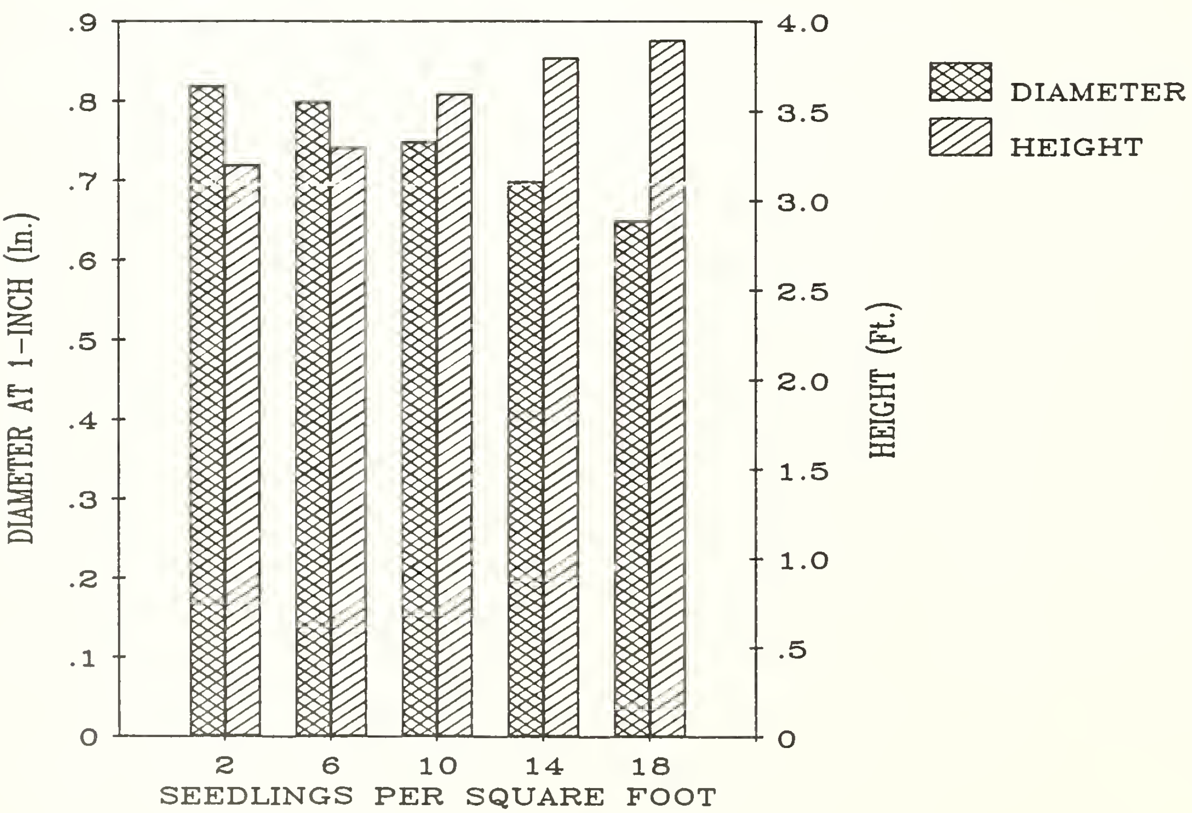

Figure 1—Height and diameter (at 1 inch) for 9-year-old western white pine sown in prepared spots (1 ft^2) in northern Idaho (Helmers 1948).

and artificial regeneration. Many of the regenerated stands were severely overstocked. Cleaning trials were established in several of these (Boyd 1959; Wellner 1940, 1946). Western white pine was the preferred species in these treatments, and to a lesser extent, western redcedar. Because small trees were difficult to remove during cleaning, grand fir and western hemlock often remained.

Cleaning can increase the proportion of western white pine in a stand, and also increase the height of dominant trees (Deitschman and Pfister 1973) (fig. 2). Moreover, diameter increment can be increased resulting in 40 percent more basal area in heavily cleaned stands than in uncleaned stands (fig. 3). These data show that a considerable increase in both height and diameter can be realized from treating young stands.

Koenigs (1969) reported an initial response of 80-year-old western redcedar to cleaning as favorable, but crop trees ultimately slowed in growth and became infected with root disease. In contrast, Deitschman and Pfister (1973) showed western redcedar cleaned at 8 to 16 years of age continued to show a good response to cleaning 30 years later (fig. 2). The older cedars apparently did not have the ability to maintain themselves and were attacked by root diseases.

A young (20-year-old) stand of western redcedar showed a good response to cleaning (10-ft [3.05-m] spacing) on a poor site in coastal Washington (Harrington and Wierman 1985). There was a slight trend for better nutrition in the cleaned stand compared to the uncleaned stand. Within the stand it appeared the better response was from the younger and larger trees. In addition, we found stands of western redcedar growing on western redcedar habitat types to be the best candidates for treatment (Graham 1982).

Western hemlock responds favorably to cleaning; its response is similar to that of western redcedar (fig. 2). But, if favored, its growth may exceed that of western redcedar.

Grand fir is one of the species most responsive to release from competition, but response is dependent on both site and tree condition (Ferguson and Adams 1980). If not subjected to severe overtopping and released in a timely manner, its growth rate in hemlock habitat types would probably equal that of western white pine (Deitschman and Pfister 1973). In addition, this species has a greater ability to respond to release later in life than western white pine (Foiles 1965).

Spacing

The cleaning trials established in northern Idaho were designed to space the crop trees at approximately 8 ft (2.4 m) for moderate cleaning. For heavy cleaning, all trees over 0.5 ft (15 cm) tall, except western white pine and western redcedar, were removed. These treatments resulted in well-developed stands; heavy cleaning was the most desirable (fig. 2, 3).

A replicated study on the Deception Creek Experimental Forest in north central Idaho showed that by 24 years of age competition begins to impact western white pine development in spacings less than 10 ft (3.05 m) (table 1). From these data and stand projections using these data,

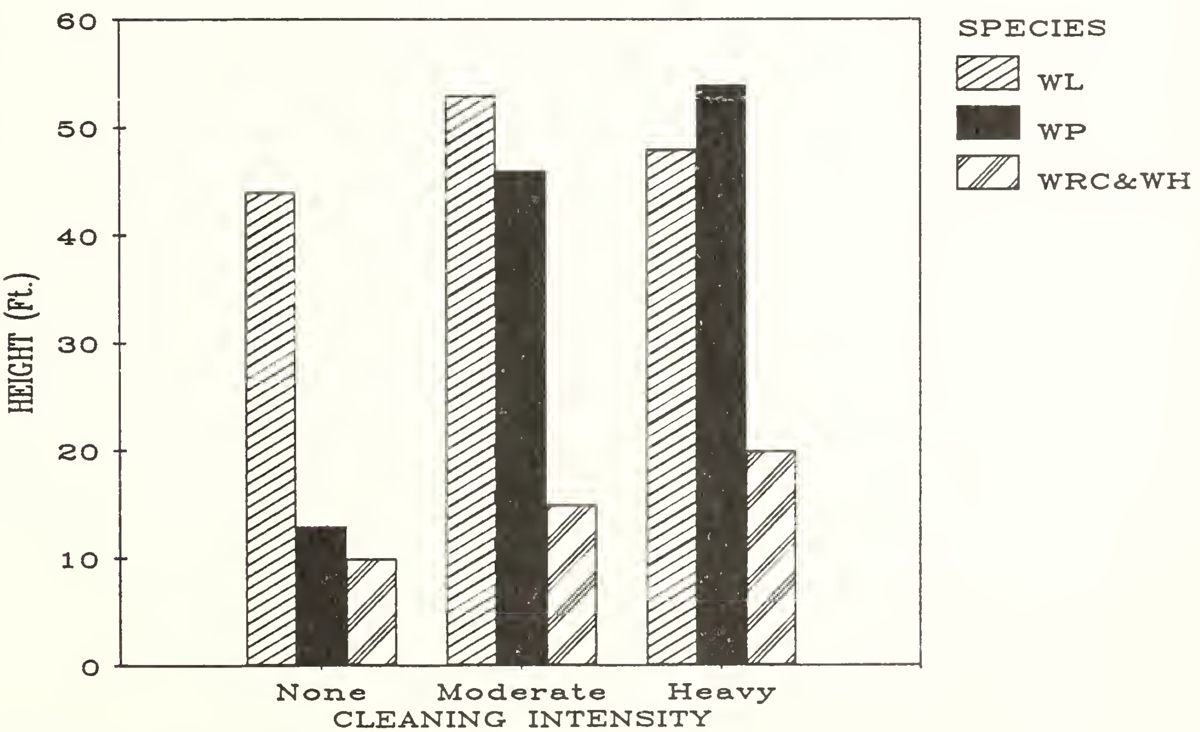

Figure 2—Height of 38-year-old western larch (WL), western white pine (WP), and western redcedar and western hemlock (WRC&WH) cleaned at 8 years of age based on the tallest 100 trees per acre (Deitschman and Pfister 1973).

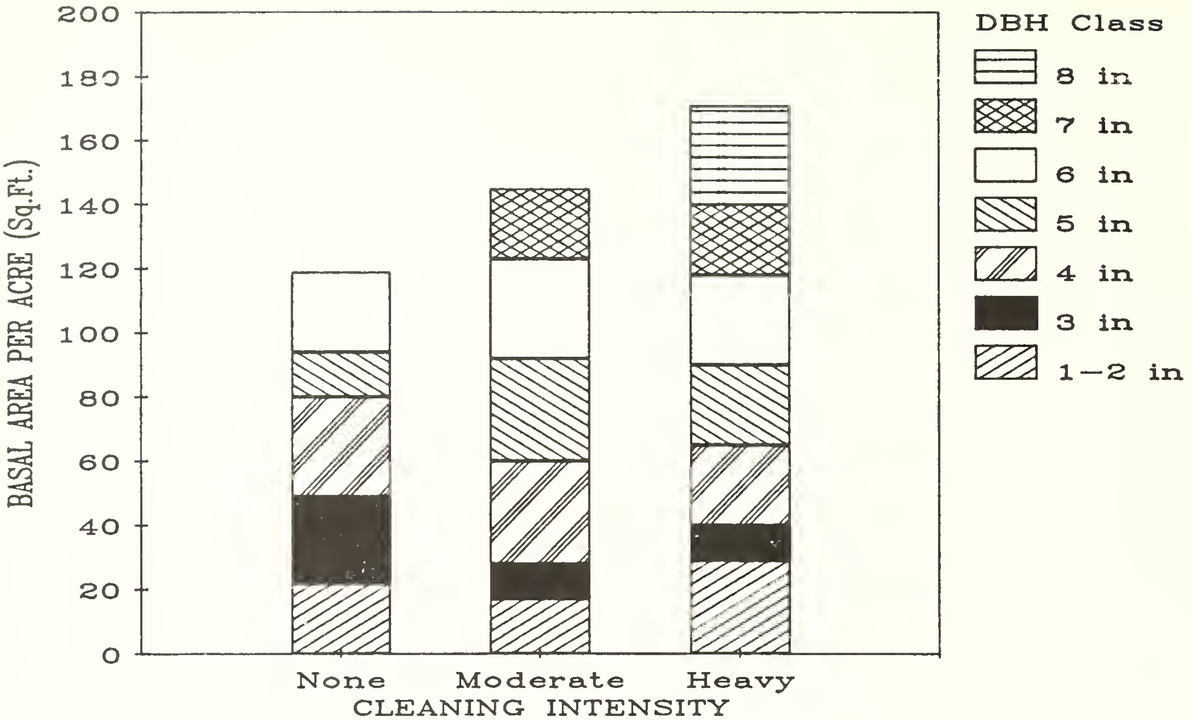

Figure 3—Effect of moderate and heavy cleanings on total basal area per acre of 38-year-old trees cleaned at age 8 years by 1-inch d.b.h. classes, in northern Idaho (Deitschman and Pfister 1973).

Table 1—Characteristics of western white pine growing at five spacings in north central Idaho[1]

Characteristic	Square spacings (ft)				
	5	7	10	14	20
	Age 13 years				
DBH-in[2]	1.4	1.0	1.5	1.7	1.3
BA-ft2	14.0	4.0	4.0	3.0	.8
HT-ft	9.0	7.0	8.0	9.0	7.0
DEN-tpa	1,462.0	697.0	396.0	194.0	97.0
VOL-ft3	91.0	23.0	30.0	17.0	5.0
	Age 18 years				
DBH-in	3.0	2.2	3.0	3.0	2.6
BA-ft2	47.0	18.0	17.0	9.0	4.0
HT-ft	14.0	12.0	14.0	15.0	12.0
DEN-tpa	1,462.0	697.0	393.0	194.0	97.0
VOL-ft3	398.0	144.0	159.0	89.0	32.0
	Age 24 years				
DBH-in	4.0	3.9	4.8	4.8	4.7
BA-ft2	100.0	53.0	48.0	28.0	12.0
HT-ft	24.0	22.0	26.0	28.0	24.0
DEN-tpa	1,378.0	649.0	387.0	188.0	93.0
VOL-ft3	1,400.0	692.0	724.0	431.0	164.0

[1]Study located on the Deception Creek Experimental Forest in north central Idaho. The study is on a good western white pine site on a north aspect with a hemlock/*Pachistima myrsinites* habitat type.

[2]Abbreviations: Diameter at breast height (DBH) in inches (in), basal area per acre in square feet (ft^2), height (HT) in feet (ft), density (DEN) in trees per acre (tpa), total tree volume per acre (VOL) in cubic feet (ft^3).

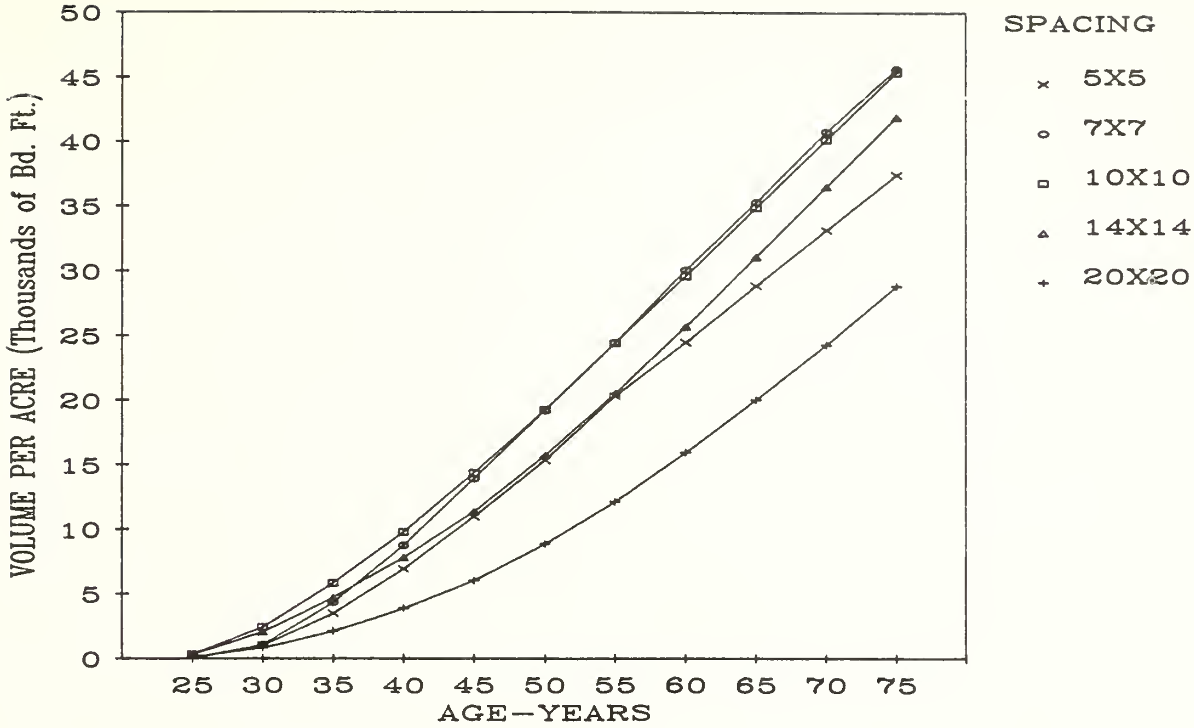

Figure 4—Stand projections of five different spacings of 24-year-old western white pine located on the Deception Creek Experimental Forest in northern Idaho. The Scribner board foot volumes (9-inch minimum d.b.h. and 8-inch top) were projected using the Prognosis Model 5.0 (Wykoff 1986).

Table 2—Characteristics of 20-year-old western redcedar and western hemlock growing at five spacings in western British Columbia[1] (Smith 1980)

	Square spacings (ft)				
Characteristic	**3**	**6**	**9**	**12**	**15**
	Western redcedar				
DBH-in[2]	3.7	5.4	7.1	6.0	7.5
HT-ft	32.0	35.0	38.0	33.0	36.0
CR-%	48.0	75.0	83.0	83.0	83.0
CW-ft	5.0	9.0	12.0	12.0	14.0
	Western hemlock				
DBH-in	3.4	3.8	4.5	6.1	5.5
HT-ft	32.0	35.0	32.0	35.0	34.0
CR-%	50.0	75.0	82.0	83.0	86.0
CW-ft	6.0	10.0	12.0	16.0	14.0

[1]Study located on a very good site in the University of British Columbia Research Forest near Haney, BC.
[2]Abbreviations: Diameter at breast height (DBH) in inches (in), height (HT) in feet (ft), crown ratio (CR) in percent (%), crown width (CW) in feet (ft).

spacings of 10 ft (3.05 m) appear to be optimum (fig. 4). However, spacings as narrow as 7 ft (2.13 m) may be preferred on some sites. These densities allow for good diameter growth, good volume production, and future thinnings.

Tree spacings near 10 ft (3.05 m) also appear to be well suited for young stands of western redcedar and western hemlock. Smith (1980) showed that on an excellent site in British Columbia spacings of 9 ft (2.74 m) were about minimum for 20-year-old trees (table 2). At spacings less than 9 ft (2.74 m), crown and diameter growth was affected; wider spacings probably sacrificed site productivity. Because such excellent growth rates occur in the stands, a thinning to 9-ft (2.74-m) spacings would be required to maintain optimum tree and stand development.

Ingrowth

Ingrowth from trees missed during cleaning or new seedlings in western hemlock or western redcedar habitat types can be high. It is not uncommon to have more trees per acre after cleaning than before (see Deitschman and Pfister 1973). Depending on the species, ingrowth can compete with crop trees for nutrients, water, and to some degree light. For example, in heavily cleaned stands western larch and lodgepole pine ingrowth can easily overtop western redcedar crop trees (Wellner 1946). In addition, root competition from ingrowth could impair crop tree development.

THINNINGS

Thinning trials were started in the Northern Rocky Mountains in 1914 on the Priest River Experimental Forest. Since that time several thinning studies have been established throughout the region, with many different methods of thinning in several different stand types. Many of these studies were unreplicated, but they offer valuable information on how stands respond to management.

The most common type is a thinning from below. The purpose is to release dominant crop trees and redistribute the growth to a select group of trees (Foiles 1955). If the stand to be thinned has been cleaned in the past, or developed naturally to densities at or below 1,000 trees per acre (2,471/ha) the impact of thinning from below on stand yields is minimal.

For example a thinning trial was established in a 60-year-old stand of western white pine, grand fir, western hemlock, and western redcedar containing approximately 1,000 trees per acre (2,471/ha). The stand was located on the Priest River Experimental Forest in northern Idaho, on a river bench in the Priest River drainage. It was a typical western white pine stand located on a good site. The stand was thinned from below favoring western white pine. Forty years after treatment, the light and moderately thinned stands showed only modest gains in board foot volumes compared to an unthinned stand (table 3). Likewise, crop tree diameters (100 tallest) did not differ greatly between the thinned and unthinned stands. Diameter increment of the crop trees was greatest in the heaviest thinning.

Multiple thinnings in a 55-year-old stand near the one described earlier also had little impact on total stand yield (table 4) (Foiles 1956). Crop trees in the unthinned stand had diameters similar to those in stands thinned 1, 2, or 3 times 40 years after treatment. Crop tree diameter growth was increased by the use of more than one thinning, thereby increasing tree sizes. But board foot and cubic foot yields remained similar in the thinned and unthinned stands. Light multiple thinnings may be very desirable in maintaining site productivity and increasing diameter growth, but 500 to 700 bd ft/acre removals in thinnings are not usually viable. A single thinning of 1,200 bd ft might be feasible.

Table 3—Thinning from below in a mixed stand[1] of western white pine, grand fir, western redcedar, and western larch favoring western white pine

Characteristic	Control	Thinning intensity		
		Light	Moderate	Heavy
	Age 60 years			
DEN-tpa[2]	1,024.0	554.0	404.0	318.0
BA-ft^2	183.0	145.0	109.0	85.0
VOL-ft^3	4,900.0	4,310.0	3,374.0	2,685.0
VOL-bf	11,270.0	12,540.0	11,220.0	9,494.0
DBH-in	10.1	10.2	9.4	8.7
	Age 70 years			
DEN-tpa	826.0	504.0	370.0	308.0
BA-ft^2	192.0	167.0	131.0	104.0
VOL-ft^3	6,036.0	5,680.0	4,559.0	3,575.0
VOL-bf	18,632.0	20,172.0	17,322.0	14,208.0
DBH-in	11.0	11.1	10.4	9.7
	Age 80 years			
DEN-tpa	652.0	454.0	334.0	290.0
BA-ft^2	204.0	192.0	153.0	126.0
VOL-ft^3	6,896.0	7,030.0	5,692.0	4,554.0
VOL-bf	24,380.0	27,698.0	23,220.0	19,514.0
DBH-in	11.9	12.1	11.3	10.9
	Age 90 years			
DEN-tpa	652.0	480.0	394.0	400.0
BA-ft^2	220.0	213.0	185.0	153.0
VOL-ft^3	7,976.0	8,317.0	7,401.0	5,928.0
VOL-bf	30,938.0	35,172.0	31,620.0	26,018.0
DBH-in	12.8	13.0	12.3	12.0
	Age 100 years			
DEN-tpa	584.0	470.0	378.0	406.0
BA-ft^2	224.0	221.0	204.0	171.0
VOL-ft^3	10,253.0	9,030.0	8,323.0	6,744.0
VOL-bf	38,292.0	39,156.0	36,760.0	30,176.0
DBH-in	13.5	13.7	13.1	13.0
MORT-tpa	564.0	186.0	126.0	74.0
YIELD-ft^3	10,253.0	11,144.0	10,745.0	9,400.0
YIELD-bf	38,292.0	43,862.0	40,690.0	37,016.0

[1]Study located on the Priest River Experimental Forest in northern Idaho. The stand is on a level bench in the Priest River drainage on a good western white pine site.

[2]Abbreviations: Density (DEN) in trees per acre (tpa), basal area per acre (BA) in square feet (ft^2), volume per acre (VOL) in cubic feet (ft^3) or Scribner board feet (bf), based on total tree height [western white pine 7.6 in d.b.h. and greater, other species 9.6 in d.b.h. and greater]. Diameter at breast height (DBH) in inches (in) based on the 100 tallest trees per acre, mortality (MORT) in trees per acre (tpa), total yields per acre (YIELD) in board or in cubic feet (ft^3). Yields include all thinnings minus any mortality.

Crown and selection thinnings are usually applied in stands that are nearing maturity (Foiles 1972). The purpose of crown thinnings is to release dominant and codominant trees; selection thinning is intended to release intermediate and codominant trees. A thinning study using these thinnings was established on the Clearwater National Forest in northern Idaho. The study was established in western redcedar and grand fir habitat types on

Table 4—Multiple thinnings in a 55-year-old mixed stand[1] of western white pine, grand fir, western redcedar, and western larch favoring western white pine

Charac-teristic	Control	Number of thinnings: Three		Two		One	
			Removal		Removal		Removal
			---- Age 55 years ----				
DEN-tpa[2]	1,068.0	550.0	1,274.0	454.0	798.0	316.0	1,068.0
BA-ft2	156.0	96.0	60.0	91.0	49.0	95.0	79.0
VOL-ft3	3,431.0	2,134.0	929.0	2,136.0	834.0	2,383.0	1,489.0
VOL-bf	4,414.0	2,014.0	516.0	1,810.0	702.0	3,448.0	1,200.0
DBH-in	8.8	7.7		7.8		8.8	
			---- Age 65 years ----				
DEN-tpa	924.0	390.0	138.0	424.0		300.0	
BA-ft2	178.0	111.0	19.0	123.0		119.0	
VOL-ft3	4,753.0	3,097.0	400.0	3,372.0		3,572.0	
VOL-bf	8,650.0	5,958.0	98.0	5,000.0		7,822.0	
DBH-in	9.9	9.1		9.1		9.9	
			---- Age 75 years ----				
DEN-tpa	772.0	258.0	124.0	268.0	142.0	274.0	
BA-ft2	190.0	108.0	29.0	106.0	40.0	134.0	
VOL-ft3	5,750.0	3,487.0	773.0	3,417.0	1,112.0	4,372.0	
VOL-bf	12,874.0	10,574.0	640.0	9,096.0	1,184.0	12,672.0	
DBH-in	10.7	10.2		10.1		10.8	
			---- Age 85 years ----				
DEN-tpa	690.0	252.0		256.0		272.0	
BA-ft2	217.0	136.0		130.0		154.0	
VOL-ft3	7,182.0	4,807.0		4,368.0		5,283.0	
VOL-bf	19,728.0	16,986.0		14,170.0		17,522.0	
DBH-in	11.6	11.7		11.7		11.5	
			---- Age 95 years ----				
DEN-tpa	574.0	238.0		248.0		256.0	
BA-ft2	226.0	161.0		155.0		176.0	
VOL-ft3	8,060.0	5,774.0		5,958.0		6,672.0	
VOL-bf	26,588.0	25,530.0		22,902.0		25,654.0	
DBH-in	12.1	13.0		12.8		12.4	
MORT-tpa	494.0	50.0		64.0		60.0	
YIELD-ft3	8,060.0	7,876.0		7,904.0		8,161.0	
YIELD-bf	26,588.0	26,784.0		24,788.0		26,854.0	

[1]Study located on the Priest River Experimental Forest in northern Idaho. The stand is on a level bench in the Priest River drainage on a good western white pine site.

[2]Abbreviations: Density (DEN) in trees per acre (tpa), basal area per acre (BA) in square feet (ft^2), volume per acre (VOL) in cubic feet (ft^3) or Scribner board feet (bf) based on total tree height, [western white pine 7.6 in d.b.h. and greater, other species 9.6 in d.b.h. and greater]. Diameter at breast height (DBH) in inches (in) based on the 100 tallest trees per acre, mortality (MORT) in trees per acre (tpa), total yields per acre (YIELD) in board or in cubic feet (ft^3). Yields include all thinnings minus any mortality.

an excellent western white pine site (see Foiles 1972 for further site description and study design).

The results of the study showed that light crown thinnings capture anticipated mortality and maintain volume production (table 5). Both types of thinnings increased annual diameter growth of both western white pine and grand fir, with grand fir having the better response. Both species in the moderate crown thinning had equally good diameter growth. By removing more larger trees, the selection thinnings had some large volume losses from mortality. These results show that light or moderate crown thinnings may be appropriate for increasing tree sizes prior to the final harvest.

Table 5—Crown and selection thinning in an 87-year-old mixed stand[1] of western white pine, grand fir, western redcedar, and western larch favoring western white pine and grand fir

Characteristic	Control	Crown Light	Crown Moderate	Selection Light	Selection Moderate
			Age 87 years		
DEN-tpa	208.0	156.0	106.0	142.0	160.0
BA-ft2	241.0	192.0	134.0	175.0	158.0
VOL-ft3	11,500.0	9,206.0	6,479.0	8,305.0	7,306.0
VOL-bf	59,440.0	47,998.0	33,919.0	42,645.0	35,681.0
DBH:WP-in	16.5	16.5	17.8	16.9	14.7
DBH:GF-in	11.4	12.6	12.2	13.3	10.1
			Age 92 years		
DEN-tpa	195.0	146.0	104.0	133.0	150.0
BA-ft2	249.0	200.0	141.0	182.0	158.0
VOL-ft3	12,000.0	9,600.0	6,850.0	8,750.0	7,350.0
VOL-bf	62,500.0	51,500.0	36,500.0	45,750.0	36,750.0
DBH:WP-in	17.7	17.9	19.4	17.4	15.1
DBH:GF-in	13.5	15.5	15.7	16.7	13.4
			Age 97 years		
DEN-tpa	187.0	140.0	98.0	131.0	143.0
BA-ft2	258.0	208.0	150.0	192.0	163.0
VOL-ft3	12,733.0	10,323.0	7,431.0	9,310.0	8,114.0
VOL-bf	66,500.0	55,750.0	40,000.0	49,750.0	40,500.0
DBH:WP-in	24.6	25.6	28.7	26.9	23.7
DBH:GF-in	16.1	18.9	19.9	20.8	17.4
MORT-bf	2,000.0	1,750.0	2,250.0	2,600.0	3,900.0
YIELD-ft3	12,733.0	12,414.0	11,451.0	11,329.0	11,501.0
YIELD-bf	66,500.0	65,894.0	58,524.0	60,993.0	58,984.0
			Annual Diameter Growth		
WP-in	0.808	0.912	1.093	1.004	0.898
% Inc		13.0	35.0	24.0	11.0
GF-in	0.942	1.265	1.538	1.486	1.454
% Inc		34.0	63.0	58.0	54.0

[1]Study located on the Clearwater National Forest in northern Idaho on an excellent western white pine site (see Foiles 1972 for further site description and study design).

[2]Abbreviations: Density (DEN) in trees per acre (tpa), basal area per acre (BA) in square feet (ft^2), volume per acre (VOL) in cubic feet (ft^3) of trees 5.6 d.b.h. and larger or Scribner board feet (bf) to a 6-inch (d.i.b.) of trees 7.6 in d.b.h. and greater. Diameter at breast height (DBH) in inches (in) of trees 5.6 in d.b.h. and larger, mortality (MORT) in board feet per acre (bf), total yields per acre (YIELD) in board or in cubic feet (ft^3). Percent increase in diameter growth compared to unthinned stand (% INC). White pine (WP), grand fir (GF). Yields include all thinnings minus any mortality.

DISCUSSION

The most important period in the life of either a plantation or a natural stand is between age 10 and 30 years. Prior to this time stand densities have minimal impact on tree development. During the 10- to 30-year period, species composition and future stand dynamics are largely determined. Past this age stand improvement can be accomplished only at high expense and at a heavy sacrifice in growing stock (Davis 1942). Western white pine over 30 years of age will respond to release, but the wide tree spacings required reduce stand yields (Deitschman 1966; Graham 1983; Ryker and Pfister 1967).

Grand fir has shown the ability to respond aggressively to cleanings and thinnings, but wounding that frequently occurs during treatments can provide entry points for stem diseases. Likewise, dying branches are entry points for some bole-rotting organisms (Ethridge and Craig 1976). Western redcedar can also respond favorably to management, but it develops best when not suppressed for long periods or when released slowly (Leaphart and Foiles 1972). Depending on crop tree species, the responses to cleaning on western redcedar and western hemlock habitat types can be negated by ingrowth, both from trees missed in cultural operations and from new seedlings.

It appears that the greatest benefit from thinning in mixed stands of western white pine and associates is improved stand and tree quality. Thinnings do not increase overall volume production, but they do increase value of stands by concentrating growth on fewer, selected, better quality trees.

Western white pine diameter growth increased after thinning, but not to the same magnitude as grand fir. In general, the greater the thinning intensity, the greater the response in diameter growth, but it appears frequent light thinnings increase diameter growth more than a single thinning.

Thinning from below and crown thinnings were effective treatments. Both thinning methods increased crop tree diameter growth. Choosing the best method to use for a particular thinning depends on the treatment required to correct a particular stand condition. If a change in composition is desired, a crown thinning would be preferable. If the crop trees are in a dominant position, a thinning from below will effectively increase tree growth and size.

In mixed stands thinning to capture anticipated mortality from white pine blister rust is a viable option. Thinning will not decrease the infection rate of blister rust (Hungerford and others 1982) but will raise the value of the final crop. If a thinning does not occur, natural mixed stands grow well at rather high densities. Not only is volume production high in dense stands, but development of individual trees in the dominant crown class is satisfactory.

Stands used in these thinning tests were beyond the age at which western white pine responds aggressively. Thinning at an earlier age is desirable, but most natural stands would not have sufficient volumes or tree sizes to be considered for thinning prior to age 50 years (Haig 1932). Likewise, using the Prognosis Model (Wykoff 1986) to thin the stands displayed in figure 4 to 60 percent of normal stocking density, the earliest removal of merchantable volume would occur in the 7-ft (2.13-m) spacing at 60 years of age. Therefore, it appears that thinning to optimize tree response is difficult in both well-spaced or natural stands. However, both now and in the near future, a premium will apparently be paid for large trees, thus making cleaning critical and thinning viable in most western white pine stands of the Northern Rocky Mountains.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (Anonymous)—In stands with substantial brush after harvest, when should thinning occur in mixed species stands of either natural or planted trees? Does brush negate thinning benefits?

A.—On hemlock habitat types shrub competition appears to have less impact on tree growth than on the cedar and grand fir habitat types. Therefore, a cleaning should occur preferably when dominance is expressed in the desired crop trees—usually near age 10 and before age 30 years. Shrub competition can impair tree development, especially on south slopes in the grand fir and cedar habitat types. Those stands in my experience would usually benefit from a weeding as well as a cleaning. Shrub competition could decrease tree response from cleanings, especially on the grand fir and cedar habitat types.

Q. (from Tom Levening)—Does growing white pine and other species at high densities have an effect on losses from insects and disease?

A.—In mixed stands of white pine and associates, insects are not usually a problem except for larch casebearer, which seems relatively independent of stand density. Mountain pine beetle can be active in white pine stands nearing maturity, and density may have a role in making trees more susceptible to attack by beetles. A similar response might be expected with Douglas-fir and the Douglas-fir beetle. It appears that changes in density may alter root disease patterns, especially with western redcedar. Western redcedar can be severely damaged by *Armillaria* spp. when released. Likewise dying branches on western hemlock and grand fir can be entry points for some bole-rotting organisms, when growing in dense stands.

Q. (from Dick Dezellem)—The stocking level left after thinning dictates a future treatment when the stand approaches maximum stocking levels. What stand development should we expect if we don't make this treatment? Should we expect stagnation?

A. —Western white pine stands will develop quite satisfactorily at very high densities. What we forgo if we do not clean young stands is the opportunity to mold species composition and increase tree and stand values. Because several species occur in the stands from shade intolerant to tolerant, stagnation, such as occurs in pure lodgepole pine, does not occur unless there is an unusual soil condition.

STAND DENSITY AND GROWTH OF INTERIOR DOUGLAS-FIR

James E. Lotan
Clinton E. Carlson
Jimmie D. Chew

ABSTRACT

Interior Douglas-fir is one of our most important timber-producing species and will benefit greatly from stocking control. It occurs in dense stands because it is relatively tolerant of shade and fills in where more intolerant species have not been able to capture a site. Published stocking guides do not exist for interior Douglas-fir. This paper discusses existing information as stand density and growth, showing how it can be used to formulate preliminary stocking level guides. Stand projection models, such as PROGNOSIS, are used to estimate effects of various stand densities. Preliminary stocking curves are presented for the Intermountain and Northern Regions, Forest Service, U.S. Department of Agriculture. A confounding influence in managing Douglas-fir in the Rocky Mountain West is the susceptibility to the western spruce budworm. Intermediate stand treatments such as thinning and weeding are effective in reducing damage by the spruce budworm.

INTRODUCTION

Stand density control is an integral part of intensive forest management. Traditionally, the objectives of controlling stand density are to redistribute growth onto fewer, more desirable trees and, as much as possible, capture merchantable material produced during a rotation, particularly suppression mortality that would occur if density is not controlled. Because the public demands more than wood from its forests, we need to extend the objectives of controlling stand density to more than the production of wood. We refer the reader to several papers in this proceedings that discuss effects of stand density on values other than wood production.

We suspect that in the future, control of stand density will become more common in our forests and will most likely be done as much to promote noncommodity values as to optimize the production of wood. In the Rocky Mountain West noncommodity values are becoming more important and are becoming the primary concern on many acres. Also, controlling stand density at less than optimum densities for wood production may be an important strategy in integrated pest management. On those areas dedicated primarily to the production of timber, it will be increasingly important to control stand density to optimize production of usable products. At any rate, controlling density requires that we know what we want from a stand. This is true whether we want wood, forage, water, or a biologically sound strategy to cope with serious insect infestations.

Interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) is one of the most important timber-producing species in the Rocky Mountain West. More than 12 million acres of Douglas-fir are widely distributed throughout the Rocky Mountains (Green and Van Hooser 1983). Douglas-fir leads all species in annual volume harvested in the Northern Region, Forest Service, U.S. Department of Agriculture.

Interior Douglas-fir occurs on a wide variety of sites and ecological situations. The Douglas-fir type occupies the area immediately above the ponderosa pine zone and below the spruce-fir type. In some areas it is seral to grand fir, western redcedar, western hemlock, and even subalpine fir, and in some areas it is climax. (The only species present on Douglas-fir habitat types are western larch, lodgepole pine, and pondersosa pine.) Although regeneration is sporadic, the species commonly occurs in dense thickets because it is relatively tolerant of shade and fills in where more intolerant species have been excluded and where seral ponderosa pine or western larch have been logged and have not been able to regenerate. Thus, past management practices have established conditions that have favored dense stands of the more tolerant Douglas-fir. In some cases stand densities are so high that growth of usable material is well below the potential for the site and stands are quite susceptible to infestation by insects such as the spruce budworm (Carlson and others 1985b). Much can be gained by controlling stand density.

Published guides are not generally available to the practicing forester interested in managing these stands; yet they are needed to select appropriate stocking levels, to determine appropriate thinning schedules, and to predict consequences of these decisions. We need to know not only how much stocking a stand can biologically carry, but how much it should carry to meet different management objectives. Studies have not been conducted in interior Douglas-fir stands to provide this knowledge.

In the absence of study results or generally applicable guidelines, we attempt in this paper to assemble existing information on stand density and growth and show how it can be used to formulate preliminary guides for making decisions on stocking levels. We discuss different concepts of stocking and how available information on the effects of stand density can be developed into useful guides. Manipulation of stand density can also reduce problems from western spruce budworms infestations, a major consideration in management of interior Douglas-fir.

CONCEPTS AND DETERMINATION OF STOCKING LEVELS

Although we can state the problem in fairly simple terms—"room to grow and none to spare"—it is exceedingly complex to determine appropriate levels of growing stock that consider all the biological, technological, and economic factors. We normally use some index of growing stock that uses an expression of mean size of trees compared to a measure of stand density. These indices have been compared and discussed elsewhere (Curtis 1970; Long 1985; Long and Smith 1984) and have been reviewed by others at this symposium. In fact, the Forest Service has been working on the development of stocking charts for all major species occurring on National Forest lands. The standardization of concepts and terminology of stocking and stand density used in this effort is discussed by Ernst and Knapp (1985) and by Nelson Loftus and Susan Stout at this symposium.

Most of us are familiar with the principles of the German forester, Möller (1946, 1947), who taught that within a wide range of density of stocking, growth of basal area tends to remain constant. Further, we often use total cubic volume of stem wood as an index of total wood produced in a stand. This cubic volume is largely a function of basal area and height. Langsaeter's curve (1941) illustrates periodic annual increment per acre of cubic volume as a function of total cubic volume of growing stock (fig. 1). The manager's problem in using this curve to determine desirable stocking levels is that of defining the transition points at both ends of Zone III densities and to determine within these limits the level of stocking needed to meet management objectives. If stocking levels are selected for other than timber objectives beyond the limits of Langsaeter's Zone III densities, then the amount of wood production forgone can be quantified and identified as a tradeoff in managing for other resource values.

Yet, without well designed growing stock level studies and an army of pre-Gramm-Rudman-Hollings foresters, how do we find the upper and lower boundaries of Langsaeter's Zone III for stands of interior Douglas-fir? Without long-term permanent studies we must rely on growth-forecasting models such as PROGNOSIS (Stage 1973; Wykoff and others 1982). These models can be used to estimate consequences of different management strategies. That is the approach taken by Chew, one of the authors of this paper, for the Northern Region of the Forest Service—as discussed in a later section of this paper.

The relation between average size and density in populations limited by growth and suppression mortality appears to be fairly constant and is commonly referred to as the self-thinning rule (Perry 1984; White 1980; Yoda and others 1963). This relationship is commonly expressed:

$$TS = C - SD^{1.6}$$

where

TS = mean tree size; quadratic mean diameter

C = constant

SD = stand density; trees per acre.

The exponent has been viewed as fairly constant for all plant life and has been called the first basic law in ecology. There is evidence, however, that it varies by tree species, with higher values for intolerant species; for example, 1.5 for tolerant oaks compared to 1.9 for intolerant loblolly pine (Zeide 1985). And we must remember that the value is an exponent with small differences having great consequences.

Reineke's (1933) stand density index is a reflection of the average size-density relationship and is commonly plotted as a straight line on a log-log scale. The value of the self-thinning concept and Reineke's use of it is that they provide easily determined reference lines for biological upper limits of stocking. We then need to determine appropriate upper and lower management levels within which we can manipulate stocking levels for different management

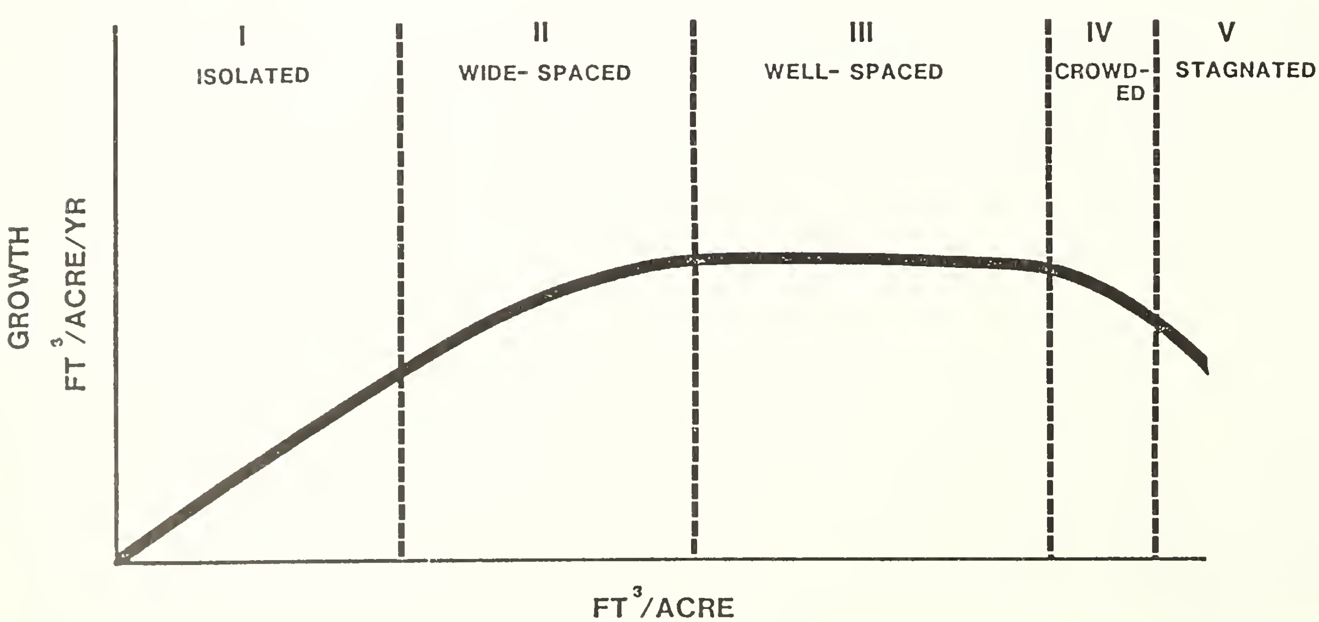


Figure 1—The relationship of periodic annual increment per acre of cubic volume as a function of total cubic volume of growing stock similar to Langsaeter (1941). In the range of stocking in Zone III, incremental growth is for the most part independent of stocking.

objectives. Within this band of stocking, we can trade some tolerable loss in total cubic volume production for a greater amount of merchantable volume and larger diameters. The upper bound is a stocking level above which production is lost due to excessive mortality or pathological damage; the lower bound is the lowest density where trees are just barely competing with one another—often considered to be somewhere near crown closure. Above the upper level is in Langsaeter's Zone IV and below the lower bound is in his Zone II.

A cooperative levels-of-growing-stock study in coast Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) has been ongoing for about 20 years (Curtis and Marshall 1986). Although the study has not been completed, 20-year results are available. In this study, growth is strongly related to growing stock. This study was designed, however, to quantify relationships in the rising portion of Langsaeter's curve, Density Zone II. They did, in fact, find a near-constant basal area growth over a wide range of densities, but gross volume increment curves were steep. This occurred partly because coast Douglas-fir sustains rapid height growth over long periods, which sustains volume growth. Therefore relatively high stand density was required for high gross cubic volume production. These studies have shown, however, that thinned plots have increasingly greater growth in merchantable volume and diameters. Thinned trees also grow to merchantable sizes sooner than unthinned trees. The value of this study to managers of interior Douglas-fir is debatable, however, because of possible differences in genetics, site, and ecological situations between the two varieties.

Despite this and because of the feeling that the two varieties respond similarly to specific environments, foresters with the Intermountain Region of the Forest Service have developed a general stocking curve for interior Douglas-fir using data from coast Douglas-fir (Hamilton 1986; McArdle and others 1961). They chose Reineke's Stand Density Index (SDI) to establish the following values: average maximum density limits (AMD) with an SDI=370, an Upper Level Management Zone (ULMZ) with an SDI=240, and a Lower Level Management Zone (LLMZ) with an SDI=149 for even-aged or storied stands. Information is then presented in a format similar to Gingrich (1967) and as suggested by Ernst and Knapp (1985) (fig. 2). In preliminary work on this paper we found that their AMD line plotted in the middle of a set of AMD lines for different habitat type groups for western Montana. There appears to be some justification for the Intermountain Region's use of this curve even though we do not have data for verification for interior Douglas-fir. We did not include all of the western Montana curves in this paper because data were missing for diameters over 10 inches. We included a sample in the section below where we discuss the Northern Region approach. The Intermountain curve at this time is a good reference point or first approximation stocking curve for that area.

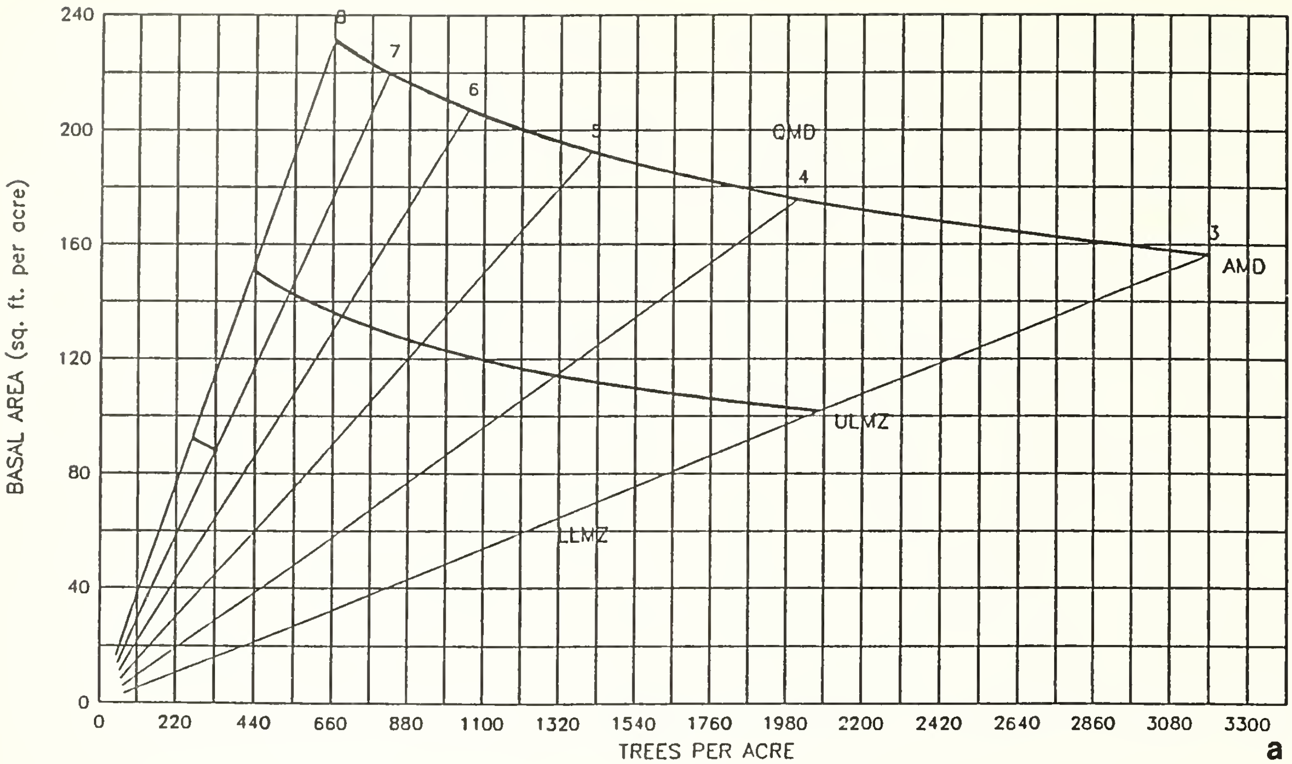
The Northern Region's approach to developing stocking guides is also based on the concept of maximum size-density relationship. Inventory data are used to determine a level of maximum density by habitat type group (Pfister and others 1977) and geographic location (groups of National Forests). This average maximum density is observed in what are considered undisturbed stands of the same type and size, called "normal stands" in older yield table publications. Stands cannot be held at this upper limit; it is the boundary between Langsaeter's Zone III and Zone IV. Stands at the average maximum density level will experience mortality and trend downward in density. Stands below this level will trend upward in density.

The first step in the Northern Region procedure is to screen inventory data (Northern Region edit tapes) for appropriate stands. Data are stratified by habitat type group and by four geographic areas: eastern Montana, western Montana, northern Idaho, and the Nez Perce National Forest. They identify even-aged stands by sorting stories or canopy layers that they feel can be accepted as even-aged and age classes within stands. During the preliminary work, species were not sorted, except lodgepole pine. For the final version stands with greater than 80 percent basal area of managed species are being selected. Trees less than 1 inch d.b.h. are also eliminated from the tree records.

For selected stands, basal area versus quadratic mean diameters (QMD's) is plotted. Those stands that lay in the upper 10 percent of stand densities for each diameter class are then selected as the upper bound for the data set. Trees per acre (TPA) are plotted versus QMD's; SDI for the data set is then plotted on the graph as the upper biological limit or density of maximum tree size in a manner similar to the Intermountain Region. For the final version of the curves, the upper 10 percent will be identified by first calculating an SDI for each stand assuming a slope of -1.6 (SDI's) similar to Reineke (1933).

Development of density management zones is based on identifying a range of stocking levels within which specific stand attributes can be achieved that meet management objectives. For maximizing timber production, volume production is the attribute selected. To identify a range of stocking levels, comparisons of yields achieved from simulated stands of varying stand density levels is made for a specified rotation age. Selecting those stands that are at or near the maximum density line, different density levels are simulated using the THINBBA keyword in the PROGNOSIS simulator (Stage 1973; Wykoff 1986; Wykoff and others 1982). Each stand is simulated several times, first with no change in stand density, and then for each incremental 20-ft^2 reduction in residual basal area. Each projection is run with enough cycles to compare stand volumes from 80 to 120 years. The actual age at which the comparison is made corresponds to the rotation age desired. The upper level of the management zone for maximizing timber production is that stocking level at which the maximum volume production is achieved by the specified rotation age. The lower level of the management zone is identified as the stocking level that will produce 90 percent of the maximum volume production by the specified rotation age. Stands across the full range of QMD's are simulated to provide curves of the upper and lower levels of the management zone. Thinning regimes are then selected within these bounds for whatever target stand is desired.

Using the above approach, preliminary stocking curves have been completed. Figure 3 is an example of those developed by the Northern Region of the Forest Service. Upper reference limits of the stocking curves have been established, and tentative management zones are being established as guides to maintaining stands at optimum



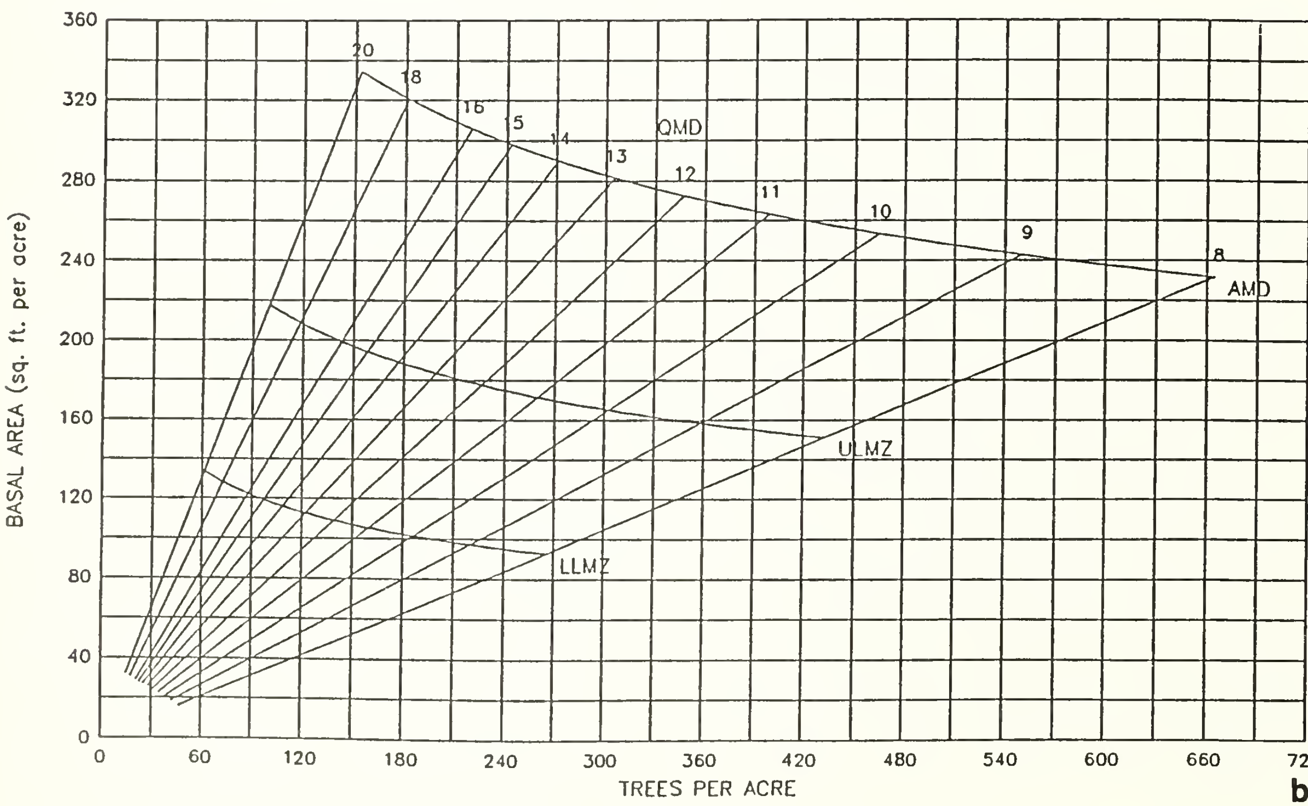


Figure 2—Stocking chart in Gingrich-type format for interior Douglas-fir in the Intermountain Region of the Forest Service. QMD is quadratic mean diameter (diameter of tree of average basal area), AMD is average maximum diameter, ULMZ is the upper level of the management zone, LLMZ is the lower level of the management zone. Figure 2a is for QMD's of 3 to 8 inches; figure 2b is for QMD's of from 8 to 20 inches. The absence of a lower level management zone for 3 to 7 inches is because the Intermountain Region has a minimum stocking standard of 300 trees per acre for small trees. This chart is based on data from coast Douglas-fir as described in the text.

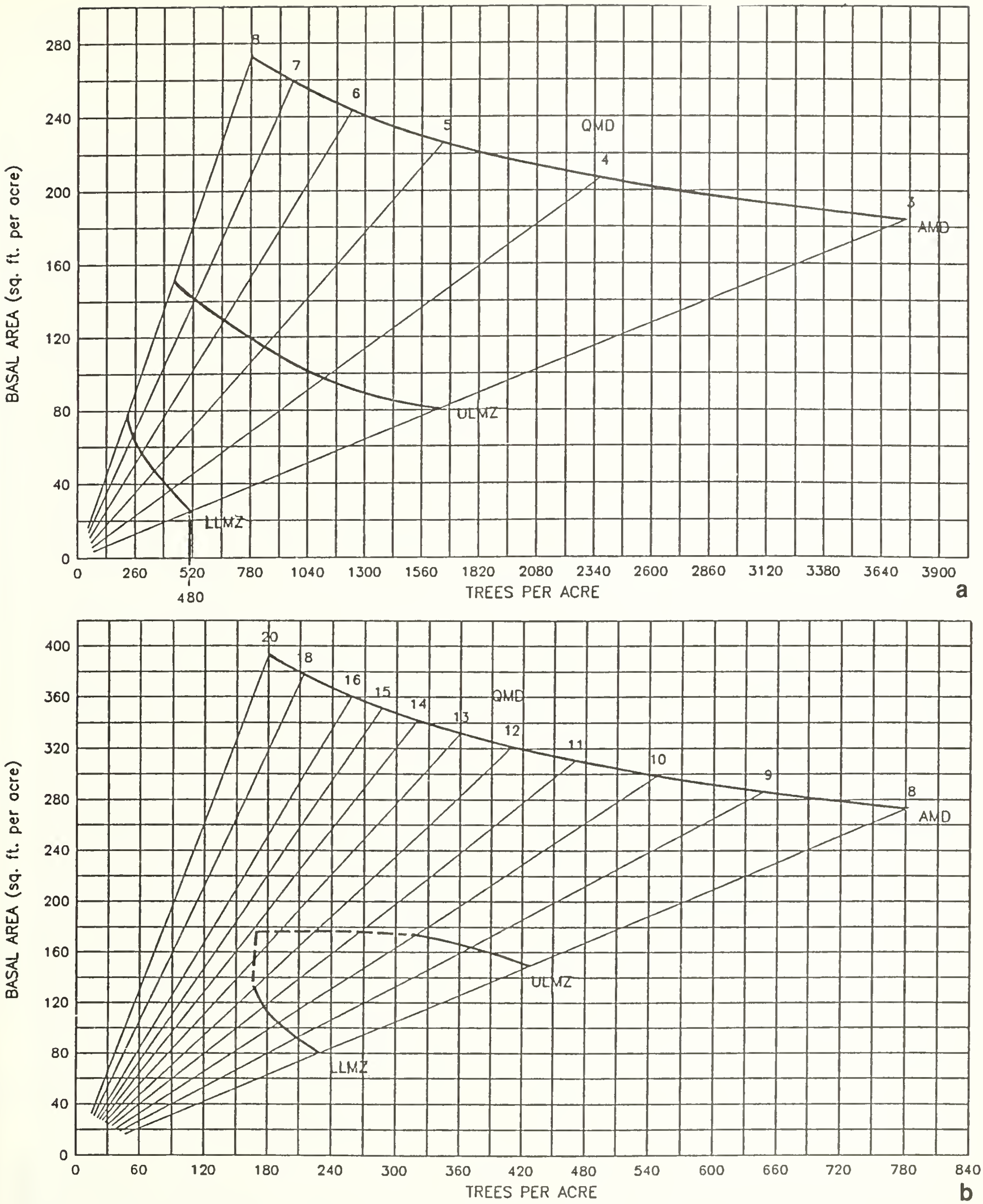


Figure 3—A sample stocking chart in Gingrich-type format for interior Douglas-fir in the Northern Region of the Forest Service. QMD is quadratic mean diameter (diameter of tree of average basal area), AMD is average maximum diameter, ULMZ is the upper level of the management zone, LLMZ is the lower level of the management zone. Figure 3a is for QMD's of 3 to 8 inches; figure 3b is for QMD's of from 8 to 20 inches. The upper and lower level management zone curves converge because the Northern Region defines management objectives such that when QMD's get larger than 10 to 12 inches stands would be harvested. This chart was developed as described in the text for the Northern Region.

stocking levels. Based on a review of efforts to develop stocking curves by each region within the Forest Service, changes are being made in procedures based on the corporate experience of the early trials. Final curves are now being constructed and should be available soon.

STAND DENSITY AND THE SPRUCE BUDWORM PROBLEM

A confounding influence in managing stand density in Douglas-fir in the Rocky Mountain West is the susceptibility of these stands to the western spruce budworm. Repeated defoliation by the insect reduces radial and height growth and often results in top-kill or tree mortality, particularly in young trees in the understory. In addition, cone and seed production are seriously reduced and establishment of regeneration is seriously delayed. Young trees in the understory in unmanaged stands are particularly vulnerable because larvae disperse from the overstory and drop to feed on the trees below. A more complete discussion on this problem may be found in a companion paper, "Using Stand Culture Techniques Against Defoliating Insects," by Carlson and Lotan, elsewhere in this proceedings.

We discuss the problem here to point out the effects of stand density on budworm population and to emphasize the importance of controlling stand density as a strategy in controlling the insect. High densities seem to increase the susceptibility of the stand to spruce budworm infestation (Carlson and others 1985b); controlling stand density may be most effective in reducing damage by the spruce budworm. Stocking control can facilitate rapid growth of individual trees and permit selection of genetically superior trees that discourage defoliating insects. Thus, stocking control may be as important as a management strategy for controlling insect infestations as it is for management of tree size for particular timber products.

Dense stands of host species provide more crown volume for egg deposition and many rough-barked tree boles needed for survival of overwintering larvae. In dense stands larvae are more likely to land on a favorable substrate. Reducing stand density lessens stand susceptibility and the opportunity for larvae to survive. Carlson and others (1985a) measured greatly reduced defoliation and twice the radial growth on residual host trees in a Douglas-fir stand thinned to 14 by 14 ft (4.2 by 4.2 m) or about 220 trees per acre compared to trees in an adjacent unthinned stands.

The flight behavior of adult western spruce budworm also appears to be related to stand density (Fellin 1981). Fellin caught fewer adult male moths in pheromone-baited traps in low stand densities than in high stand densities.

Immature stands probably offer the best opportunity to use stand density control to develop stands less susceptible to the spruce budworm. Immature trees are still growing at a rapid rate, seral species in the stand have not yet been shaded out, and insects have not yet become a problem. Silvicultural objectives should include: targeting stands that provide the least hospitable environment for the spruce budworm; maintaining vigorous stands so that even if they become infested, they can survive and recover rapidly; and favoring natural resistance of species and individual trees.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Dennis R. Parent)—Langsaeter's curve was developed in Europe. Is it . . . relevant for western conifers where height growth generally continues regardless of density; such as in the Douglas-fir LOGS study, Russ Graham's data?

A.—Yes and no! The flat part of Langsaeter's curve is a reflection of total cubic volume being distributed over numbers of trees per acre where we can have more small diameter trees or fewer large diameter trees and still have about the same cubic volume. Both thinning studies and our growth projection models generally show this. Generally speaking, Langsaeter's curve is a good model or reference point for pure, even-aged stands in North America. It is particularly relevant to the lodgepole pine stands that I have encountered over the years and, no doubt, to most of our western conifers. Mike Cole has shown this over and over again in the case of lodgepole pine. But, of course, exceptions occur and so we can say that no, it isn't perfectly relevant.

If height growth is affected by density (beyond CCF of 125 for lodgepole pine, for example), then of course the curve isn't flat because we are not dealing with the flat part of the curve, but out into Density Zone IV where competition is affecting growing stock. The LOGS study in coast Douglas-fir was designed by Staebler to measure Zone II responses, so I do not feel that it makes Langsaeter's curve irrelevant. In the case of Russ Graham's data, I would have to look at his data closer. When we get into mixed species and uneven-aged interrelationships (such as the physiology of different shade-tolerant species, or photosynthetic efficiencies), I think we might have a new ball game.

Q. (from Gordon F. Weetman)—Do you know if anyone is trying to develop the -3/2 self-thinning stand density management diagram for interior Douglas-fir equivalent to the coastal Douglas-fir diagram?

A.—At the podium I said, "No, I do not know of anyone." Since then, I have found out that Robert Monserud, Research Forester, Quantitative Analysis Research Project at the Forestry Sciences Lab in Moscow, ID, is developing one. This should be published as an Intermountain Research Station Research Note in the near future.

Q. (from Don Banks)—What effect on spruce budworm does stand density have in interior Douglas-fir?

A.—Low stand densities provide less favorable habitat for the spruce budworm than the typical Douglas-fir thickets that are prevalent in our country today. These stand conditions are thought to be the result of previous high grading of seral species such as ponderosa pine and larch and significant decreases of area burned by wildfires. This means that in this case, good silviculture is also good pest management. This question is further covered in the text in the proceedings and in the companion paper by Carlson and Lotan in this proceedings.

GROWTH AND YIELD OF SPRUCE IN THE INLAND MOUNTAIN WEST: A LITERATURE REVIEW

Guy Larocque
Peter L. Marshall

ABSTRACT

*This paper contains a compilation of the literature available on the growth and yield of the spruce species found in the Inland Mountain West of the United States and Canada. With the exception of Engelmann spruce (*Picea engelmannii *Parry), little information was found on the growth of natural stands of these species within this region. Almost no information was located on the effect of density on the development of managed stands. The necessity of maintaining existing spacing studies and implementing new trials is noted.*

INTRODUCTION

Four species of spruce are found growing naturally in the Inland Mountain West region of Canada and the United States: Engelmann spruce (*Picea engelmannii* Parry), white spruce (*P. glauca* [Moench] Voss), black spruce (*P. mariana* [Mill.] B.S.P.), and blue spruce (*P. pungens* Engelm.). This paper provides a brief overview of the distribution and silvics of each of these species and lists available information sources on their growth and development. An attempt was made to include as many published references as possible on the effect of stand density on tree and stand development.

ENGELMANN SPRUCE

Engelmann spruce grows naturally in the Rocky Mountain area of North America from Yukon Territory to Mexico (Betts 1945). In Canada, it is found in the southern and central mountainous areas of British Columbia and along the east side of the Rocky Mountains in Alberta (Smith 1950). Although it grows on various sites, its best productivity occurs on deep, rich, moist loams along streams (Hosie 1969). According to Smith (1950), optimum conditions for the growth of this species are found in the southern region of British Columbia. Usual elevations are between 3,000 and 6,000 ft (900 and 1,800 m)(Hosie 1969; Smith 1950). As the altitude increases, the reduction in growing season affects both the growth rate and the taper (Smith 1950). In the United States, Engelmann spruce colonizes the highest and coldest forest sites of the nine western States (Alexander 1958; Fowells 1965). It may be found growing at elevations as high as 9,000 to 12,000 ft (2,700 to 3,750 m) in the southwestern portion of its range (Betts 1945).

Engelmann spruce is shade-tolerant and interbreeds with white spruce (Hosie 1969). It may grow in pure stands but is normally associated with hemlocks (*Tsuga* spp.), larches (*Larix* spp.), firs (*Abies* spp.), and pines (*Pinus* spp.)(Hosie 1969). It forms the climax vegetation at high elevations with alpine fir (*Abies lasiocarpa* [Hoss.] Nutt.)(Weetman 1979). Development of stands of Engelmann spruce and associated species has been described by Barnes (1937), Fraser and Alexander (1949), and Hanley and others (1975).

The range of maximum diameter for Engelmann spruce is normally between 1 and 3 ft (30 and 90 cm), and maximum height is normally between 100 and 120 ft (30 and 37 m)(Hosie 1969). Smith (1950) indicated that diameter growth at old ages may reach 4 inches (10 cm) per 10 years on rich sites and 0.3 inches (0.8 cm) per 10 years on poor sites. Generally speaking, it may be considered a slow-growing species. More detailed growth and yield information may be found in Alexander (1958), Betts (1945), Embry and Gottfried (1971a, 1971b), Goudie (1980), Smith and Kozak (1981), Smith and Yang (1982), Stettler (1958), and Vankka (1983).

Arlidge (1955) compared the growth of two Engelmann spruce-alpine fir associations. Stanek (1966a, 1966b) made further detailed growth comparisons of Engelmann spruce associations along with other species growing in the interior of British Columbia. Yield tables for even-aged stands of spruce-fir under management in the central Rocky Mountains have been prepared by Alexander and others (1975). Viszlai (1983) prepared variable density yield projection equations for pure stands in British Columbia that include equations for Engelmann spruce. Smith (1977) included interior spruce in his study of yield estimates and preliminary curves for spacing and thinning of British Columbia forests. Site index curves were developed by Alexander (1967) for the central Rocky Mountains, by Brickell (1966, 1970) for the central and northern Rocky Mountains, and by Hegyi and others (1979) for British Columbia. Diameter and basal area distribution of uneven-aged stands of Engelmann spruce may be found in Alexander (1985). The effect of different silvicultural treatments on old-growth spruce-fir stands is documented by Alexander (1963).

According to Alexander (1974) and Alexander and Edminster (1980), the diameter growth of Engelmann spruce is very sensitive to stand density. The response in diameter growth after release depends on initial diameter, tree vigor, and number of competitors. Following the establishment of 556 sample points in Arizona, Gottfried (1978) observed that periodic annual basal area increment per acre increased with diameter between d.b.h. size classes of 2 and 12 inches (5 and 30 cm) and decreased with diameter between d.b.h. size classes of 12 and 32 inches (30 and 86 cm). He also observed that height growth remained unaffected by the degree of crowding over a broad range of stand densities.

Only one spacing trial was found in the literature, that of Seidel (1984). This study involved an even-aged stand of Engelmann spruce and western larch (*Larix occidentalis* Nutt.) in Oregon. A thinning treatment at age 10 (1971) resulted in residual spacings of 9 by 9 ft (2.7 by 2.7 m) and 15 by 15 ft (4.6 by 4.6 m). Measurement values obtained in 1971, 1976, and 1981 are reported. The results show that diameter growth increases with spacing, whereas higher values of basal area and total volume are found at the narrower spacing. Height growth was not significantly affected by stand density. Some of the spruce plantations established in the interior of British Columbia between 1968 and 1977 (Vyse 1981) could conceivably be converted into spacing studies if sufficient funding could be found.

A number of growth models have been documented in the literature as being calibrated for Engelmann spruce. RMYLD (Alexander and Edminster 1980; Edminster 1978) is a whole stand model (according to the classification of Munro [1974]) and has been used to derive growth models for this species. This program superseded a number of earlier programs including TEVAP2 (Alexander and others 1975). Finally, Prognosis (Stage 1973, 1975; Wykoff and others 1982) is a single-tree, distance-independent growth model that can also be used.

WHITE SPRUCE

White spruce grows in a wide range of soil and climatic conditions, and its area of distribution covers almost all of Canada (Hosie 1969). In British Columbia, it is found in the central interior region (Eis and others 1982). It also is common in the States of Minnesota, Wisconsin, Michigan, New York, and Maine; some "outlying populations" exist in South Dakota, Montana, and Wyoming (Fowells 1965). Its best growth is on well-drained, moist, silty soils (Hosie 1969). This species rarely grows alone, and it is usually found in association with trembling aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), black spruce, balsam fir (*Abies balsamea* [L.] Mill.), and Engelmann spruce. White spruce may achieve heights of 80 ft (24 m) and diameters of 2 ft (61 cm).

Yield information for pure white spruce stands is scarce because of the tendency of this species to be found in mixed stands under natural conditions and because white spruce has not been widely planted in the past. Plonski (1974) provided information on black spruce-white spruce mixtures in Ontario but only for very good sites. Stiell and Berry (1967, 1973) provided yield information for white spruce plantations based on data from remeasured plots at the Petawawa National Forestry Institute in Ontario. A number of studies exist on the dynamics of mixed forests in northeastern North America in which white spruce is a component.

Few studies of the growth of white spruce in the western portion of North America could be found. Notable exceptions include the work by Vyse (1981) and Eis and others (1982). The former paper documents the early development of a number of white spruce, Engelmann spruce, and hybrid plantations in the interior of British Columbia. The latter paper contains a comparison of the growth of white spruce stands on three common sites also in the interior of British Columbia.

The most important stand density effect study that was found consisted of spacing trials established at the Petawawa National Forestry Institute in Ontario (Berry 1978; Stiell and Berry 1967, 1973). Stand ages ranged from 30 to 60 years and spacings from 4 by 4 ft (1.2 by 1.2 m) to 10 by 10 ft (3.0 by 3.0 m). Growth on the study plots has been monitored for some time. Results to date indicate that diameter growth increases with spacing, total volume is highest at the narrowest spacing, and merchantable volume is highest at the widest spacing. This data set was also used by Alemdag (1978) to test the predictive ability of several competition indexes.

Two growth models calibrated for white spruce are documented in the literature. TASS (Mitchell 1969) is a single-tree, distance-dependent model that was originally developed from white spruce data from Ontario and British Columbia. STEMS (Belcher 1981; Belcher and others 1982; Holdaway 1984; U.S. Department of Agriculture 1979) is a single-tree, distance-independent growth model developed with data from the northern States where white spruce is found.

The yield tables and growth models developed using eastern data could be used to provide reasonable approximate yields in this region until locally calibrated tables or models are available. Alternatively, Engelmann spruce growth and yield information could be used until more information is available. This seems reasonable since the two species interbreed and are difficult to distinguish in areas where their ranges overlap.

BLACK SPRUCE

Black spruce is distributed widely across Canada. In British Columbia it is found in the northern interior portion of the province (Hosie 1969). It is also found in several of the northern States, including Minnesota, Michigan, Pennsylvania, Maine, and New York (Fowells 1965). This species may be found growing in various soil and climatic regimes, but it generally colonizes sphagnum bogs in the southern portion of its range and well-drained soils in the north (Hosie 1969).

Black spruce is of great commercial importance in the eastern part of Canada. Consequently, several yield tables have been produced covering this portion of its range. These include the tables produced by Boudoux (1978) and Vezina and Linteau (1968) for Quebec and by Plonski (1974) for Ontario. According to Heger and Lowry (1971), Plonski's tables could be applied to stands from Newfoundland to Saskatchewan. Evert and Lowry (1971) made growth predictions using stand volume relationships.

Studies on the effect of density on the growth and yield of black spruce are scarce. Evert (1970) conducted a survey of black spruce stands characterized by different conditions of density and site. He observed that as stand density increased for a given site quality, basal area and total volume increased, average diameter decreased, and mean height did not vary significantly for the different densities. When only merchantable trees were measured, it was found that average diameter and total volume did not vary with stand density.

Four growth models are documented as being calibrated for black spruce. The models of Evert (1972) and Ung and others (1978)(DYPEUFOR) can be classified as whole stand models. FOREST (Ek and Monserud 1974) is a single-tree, distance-dependent model. STEMS (previously mentioned for white spruce) is also calibrated for black spruce.

BLUE SPRUCE

Blue spruce is found in the western mountainous region of the United States, where it colonizes mountain slopes, usually along streams (Brockman 1968; Fowells 1965). It usually grows at altitudes of between 6,000 and 8,500 ft (1,800 and 2,600 m) but may be found up to 10,000 ft (3,000 m). It is usually found growing in association with other species. Blue spruce may reach a maximum height of 80 to 100 ft (24 to 30 m) and a maximum diameter of 1 to 2 ft (30 to 60 cm)(Grimm 1967).

The growth of this species does not appear to have been much studied; however, basal area growth information and relationships between height and diameter for stands located in Arizona may be found in Embry and Gottfried (1971a, 1971b). The development of an uneven-aged mixed conifer stand containing some blue spruce was followed by Gottfried (1978). He observed that, for blue spruce, the periodic annual basal area growth per acre increased for trees within the range of 2 to 4 inches (5 to 10 cm) in diameter and decreased for trees from 16 to 22 inches (41 to 56 cm) in diameter.

CONCLUSIONS

With the possible exception of Engelmann spruce, the growth and yield of natural stands containing spruce in the Inland Mountain West have not been widely studied. White and black spruce are widely distributed outside this region, and information from other areas could be used until local data are available. Blue spruce is not of major commercial importance. Little information, within this region or outside it, is available from spacing and thinning studies. Because spruce is an important component of the forest in many areas of the Inland Mountain West, such information is necessary if spruce is to be more intensively managed in the future. The results of density control studies are most valuable after several remeasurement periods, so maintenance of existing studies should have a high priority. New studies encompassing a wider range of spacing and thinning regimes need to be established in the near future in anticipation of future management information requirements.

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GROWTH RATES FOR MANAGED STANDS OF WHITE FIR

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ABSTRACT

*White fir (*Abies concolor*) stands thinned from below display a great capacity to produce wood. Stands at stocking levels of 75, 50, and 25 percent of "normal" density can produce 93, 80, and 53 percent of the gross periodic annual cubic volume increment of fully stocked stands. Stands at densities of 75, 50, and 25 percent of "normal" can produce 96, 87, and 62 percent of the gross periodic annual basal area increment at full stocking.*

INTRODUCTION

White fir (*Abies concolor* [Gord. & Glend.] Lindl.) occurs in pure stands and also is an important component of the mixed conifer stands of northern California, Oregon, and parts of Washington. White fir hybridizes with grand fir (*Abies grandis* [Dougl.] Lindl.) west of the study area in California (Hamrick and Libby 1972) and an *Abies grandis—A. concolor* species complex is recognized in the central Oregon Cascade Range (Zobel 1973). Many of the trees in Oregon and Washington, which are referred to locally as white or grand fir, display characteristics of both species. In our studies no attempt was made to separate species or their hybrids. Data were handled as if all study trees were one species.

In the absence of disease and insect problems, fully stocked stands of these firs are capable of producing more gross volume per acre than all associated species except red firs (*A. magnifica* Murr. and *A. magnifica* Murr. var. *shastensis* Lemm.) on comparable sites. Gross yields of fully stocked even-aged stands of white or grand fir east of the Cascades in Oregon and Washington have been investigated (Cochran 1979b). Stocking levels between 50 and 75 percent of "normal" have been suggested for managed stands of commercial size (Cochran 1983). Residual stocking levels for some commercial thinnings may have to be less than 50 percent of normal to avoid damage to leave trees in logging and slash treatment operations. An important concern is the percentage of potential productivity that can be obtained in stands thinned to varying levels of stocking. This paper presents some preliminary estimates of growth rates for managed even-aged stands east of the Cascade crest in California, Oregon, and Washington over wide ranges in density. All of the growth rates or increments mentioned in this paper are gross growth values. That is, increments were obtained from plots where decay was absent or ignored during periods when mortality was absent, negligible, or accounted for and included as part of the basal area and volume used in determining increments.

METHODS

Data for volume growth were obtained from two different sources. The first source was a study in Oregon and Washington where temporary sample plots (0.1 and 0.2 acre in size) were destructively sampled (Cochran 1979b). Each plot had a buffer strip at least as wide as the height of dominant trees. These plots had very little mortality and stem analysis was used to determine volume and basal area in 1955, 1960, 1965, 1970, and 1975. Periodic annual increments for these 5-year periods were then determined. One hundred fifty observations of periodic annual basal area and volume increments were obtained from 41 plots where mortality was thought to be negligible.

The second data source was from 54 permanent sample plots. Twenty-nine of the plots (0.5 acre in size) were from three different levels-of-growing-stock studies in California, 20 of the plots (0.4 acre in size) were from a levels-of-growing-stock study with replicated blocks in central and south-central Oregon, and five plots (0.2 acre in size) were control plots in a fertilizer study in central Oregon. All plots had buffer strips 33 ft wide treated similarly to the interior of the plot. Gross periodic annual basal area and volume increments were calculated for 5-, 7-, 10-, 3-, and 5-year periods respectively for the five different groups of plots in this data source. The three studies in California had 5-, 7-, and 10-year measurement periods since original treatment. The 0.4-acre plots in Oregon were established in stands thinned 5 years before the start of the study and rethinned from below just before the start of the 3-year measurement period. The 0.2-acre plots were in stands thinned from below 5 years before remeasurement.

A third source was used for basal area growth data only. Basal area growth was determined on 0.1-acre plots (with buffer strips at least 33 ft wide) taken in stands that had been thinned prior to the 1973 growing season. Sixty-four of these temporary plots were established on the Deschutes, Fremont, and Winema National Forests in central and south-central Oregon. These plots exhibited no evidence of mortality since thinning. Diameter at 4.5 ft was measured on every tree in the fall of 1980. Increment cores were also taken from each tree on the side facing the center of the plot. Measurements of radial growth were converted to gross periodic annual basal area increments for each plot for the period encompassing the 1976 through 1980 growing seasons.

Site index was determined for each plot in Oregon and Washington and for each study area in California using Cochran's (1979a) system. For all plots, age at 4.5 ft as well as the stand density index (SDI) for the midpoint of the measurement period were determined. Stand density index was determined using

$$SDI = N(Dg/10)^{1.73} \quad (1)$$

where N is the number of trees per acre and Dg is the quadratic mean diameter at the midpoint of the measurement period. The exponent in equation (1) comes from the Reineke expression for "normally" stocked stands of white or grand fir in Oregon and Washington (Cochran 1983)

$$\ln N = 10.31 - 1.73(\ln Dg) \quad (2)$$

where the symbol ln indicates the natural logarithm. According to this equation a "normally" stocked stand has a SDI of 560.

Attempts were made to relate gross periodic annual increment of both basal area (BA-PAI) and total cubic foot stem volume (V-PAI) to site index, age, and stand density index, as well as elevation and latitude where available for each appropriate data set using several different models. Several linear models were tried with and without logarithmic transformations of all variables and interactions of the independent variables. Exponential functions and a form suggested by the Chapman-Richards equation (Richards 1959) were also tried as models. The 150 observations from the first data set were treated as totally independent even though up to four observations representing four different time periods came from a single plot. In the second data set, with 54 observations from 54 plots, the differing plot sizes and time periods were ignored after the measurements were converted to a per-acre basis.

RESULTS

The number of observations and the averages (and ranges) of the variables for each data set are:

	Data set 1	Data set 2	Data set 3
Number of observations	150	54	64
Site index (ft)	82(48-103)	89(48-112)	60(40-89)
Age at breast height (years)	55(20-94)	66(36-90)	60(38-105)
SDI	475(252-799)	304(76-705)	267(52-598)
V-PAI (ft^3/acre/yr)	219(97-412)	211(43-438)	—
BA-PAI (ft^2/acre/yr)	5.3(2.1-12.6)	4.7(2.4-7)	3.7(1.2-6.1)
Latitude (degrees)	44.3(42.4-47.4)	41.7(40.5-44.6)	—
Elevation (feet)	4,765(3,600-6,420)	5,747(4,200-6,400)	—

A model superficially resembling the Chapman-Richards function fitted using nonlinear regression techniques appeared to provide the most reasonable description of periodic annual increment as a function of site index, age, and stand density. The Marquardt algorithm was used to converge to the parameter estimates in the nonlinear regression program (SAS Institute 1982). Gross periodic annual volume increment (V-PAI) is described by

$$V\text{-}PAI = a(S/\ln A)(1-EXP(-b\ SDI)) \quad (3)$$

where S is site index and A is age at 4.5 ft. Use of more complex models which included latitude and elevation was rejected after application of the hypothesis tests suggested by Gallant (1975). Approximate R^2 values were calculated by subtracting the residual sum of squares divided by the corrected total sum of squares from 1. The three regressions are significant at the 1 percent level of probability. Values of a and b (and the half-widths of the asymptotic 95 percent confidence limits) with approximate R^2 values are:

Data set	a	b	Approximate R^2
1	13.49 (± 2.17)	0.00322 (± 0.0012)	0.56
2	12.32 (± 1.90)	.00574 (± .0026)	.68
combined	11.98 (± .96)	.00492 (± .0013)	.59

Equation (3) was not adequate for describing gross periodic annual basal area increments (BA-PAI) for the first two data sets. The nonlinear regression program failed to converge unless the two data sources were combined. The resulting equation, determined from the two combined data sources, produced unrealistically high gross periodic annual basal area increments for stand densities lower than densities found in the first data set. Variations of this model where the term ($S/\ln A$) was replaced by ($\ln S/\ln A$) and ($S/A^{0.5}$) were also tried with the same negative results. The program either failed to converge or the plotted residuals (actual values minus predicted values versus predicted values) were unevenly distributed. Failure of the nonlinear regression to converge is not evidence by itself that the model is incorrect. Failure to converge was not believed to be due to poor starting estimates for the parameters or the convergence algorithm. The starting values used by the Marquardt algorithm were the estimated optimal values of parameters obtained by fitting the model that worked with adjustments for the differences in the site index and age transformations. For data sets 2, 3, combinations of 2 and 3, and a combination of 1, 2, and 3, the model

$$BA\text{-}PAI = a_1(\ln S/A^{0.5})(1 - EXP(-b_1\ SDI)) \quad (4)$$

converged and was significant at the 1 percent level of probability. When equation (4) was used with the first data set the parameter b_1 was not significant probably because the range of density levels was too narrow. Values of a_1 and b_1 (and the half-widths of the asymptotic 95 percent confidence limits) with approximate R^2 values are:

Data set	a_1	b_1	Approximate R^2
2	9.83 (± 0.90)	0.00782 (± 0.0025)	0.41
3	8.98 (± .79)	.00660 (± .0016)	.67
2 & 3	9.58 (± .68)	.00673 (± .0014)	.57
1, 2 & 3	8.98 (± .37)	.00897 (± .0021)	.59

DISCUSSION AND CONCLUSIONS

Data sets with more elevational range at all latitudes would allow for better assessment of the effects of elevation and latitude on growth rates. The data show some tendency toward greater growth rates at more southerly latitudes and lower elevations for given values of site index. Elevation and latitude were highly correlated in our data sets because white fir occurs at higher elevations at lower latitudes.

We recommend the use of equation (3) with parameters a and b determined from combining data sets 1 and 2 for describing gross periodic annual cubic foot volume increment of thinned even-aged white fir stands older than 25 years at breast height. We recommend the use of equation (4) with parameters a_1 and b_1 determined from combining data sets 2 and 3 for describing gross periodic annual basal area increments of similar stands. Use of parameters a_1 and b_1, determined from combining all three data sets, produces a curve that predicts values that are too high for most of the actual values from plots with densities below those for the first data set. This may result from improperly estimating past bark thickness associated with the stem analysis data used to obtain the first data set. A constant ratio was assumed for diameter inside bark divided by diameter outside bark and this ratio probably decreases with decreasing diameter. An improper estimate of bark thickness could produce basal area increments that were too high in the past when stand densities were lower. However, the trees in the thinned plots may not have adjusted completely to the available growing space and the parameters we recommend for equation (4) may give conservative estimates of basal area increment. Since volume increments in the first data set did not involve estimates of past bark thickness, volume increments are free of any error associated with possible incorrect estimates of bark thickness.

Using equations (3) and (4) with the recommended parameters (a =11.98, b =0.00492, a_1=9.58, and b_1=0.00673) and an SDI of 560, gross periodic annual increments for fully stocked stands were estimated as functions of site index and age and then compared with previously published values (Cochran 1979b). For ages at breast height of 30 to 100 years and site index values of 50 to 110 ft, gross volume increments estimated as suggested here were close to previously published estimates. Ratios of new estimates divided by old estimates ranged from 0.98 to 1.14. The higher ratios were obtained at older ages on higher sites. At ages of 70 down to 30 years, ratios were no higher than 1.04. Discrepancies between new and old estimates of gross basal area increments were much greater. Ratios of new divided by old estimates ranged from 0.97 to 1.68. Increasing ratios are related to increasing ages. The old methods of estimating gross periodic annual increments of basal area and volume were based on growth data for the 1970 to 1975 period only. In light of the additional data assembled for this paper, equation (4) with a_1, b_1, and SDI values of 9.58, 0.0067, and 560 gives better estimates of gross periodic annual basal area increments for fully stocked stands than the previously published equation.

Our results show that white fir stands that have been heavily thinned from below display a great capacity to produce wood. Using the recommended parameters in equation (3), V-PAI was calculated at various levels of stocking and divided by the corresponding growth rate at full stocking. The resulting ratios indicate that stands 75 percent of "normal" density produce 93 percent of the gross periodic annual cubic volume increment of fully stocked stands. Stands at 50 percent of "normal" density produce 80 percent of the gross periodic annual increment of fully stocked stands and stands at 25 percent of "normal" density produce 53 percent of the gross periodic annual volume increment at full stocking (fig. 1). The same procedure was carried out for BA-PAI. Stands at densities of 75, 50, and 25 percent of "normal" produce 96, 87, and 62 percent of gross periodic annual basal area increment at full stocking (fig. 1).

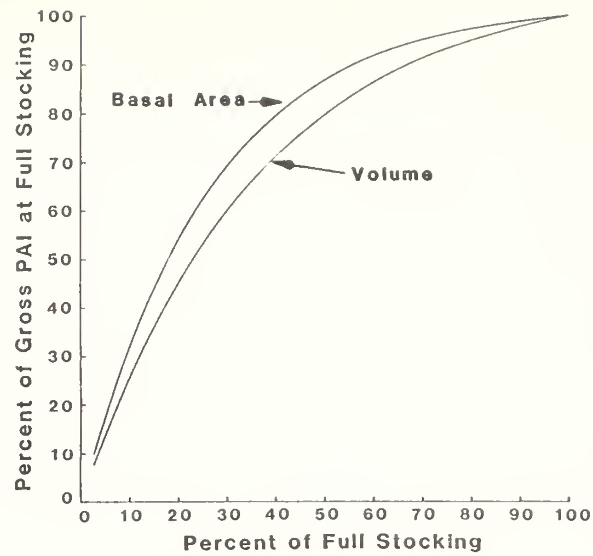

Figure 1—Change in gross periodic annual increments (PAI) of basal area and cubic foot volume with stocking level. Percent of full stocking is 100(SDI/560). Percent of gross periodic annual increment at full stocking for basal area is 100(1–EXP((–0.00673)(SDI)))/(1–EXP((–0.00673)(560))) and 100(1–EXP((–0.00492)(SDI)))/(1–EXP((–0.00492)(560))) for volume.

While the models described by equations (3) and (4) are somewhat simplistic, they do fit the data now available as well as more complex models. As more data are collected models using latitude, elevation, and perhaps other factors will be tested.

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IS MANAGING ASPEN DENSITY WORTHWHILE?

H. Todd Mowrer

ABSTRACT

In addition to being subject to a weak and unpredictable market, aspen has unique characteristics that complicate traditional management objectives. Clonal growth, combined with extreme shade intolerance and apical dominance, enable naturally occurring aspen stands to successfully regulate their density. Aspen stems are easily wounded mechanically during thinning and often are infected subsequently by fungal pathogens. Artificial thinning also may create new layers of reproduction that hamper redistribution of growth to the desired stems. However, growth simulations indicate that sawlog volume may be produced more quickly by thinning. For longer rotations, total cubic foot volume is maximized over all site qualities in stands receiving no intermediate thinning. Sawlog volume also is maximized for better site qualities in naturally thinned stands.

INTRODUCTION

There are many traditional reasons to thin forest stands: shortened rotations, improved sawlog or forage yield, better esthetics and visual diversity, or removal of undesirable stems of the same or other species. Many of these objectives are confounded by species characteristics of aspen. The most notable of these, influencing many of its silvicultural traits, is the occurrence of aspen in clones of genetically identical individuals. Thin-barked aspen stems are easily wounded during thinning operations and subsequently are often infected by canker diseases. After thinning, resprouting or weather damage in the residual stands also may affect the desired result. This paper discusses the interactions of these factors in thinned stands of aspen, using computer simulated thinning results to provide insight into the response of aspen to density reduction.

EXTENT

Aspen (*Populus tremuloides* Michx.) is extensive in two areas of the Inland Mountain West. In western Canada, most aspen occurs in a broad band, running approximately southeast to northwest through the aspen grove and mixed wood sections of the boreal forest region in the province of Alberta and in the Upper Laird section of the boreal forest region, and the northern aspen and montane transition sections of the montane forest region in British Columbia (Rowe 1972).

Recent figures indicate approximately 22.6 million ft^3 (640 thousand m^3) of large sawlog aspen volume[1] in the western half of Alberta (Dermott 1986). In 1968, there were 28 billion ft^3 (793 million m^3) of poplar (mostly aspen) in Alberta and British Columbia (Manning and Grinnell 1971). Utilization was about 1 percent of the allowable cut in Alberta in the early 1970's. Reasons for underutilization included abundance of coniferous timber and remoteness of markets (Bella and DeFranceschi 1980).

In the Western United States, aspen is most extensive in the central Rocky Mountain region, including the subalpine and montane regions from Wyoming to southern Colorado, and from the Front Range of the Rocky Mountains to the eastern portion of Utah. In these three States, there are more than 3.78 million acres (1.53 million hectares) of commercial aspen, with a net bole volume of more than 3.25 billion ft^3 (92 million m^3)(Green and Van Hooser 1983).

SILVICULTURAL CHARACTERISTICS

Aspen, a seral species, is extremely intolerant of shade, and is usually replaced by conifers in the Inland Mountain West, although pure stands exist in even-aged conditions for prolonged periods. Uneven-aged or multistoried stands also exist naturally. Shade intolerance, reproduction by suckering, natural thinning, and susceptibility to fungal infection make Rocky Mountain aspen most compatible with an even-aged silvicultural system using the clearcutting method (Shepperd and Engelby 1983).

Vegetative Reproduction

Soon after overstory removal, the existing root system sends up sprouts (suckers) that grow rapidly, since the fully developed parent root system is available to provide nourishment. Suckers initially adopt a portion of this parent root system, sharing water and solutes with other suckers, but this dependence diminishes as their own root systems mature. Suckers remain interconnected for at least 2 to 3 years, though this interconnection may occasionally continue throughout the life of the stand (Jones and DeByle 1985). As individual suckers gain dominance over adjacent stems, rapid self-thinning occurs, reducing densities dramatically during the early portion of stand development. During the period in which suckers are primarily dependent on the parent root stock, height

[1]Minimum stump diameter of 15 inches (38 cm) measured to a 9-inch (23-cm) top.

growth does not necessarily correlate to later growth potential (Jones and Schier 1985).

Clonal Growth

An aspen clone consists of many genetically identical individuals (ramets). Schier (1985) explained that despite the production of large numbers of germinable seed in the Rocky Mountains, few survive since the seed are short-lived and the seedlings are highly sensitive to water and temperature stress and the lack of proper physical conditions in the seedbed. Schier further suggested that current clones were established from seedlings during the moister Pleistocene epoch. Since then, wildfire has played a major role in continued vegetative reproduction and clonal expansion. In the Rocky Mountains, aspen clones are larger than in the Great Lakes areas and may occupy more than 100 acres (Kemperman and Barnes 1976). When compared to a genetically heterogeneous species, the ramets in a clone of aspen will more uniformly exhibit many phenotypic characteristics. Shepperd (1986) enumerated traits that may be used to differentiate clones: leaf color and timing during fall senescence and spring flush, bark color, branching habit, and stem form. From a management perspective, other clonal characteristics are relevant: the degree of overstory disturbance necessary to promote adequate suckering (Shepperd and Engelby 1983); the degree of susceptibility to particular diseases (Anderson and Anderson 1969; Kemperman and Barnes 1976); and the degree of biomass and volume production (Lehn and Higginbotham 1982).

Self-Thinning

Extreme intolerance, apical dominance, and clonal growth contribute to self-thinning in aspen. Jones (1975) and Jones and Trujillo (1975) found high sucker mortality up to 22 years after clearcutting. Graham and others (1963) found periodic intense competition among trees forming the canopy of immature aspen stands, culminating in marked mortality, and followed by a strong recovery in diameter growth. Bella (1970) suggested that moisture stress was the trigger for cyclic mortality and growth patterns in aspen in British Columbia.

Living Bark and Fungal Infection

Aspen generally lacks the protective rough bark found in other associated tree species. The stem covering consists of a persistent layer of periderm, containing chlorophyll (Jones and DeByle 1985), and capable of photosynthesis (Schaedle and Foote 1971). This lack of protection makes aspen easy to wound and susceptible to subsequent fungal infection (Hinds and Krebill 1975). Sooty-bark cankers cause more than one-half of the mortality in commercial aspen stands in Colorado (Juzwik and others 1978). Wounding by recreationists resulted in canker infections in aspen, with a direct relationship between cumulative aspen mortality and campground age (Hinds 1976).

Anderson (1964) discussed results from a large-scale thinning study in Minnesota that showed significant evidence of increased mortality and infection caused by hypoxylon canker in thinned stands. Jones (1976) attributed increased mortality to hypoxylon and other cankers introduced through bark wounds and increased insect activities after thinning. Five to 7 years after partial cutting of aspen in northern New Mexico and southern Colorado, Walters and others (1982) found 20 percent canker-related mortality in residual trees, while the mortality in uncut control plots was negligible. Moreover, 45 percent of the residual stems alive after logging were infected with canker. Preliminary findings from a thinning study in a pole-sized aspen stand in Colorado indicate an increase in cankers and resultant mortality on the treatment with the greatest density reduction (Jones and Shepperd 1985a).

EFFECTS OF DENSITY MANAGEMENT

Volume Production

Jones (1976) noted that, despite natural self-thinning to adequate levels, high density levels in early aspen regeneration have repeatedly encouraged interest in thinning. No long-term thinning studies are available for aspen in the intermountain region, however, and few have been maintained in North America. Numerous short-term studies have been conducted in sapling- and pole-sized stands, particularly in the Great Lakes area of the United States and in central Canada.

Jones and Shepperd (1985a) cited a number of studies, conducted in various locations, in which thinning of new sucker stands had either a positive or negative effect on diameter growth increment. Brinkman and Roe (1975) found the benefit from thinning sucker stands in the Great Lakes area to be inadequate, considering the large number of trees that had to be removed. Diameter growth was believed to be independent of site quality by Jones and Schier (1985), who deemed height growth to be much more dependent on site quality than density. In their analysis, the final diameter of dominant stems was only modestly affected by stand density.

In 1975, Bella reported improved diameter increment from short-term thinning results in sapling stands in Saskatchewan and Alberta. Height increment trends were inconclusive. Later inspection showed thinning-induced regeneration had died as crown closure occurred in the residual canopy (Bella 1986). Nineteen-year results of sucker thinning in Minnesota indicated growth could be redistributed onto desirable aspen stems by removal of other species (Schlagel 1972). After a thorough review of the literature, Bella (1970) concluded that thinned stands generally yielded less volume than their unthinned counterparts, though an increase in diameter increment commonly was noted.

Jones and Shepperd (1985a) and Brinkman and Roe (1975) found results from studies of pole-sized aspen thinned from below to be variable and inconclusive. Perala (1977) recommended intermediate thinnings on better aspen sites to shorten rotations and increase production of sawtimber and veneer logs. Steneker (1974) remeasured growth 21 to 23 years after thinning at ages 11 to 23 years in Manitoba aspen. Total cubic foot volume showed no clear treatment effects, with some improvement at closer spacings, mixed results in wider spacings, and decided losses in strip thinnings. An increased diameter increment resulted in improved cubic foot production in stems 8 inches (20 cm) d.b.h. and larger.

Perala (1978) developed a thinning model for Great Lakes aspen from eight successive 5-year remeasurements of an aspen thinning study encompassing only one site index level. While thinning improved total gross production (including noncommercial and commercial thinnings, mortality volumes, and regeneration removal), unthinned stands showed the greatest regeneration cut volume for total bolewood to a 6-inch (15-cm) top. Sawtimber and veneer volumes at final removal were substantially less for the unthinned stand, however.

Overall, these studies indicate mixed results for total volume production, while production of large-diameter products generally is accelerated by thinning. Jones and Schier (1985) suggested growth responses of dominant stems in sucker and sapling stands were short-term in nature, corresponding to external factors rather than any age-determined response pattern. Similarly, early height growth of suckers was not necessarily a meas-ure of future growth potential of the stand. Extrapolation of growth improvements past the actual measurement period in these studies should be avoided, particularly in younger stands.

Application of results from these studies to aspen in the Intermountain West also is questionable, because growth conditions vary greatly. Brissette and Barnes (1984) found differences in survival and height growth between aspen progeny from the Intermountain West and the Great Lakes region. Differing growth and decay infection rates between these geographic areas necessitate a pathologic rotation of 40 to 70 years in the Great Lakes area (Perala 1978), while 90 to 120 years is suggested for Colorado aspen (Hinds and Wengert 1977). Careful comparisons may provide validation of observed trends for aspen within the intermountain area.

Thinning Simulations

As a result of the dearth of longterm thinning information in the Intermountain West, results have been estimated by using the aspen subroutine for RMYLD, a growth and yield model for pure, evenaged stands of several major tree species in the central Rocky Mountains of the United States (Edminster and Mowrer 1985). This modeling approach assumes development in a thinned stand will follow the same trends as in an unthinned stand with similar (postthinning) characteristics. RMYLD relationships do not take into account any effects of wounds or subsequent decay and mortality from thinning. Only gross volumes are estimated, with no reduction for rot, cull, or unstocked areas. Board foot volumes are not calculated until the average stand diameter is 7 inches (17. 8 cm) or larger. The aspen subroutine for RMYLD was calibrated using data from 100 even-aged temporary growth plots. Table 1 summarizes conditions in the sampled stands.

Table 1—Stand condition summary for RMYLD aspen calibration

Characteristic	Mean	Minimum	Maximum
Site index (feet)	63.3	29.0	111.0
Average age at breast height (years)	68.6	17.0	131.0
Trees per acre	1,088.0	128.0	5,469.0
Basal area per acre (ft^2)	160.5	12.0	351.0
Total volume per acre (ft^3)	3,551.4	97.2	12,879.2
Sawtimber volume per acre (board feet Scribner)[1]	22,724.1	2,238.0	61,031.0

[1]Values for sawtimber volume are based on 36 plots with an average diameter of 7 inches or larger.

Clonal differences may complicate growth estimates for aspen (Bella 1975). Homogeneity of measurements within a clone may alter the error structure of growth estimates if actual variability is unintentionally minimized. Zahner and Crawford (1965) discussed the effect of clonal growth on the overestimation or underestimation of site quality within a single clone. The range of RMYLD model calibration data should help minimize these problems.

The following hypothetical stand conditions were used to initiate simulations of aspen yield:

1. Ten-foot site index classes (Edminster and others 1985) ranged from 40 through 90 (12 through 27 m) feet at a base age of 80 years.
2. Simulations were initiated at age 20 for stands with initial densities of 2,000 stems per acre (4,942 stems per hectare) on all sites.
3. Quadratic mean stand diameter (breast height) was 2.0 to 3.3 inches (5.1 to 8.4 cm), depending on site quality.
4. Average total heights of dominant and codominant trees increased from 14 to 28 ft (4.3 to 8.5 m) with site quality.
5. Board foot Scribner volumes were calculated using Edminster and others' (1982) volume relationships for stems 7. 0 inches (18 cm) and larger at breast height, calculated to a 6.0-inch (15-cm) top.

Initially, a number of different rotations and thinning options were considered: 60-, 80-, and 100-year rotations; with no thinning, one thinning at age 20, or a second thinning at age 60 (for the latter two rotations). Rotations in excess of 100 years were not considered, since they exceeded the optimal pathologic rotation applied by Edminster and Mowrer (1984). Total volume production was compared over management periods of equal length. For example, volume harvested from four 60-year rotations was less than that from three 80-year rotations. The relative trends were consistent over all the comparisons, with longer rotations producing more volume. The 100-year rotation produced the greatest volume.

Perala suggested that the optimal basal area for aspen growth in the Great Lakes area may change with age (Jones and Shepperd 1985a). The use of growing stock level as a density reduction target reduces basal area in young stands. Basal area is increased up to the equivalent growing stock level value after 10 inches (25 cm) d.b.h. is reached (Myers 1971). The following combinations of projection possibilities were used for the simulations in figures 1A and 1B:

1. All thinnings were from below, and were of an intensity necessary to reduce density to a growing stock level (Myers 1971) of 60, 80, 100, 120, 140, 160, or 180. A no-thinning option also was simulated for each set of stand conditions.
2. Noncommercial thinnings occurred at age 20 for the 80-year cutting cycle, or at ages 20 and 60 for the 40-year cutting cycle.
3. Total overstory removal occurred at age 100.

Figures 1A and 1B show the volume response surfaces generated by RMYLD for simulated yields of total cubic foot and board foot Scribner rule volume over one 100-year rotation for a single thinning, two thinnings, and no thinning. Growing stock level increases from front to back, with the unthinned values displayed after growing stock level 180. It should be emphasized that a discontinuity exists between growing stock level 180 and the unthinned stocking level. As a result, the change in the response surface between growing stock level 180 and the unthinned stocking level is much more gradual than is shown in these figures. The relative volume production values are accurately displayed, however.

Two response surfaces are shown on each figure. The upper response surface represents the volume-per-acre yield for an 80-year cutting cycle. The lower response surface indicates the per-acre volume yield for a 40-year cutting cycle. Only the final removal volume is used since few markets exist for mortality or thinning removals. As in the 80-year cutting cycle, an initial precommercial thinning occurs immediately at age 20, but a second precommercial thinning to growing stock level 80 through 180 occurs at age 60 for the 40-year cutting cycle. The unthinned volume responses are identical for both management regimes, since they are unaffected in either case.

Generally, both figures 1A and 1B show more final harvest volume for the one-thinning management option than for two thinnings. Segments of the two-dimensional vertical planes between upper (one thinning) and lower (two thinning) response surfaces have been shaded at 10-foot site index increments to enhance visibility of the volume differences produced by the two management regimes across the range of stocking levels. This relative difference is more pronounced at higher site levels, but is reduced with increased stocking. Both response surfaces coincide at unthinned levels of growing stock.

Total Cubic Foot Volume Production

Figure 1A, which provides a comparison of total cubic foot volume produced across all site index values, indicates that both the 40- and 80-year cutting cycles produce less final removal volume than a no-thinning management option. The 80-year cutting cycle produces more removal volume than the 40-year cycle, at less cost, because only one precommercial thinning occurs instead of two. Less yield difference between the two thinning sequences is apparent at lower site qualities. As expected, yields increase with improved site quality. However, yields also increase consistently with increased stocking levels.

Sawtimber Production

As shown in figure 1B, results are less consistent across site quality for sawtimber volume. While volume production consistently increases with increasing site quality, sawtimber production improves when lower site quality stands are thinned. Differences between the 40- and 80-year cutting cycles are minimal within this site range, however. It is therefore questionable whether stands with lower site quality (below an approximate site index of 65 ft) would be likely candidates for investment in saw-timber production. For stands with site index values above 65 ft (20 m), unthinned stands support more sawtimber at a 100-year rotation than those at growing stock levels 80 through 180. In this site index range, an 80-year cutting cycle also supports more sawtimber volume than the 40-year cycle.

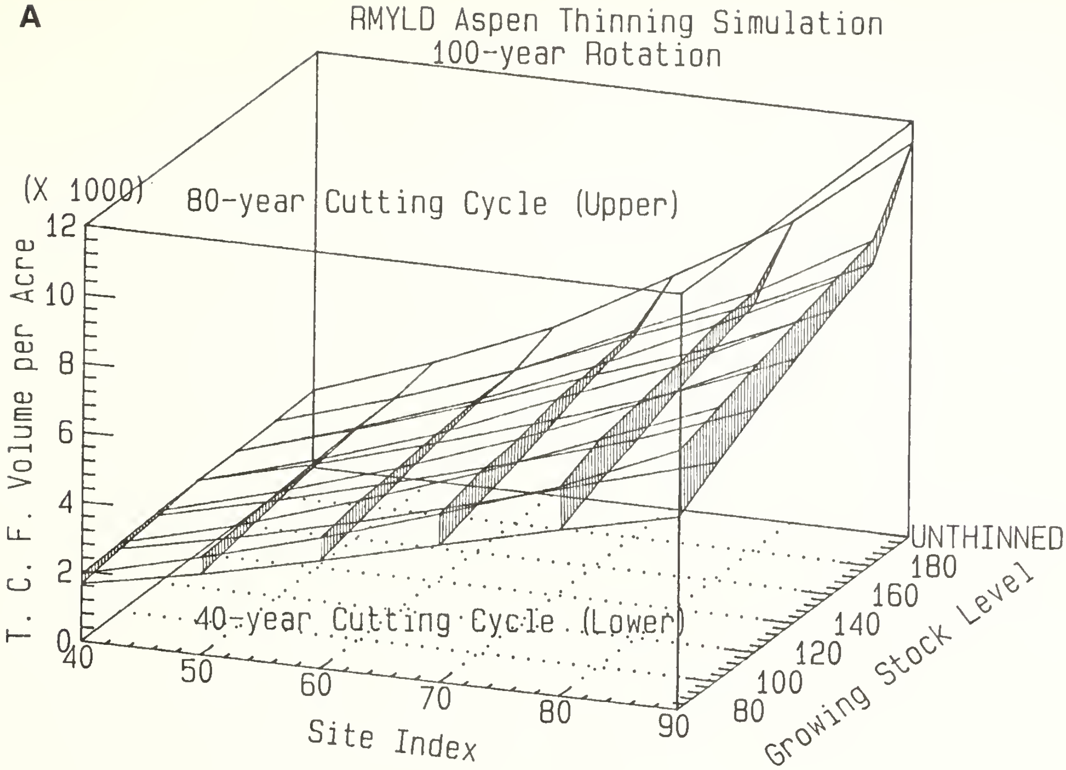
Accelerating Sawtimber Production

The accelerating effect of thinning on sawtimber production was examined for the same two thinning regimes for site indexes 50, 70, and 90, corresponding approximately to low, medium, and high productivity classes. The time to first sawtimber production was shorter for thinned stands than unthinned stands across all sites. Lower growing stock levels produced more overall board foot volume, Scribner rule, at site index 50. The opposite was true for site indexes 70 and 90. As discussed above, stands with low productivity are unlikely to be managed intensively for sawtimber.

Figure 2 shows Scribner rule board foot production as a function of various rotation ages and growing stock levels for a site index of 70 ft. Again, two response surfaces are shown for comparison. Below approximately growing stock level 160, the 80-year cutting cycle indicates higher board foot volume yields before age 70, after which the 40 year cutting cycle generates more board foot volume. There is a general upward convergence in board foot volume productivity for both cutting regimes for higher stocking levels, with the highest board foot volume produced by unthinned stands after rotation age 80. Again, note that a discontinuity exists in the growing stock level axis between 180 and unthinned, and that the trend between these values is exaggerated by this axis compression.

Board foot volume is produced more quickly by thinning otherwise equivalent stands. Overall yield is greatest for longer rotations in unthinned stands, however. This relationship was even more pronounced in a simulation for site index 90 stands. Any thinning from below will serve to increase mean diameter of the stand and, with stand average growth models, to accelerate apparent volume production. Thinning aspen does offer the opportunity to redistribute growth onto selected desirable stems, rather

A



B

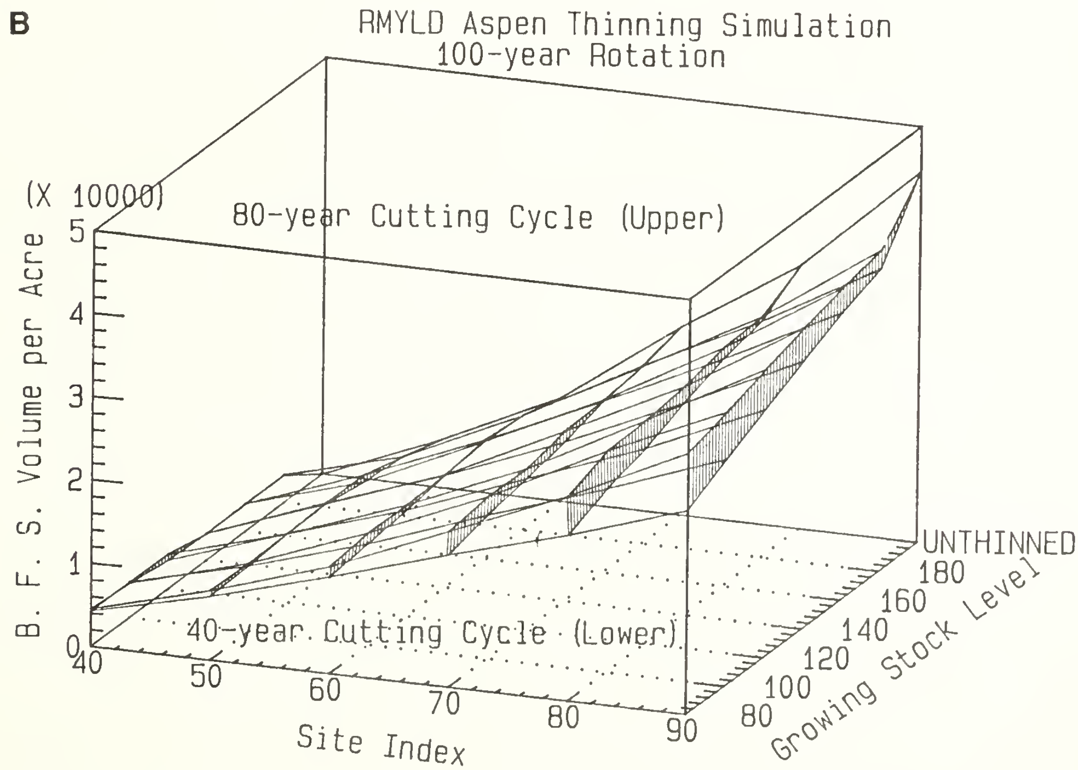


Figure 1—RMYLD aspen thinning simulation of (A) total cubic foot volume harvested at 100-year rotation for thinning at age 20 and for thinnings at ages 20 and 60 as a function of site index and growing stock level and (B) board foot volume (Scribner rule) harvested at 100-year rotation for thinning at age 20 and for thinnings at ages 20 and 60 as a function of site index and growing stock level.

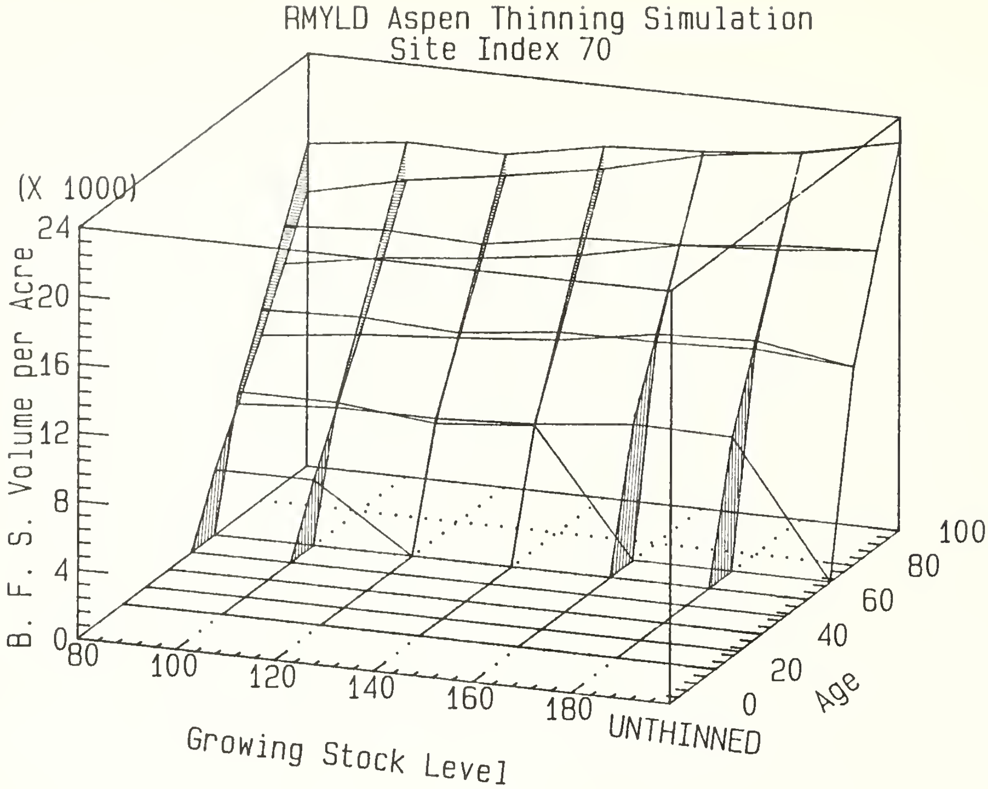


Figure 2—RMYLD aspen thinning simulation of board foot volume (Scribner rule) on site index 70 lands, as a function of stocking level and rotation age.

than accept the results of natural selection through self-thinning.

CONSIDERATIONS WHEN THINNING ASPEN

The expected increase in financial returns from thinning must be balanced against the clonal ability to self-thin, the clonal susceptibility to fungal infection, and the clonal propensity to sucker when determining the suitability of a clone for thinning. Jones and Shepperd (1985a) noted that aspen thinning decisions usually are based on economics, rather than silvicultural requirements, and that sawtimber stands ordinarily are the only candidates. In most cases, however, aspen will thin itself adequately at no cost. Simulations presented here show that thinning may not improve total volume production at all, and only affects sawtimber rotation age on sites with lower productivities. Lack of markets for sawlog products and the necessity of noncommercial thinnings make aspen thinning for economic reasons unusual.

Product value at rotation age may be reduced because of fungal infection through trunk wounds created by thinning. The susceptibility to fungal infection is a genetically determined trait (Kemperman 1977; Weingartner and Basham 1985). Jones (1976), noting a reduction in volume growth, recommended against commercial or precommercial thinning of aspen due to its ability to self-thin and its susceptibility to thinning-induced disease. If thinning is selected, wounding of the ultimate crop trees cannot be allowed (Jones and Shepperd 1985a). Wounds are more likely and more often severe if thinning takes place during the growing season, prior to midsummer, when the cambium is active and the bark is most easily peeled (Jones and Shepperd 1985b). In addition, the necessary severity of artificial thinning would leave residual stems susceptible to bending and breaking due to snow and blowdown (Crouch 1986).

Thinning may create additional canopy layers because of the suckering that occurs after each entry. This results in decreased redistribution of potential growth to desired stems, even if new sucker layers are suppressed eventually and die. How readily a clone suckers after disturbance will affect the degree to which the increased growing space is reoccupied by new sprouts (Kemperman 1977). The clonal ability to self-thin will affect how readily any regeneration resulting from a thinning operation will be suppressed and eliminated by the intended crop trees. A two-storied or multistoried stand may result from thinning a poorly self-thinning clone.

If thinning is to be undertaken for reasons other than maximum growth or because of extenuating economic circumstances, Jones and Shepperd (1985a) make specific subjective recommendations.

NONVOLUME DENSITY MANAGEMENT OBJECTIVES

If increased volume production is not a priority, thinning in aspen stands may have several objectives, many of which were enumerated by Perala (1978). Nonvolume thinning objectives may include reduced costs during overstory removal, improved forage for livestock and wildlife, increased visibility for esthetic purposes, reduced conifer competition for aspen regeneration, or improved conversion to conifer species.

Thinning can stimulate the herbaceous understory production for both wildlife and cattle. However, the impact of grazing, trampling, or possible soil compaction on desired reproduction after overstory removal should also be considered (Crouch 1981, 1983). DeByle (1985) recommended keeping permanent scenic vistas open and intact. Neat, well-organized intermediate treatments should be timed for minimal visual impact. Conifer competition for regeneration is most easily and economically removed during the single-entry regeneration cut.

CONCLUSION

As a species, aspen has unusual silvicultural and growth characteristics that complicate traditional management objectives. Naturally occurring aspen stands regulate their density very successfully. Aspen stems are easily wounded and fungal infection often results. Depending on the propensity of the clone to sucker, thinning may create new canopy layers that hamper redistribution of growth to the desired stems.

Growth simulations show that sawlog volume may be obtained earlier in thinned stands. Over longer aspen rotations, total cubic foot volume is maximized over all site qualities in stands receiving no intermediate thinning. Sawlog volume is maximized for better site qualities in naturally thinned stands, also. In view of these considerations, aspen seems most compatible with unthinned, single-entry, even-aged management.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Paul Hansen)—Are all stands of aspen seral and even-aged, or are some stands uneven-aged and climax?

A. —The expression of traits affecting self-thinning and degree of overstory disturbance necessary to promote suckering creates uneven-aged conditions in some clones. Even if an aspen clone arrives at an uneven-aged condition naturally, the same factors outlined above, particularly susceptibility to fungal infection after mechanical damage, indicate that even-aged management is the only reasonable alternative. Some aspen stands do exist in an uneven-aged condition for prolonged periods, but whether this constitutes a "climax" condition is an open question.

NUTRIENT CYCLING CONCEPTS AS RELATED TO STAND CULTURE

Nellie M. Stark

ABSTRACT

Although current stand culture techniques utilize little of the available nutrient cycling technology because of economic constraints, the types of cultural practices used can influence significantly the availability of nutrients for tree growth. New technologies are being developed that will be useful in guiding cultural practices in the future when better financial resources allow intensive culture. This paper addresses what is known about nutrient cycling in Rocky Mountain forests and how fertilization can influence the availability of nutrients. Sources of natural fertilizer are discussed, with emphasis on nutrient cycling. Various methods of applying different types of fertilizers are examined in terms of their effect on soil pH and nutrient availability. Two models—NUTROSS and FORCYTE-10—that evaluate the effects of nutrients and nutrient loss on growth are presented. Fertilizer studies in Sweden and fertilizing on demand are discussed.

INTRODUCTION

Until recently, land managers were not able to concentrate on the influence of harvesting on nutrient cycling in forest ecosystems. Economic constraints make it difficult to justify special stand manipulations that would favor nutrient conservation. In years past, technology for evaluating the impact of stand cultural measures on nutrient cycling was not available, or not tested. Today, we have some new technology, but the economic atmosphere is not suited to its use. Thus, today's technology will be of value in the future as the economic climate improves.

Knowledge of nutrient cycling rates and pathways is important in planning stand culture where long-term productivity is a concern. We know from research that many forest ecosystems can continue to produce wood for many rotations, but we still need to be able to recognize those chemically fragile soils that cannot withstand intensive harvest and still maintain fertility.

Certain cultural practices may inadvertently interfere with good nutrient cycling and stand development. Site preparation with slash or broadcast burning that produces temperatures of much over 608 °F (320 °C) in the soil surface (upper 2 inches) can damage the physical structure of the soil and create conditions unfavorable to tree growth because of lowered exchange capacity (Stark 1983). Slash pile and windrow burning are particularly harmful to many soils. In addition, productivity on chemically fragile sites may be harmed by too careful cleanup of slash, which can remove fine and coarse organic matter needed for physical structure and to support nitrogen-fixing organisms and mycorrhizal fungi. Chemically fragile soils cannot withstand intensive stand harvest because it is likely to create a deficiency of one or more biologically essential nutrients in available form (Stark 1985). The effects of "cultivating" forested land prior to planting for stand culture, using disks and other agricultural equipment, have not been extensively studied in relation to nutrient cycling. The potential exists for accelerated decay and erosion under disking practices, resulting in nutrient shortages later on in the rotation, especially on coarse-textured soils.

NATURAL FERTILIZATION

If a soil is fertile initially, good management of the natural nutrient pool can maintain long-term productivity with modest or no investment in fertilizer. Because it is often not economically feasible to fertilize forest stands, it becomes more important to manage and protect natural nutrient cycles.

Forests have at least seven sources of natural fertilizer:

1. Rainfall
2. Mineralization
3. Weathering
4. Pollen rain and dry fall, including deposition on foliage
5. Nitrogen-fixing lichens, algae
6. Nitrogen-fixing bacteria - free-living or symbiotic
7. Others.

Rainfall

Rainfall brings in low but predictable amounts (0.9 to 56 lb/yr) of biologically essential nitrogen and other nutrients (Black 1968). These nutrients come from dust, exhaust, industrial particulates, volcanic eruptions, pollen, spores, and fires. The low concentrations of nutrients in a year's rainfall are not adequate to support normal forest growth for a year, but rainfall does add significant amounts of calcium, copper, iron, potassium, magnesium, phosphorus, nitrogen, and zinc to the soil. These nutrients just about equal the amounts of the same nutrients lost beneath the feeder root zone over a year's time in an undisturbed forest (Stark 1982). For this reason, nutrient additions from rainfall do not increase the total pool of nutrients available in most forest ecosystems. However, areas with heavy air pollution (nitrous oxides) may get 40 to 50 lb/acre/yr of N fertilizer from rainfall.

Mineralization

Mineralization is a process involving the conversion of organic litter to individual nutrients such as calcium, potassium, magnesium, and others. The process involves many microorganisms working over time. In northern or more arid climates, mineralization can be slow (8 to 12 years for decomposition of a pine needle), while a leaf may be mineralized in 6 to 9 months in tropical climates. Rates of mineralization depend on the combination of suitable litter-soil moisture, temperature, O_2/CO_2, energy and nutrient source, insulation from climatic extremes by deep litter, and the types of microorganisms involved.

Litter is decayed by a series of decomposers. The first fungi to attack litter in cold climates are psychrophils (cold-adapted organisms) living under the snow in winter (Stark 1973). These organisms use the nutrient and energy-rich cell contents of leaves or needles. For this reason, it is advisable to leave fresh slash on the ground under the snow for one winter. Fungi actively move nutrients from the slash into the soils. Most decomposition in coniferous forests in climates with snow occurs during winter by fungi under the snow (Stark 1973).

During the second year of decay, microbes begin to work on low nitrogen substrates such as cell walls and lastly on decay-resistant lignin and tannin. Fertilizer, especially NPK, will stimulate mineralization and the release of more nitrogen and other nutrients needed for plant growth. Thus, fertilizer may have an immediate stimulating effect on tree growth and a more prolonged influence by increasing the release of nutrients from litter.

Nutrient uptake from soils of coniferous forests is thought to be indirect (Stark 1978). Nutrients are released from litter by mineralization and become part of the soil solution where they enter into dynamic equilibrium with the root surface, soil solution, exchange sites, soil microbes, and organic colloids. Uptake of nutrients is from the soil solution (an indirect route) or is aided by mycorrhizal fungi or energy expenditures by the root itself to facilitate selective uptake.

Weathering

The process of weathering releases nutrients from minerals in rocks. The rate of release is thought to depend on temperature, moisture, microorganisms, and the chemistry of the soil solution and the rock itself (Hausenbuiller 1985; Zajic 1969). Warmer and more humid sites are thought to release nutrients in available form more readily than dry or cold sites. Unfortunately, little is known about the actual rates of nutrient release from rock because the process is so slow.

Research by Stark (1982, 1985) indicated that it is unwise to grow each successive rotation on nutrients released from weathering during that rotation. If newly weathered ions are needed to subsidize each rotation, the soil can never become more fertile. Many soils have adequate nutrient supplies to support conventional harvest of wood to a 5-inch top, provided that enough large cull wood is left to support nitrogen fixation (Stark 1979). There should be left onsite at the time of harvest enough of each nutrient in available or recyclable form to grow the next three to four forest rotations (Stark 1982). "Available" nutrients refers to 0.5N ammonium acetate and 0.001N DTPA extractable soil nutrients. "Recyclable" nutrients are those in materials left behind like needles that can, theoretically, be used to grow the next set of needles for future rotations. The amount of each nutrient needed to support the next three to four rotations would be the amount of each nutrient in the organic matter of the present stand (litter, duff, boles, branches, needles) that is planned to be harvested in future rotations, times either three (good site) or four (poor site). If the present stand is nutrient deficient, then the calculations may need to be adjusted for higher nutrient contents that should be in the existing stand if superior growth is desired. Nitrogen, which is biologically fixed, is an exception since it is not derived primarily from rock. Greater harvest intensity to remove more wood, branches, and needles often causes future problems of nutrient availability.

Weathering is influenced by fertilizer mainly in terms of the altered chemistry and pH of the soil solution. Fertilizers that alter the pH in a direction unfavorable for weathering may, in theory, slow down the weathering process. Organic matter added to the soil provides substances that aid weathering (Hausenbuiller 1985).

Pollen and Dry Fall

Each spring when trees shed pollen, considerable amounts of N and P are brought in from nearby surrounding trees. This "pollen rain" is an important natural fertilizer (Stark 1973), especially for litter decomposition. It has been shown to stimulate mineralization and seedling growth (Stark 1973). Pollen rain, a natural fertilizer, adds essential nutrients like N and P to litter. Dry fall, or the input of particulates from the atmosphere, also is a constant source of plant nutrients to the forest floor.

Nitrogen-Fixing Lichens and Blue-Green Algae

Lichens that contain blue-green algae are able to fix nitrogen. The goats' beard lichen (*Alectoria jubata*) is a common lichen of this type in the Northern Rocky Mountains. When lichens fall to the ground, especially during winter, they are decomposed by a variety of microorganisms, releasing nitrogen and other nutrients during spring and early summer. Lichens concentrate nutrients from the atmosphere, making them desirable mineral sources for wildlife. Lichens also add minerals to the litter after they fall from the tree and decompose. The decomposition of lichens and subsequent nutrient release can be accelerated by fertilizer containing N and P.

Some species of free-living blue-green algae and a few bacteria also fix nitrogen on the forest floor.

Nitrogen Fixation

Other nitrogen-fixing symbionts occur within the roots of forest shrubs such as *Ceanothus* spp. (tobacco brush and related species), *Shepherdia canadensis* (buffaloberry), and *Alnus rubra* (red alder). Some leguminous plants such as clover also fix nitrogen in the forest. These understory plants have bacteria that live in nodules in their roots and remove nitrogen from the soil atmosphere. The nitrogen is "fixed" or converted from nitrogen gas into ammonium. Nitrification in the soil converts ammonium to nitrate at a later step. Most forest plants can use either nitrate or ammonium but with varying efficiencies.

Some mycorrhizae absorb ammonium more readily than nitrate (Corrodus 1966), so the ammonia fertilizers, if they reach the tree root zone, are likely to be used by roots. Most higher plants can use nitrate readily, and many mycorrhizae absorb nitrate as readily as ammonium (Lundberg 1970). There are conflicting reports on the effect of nitrogen fertilizer on mycorrhizal development (Marks and Kozlowski 1973).

Some nitrogen fixation occurs separately from plant roots in the soil because of free-living nitrogen fixers. These organisms are benefited by organic matter in the form of rotten logs or rotting litter. Nitrogen fertilizer tends to reduce the rate of nitrogen fixation (Black 1968). If natural nitrogen fixation is suitable to support good tree growth, nitrogen fertilizer is not needed. Unfortunately, nitrogen-fixation rates are not easy to measure directly.

Work by Harvey and others (1979) indicated that about 16 tons of coarse rotting wood (>12 inches diameter) per acre should be left on site at the time of harvest to support nitrogen-fixing organisms and mycorrhizae. Large logs a foot or more in diameter are essential, especially in drier forest types, to supply energy and a temperature- and moisture-stable environment for nitrogen-fixing organisms and mycorrhizal fungi (Marks and Kozlowski 1973). The mycorrhizae aid in the uptake of nutrients by a large number of plants.

Other Sources

Fire—Nutrients can be recycled back into the soil as a result of moderate or hot fires. Fires with 1-inch surface soil temperatures of 356 °F (180 °C) add few nutrients to the soil because of incomplete combustion. Fires with 1-inch surface temperatures in the range of 536 to 608 °F (280 to 320 °C) release considerable amounts of nutrients needed for plant growth. These nutrients become available slowly as the soil pH changes, with more calcium and magnesium available initially in the more alkaline soil solution and more acid-soluble ions such as Cu, Fe, Mn, and Zn available as the ash becomes more strongly leached (Stark 1979, 1980). Available iron concentrations are often quite low in the soil solution after hot burns. Some plants, however, are able to increase the iron content of their foliage after burns, apparently through mycorrhizal uptake (Stark 1979a, 1979b). Nutrients released after light burns that leave considerable organic matter in the soil may stimulate nitrogen fixation and other microbial processes.

Although fire does return appreciable amounts of nutrients back into the soil in a short time, it does not represent an outside input of nutrients that will make the soil more fertile. Fire at low intensities (<608 °F at 2 inches depth, or <320 °C 0-5 cm depth) can stimulate short-term plant growth, but the site will not necessarily be more fertile on a long-term basis. Fire speeds up the release of nutrients that were already in the litter or vegetation and would have been released more slowly by mineralization. Some nitrogen and sulfur are volatilized during burning, but substantial amounts of nitrogen are deposited in the soil in the ammonium form after even hot fires. If fire releases more nutrients than the soil can store, nutrient losses are likely to occur.

Thinning—Thinning a dense stand on a moderately fertile soil can produce an effect similar to fertilization. Thinning makes more total resource available to the tree and gives each remaining tree access to more nutrients. If the needed nutrients are available in the expanded soil area for exploitation by root growth and if the roots are able to grow more extensively after thinning (the tree has juvenile vigor), annual additions of biomass to the crowns should occur first with an ultimate increase in diameter growth. Trees are often unable to extend their roots into new soil after thinning because of hormonal deficiencies, soil compaction, or other causes, so it may become necessary to fertilize the soil to encourage more rapid tree growth.

Acidification—Acid deposition is an extremely controversial subject. Even more controversial is the subject of forest decline (D'itri 1982; Hutchinson and Havas 1980; McLaughlin 1985). Although acid precipitation is one possible cause of worldwide forest decline, there are isolated reports of improved tree growth on some soils (Hutchinson and Havas 1980). The high nitrogen in acid rain could account for improved tree growth. Acidification from rainfall or other causes may increase the availability of acid-soluble nutrients such as iron and manganese in soils with more alkaline pH.

DETERMINING NUTRIENT DEFICIENCIES

Fertilizer is applied as a means of overcoming nutrient cycling deficiencies that influence plant growth in the ecosystem. It has become common practice in forestry to assume that nitrogen deficiency automatically limits tree growth on almost any site. The standard cure is to apply either urea or NPK fertilizer. Fertilizer is usually applied without prior foliar or soil analyses. Inadequate nitrogen does limit tree growth much of the time, but recent studies suggest that lack of other nutrients may also limit growth (Stark and Spitzner 1985; Stark and others 1985; Turner 1983). One study showed chronic deficiencies in calcium, potassium, and boron (Stark and Spitzner 1985). More serious deficiencies of nitrogen and manganese were identified. Fertilizers are being applied by injection to determine if these ions do limit growth in Douglas-fir. These deficiencies are apparent only because they are based on statistical significance of nutrient levels in xylem sap, not on proven growth responses. In all cases where nutrient deficiencies were studied in Douglas-fir, good tree growth was associated with significantly higher concentrations of Ca, K, Mn, P, and N in plant components. A nitrogen fertilizer that also acidified the site may make deficient nutrients such as Mn and P more available (if the soil is alkaline).

A nutrient deficiency may be spotted by:

1. Analyzing soil from sites with poor growth, but apparently little water or energy stress and no serious insect or disease pests.
2. Analyzing foliage from plants growing under the conditions specified in 1 above and taking into account tree age, needle age, time of year.
3. Analyzing soil water extracted in the field from stands qualifying under 1.
4. Analyzing xylem sap prior to growth flush from trees of the same age, elevation, aspect, but growing under the conditions specified in 1.

Soil extractions require digging a soil pit, collecting one or more soil samples from the feeder root zone, and extracting these using artificial extracting solutions (usually ammonium acetate or DTPA) in the laboratory. The method is time-consuming because several soil samples are needed for each stand, but can provide useful information if the levels of artificially extractable ions needed for good growth of that species in that soil type are known. This method is still commonly used, in spite of the high variability in soil nutrient concentrations. Soil may have to be collected and extracted from better growth sites for comparison if the concentrations needed for good growth are not known.

Foliar analyses require collecting needles or leaves, then cleaning, drying, grinding, and ashing them. The ash is taken up in a strong acid that converts all ions into chlorides or sulfates that can be analyzed by a number of different instruments. For comparison, it is usually essential to collect foliage of the same age from individuals of the same species that are growing well and from plants growing poorly. Sample collection and preparation is time-consuming and expensive, but foliar analysis provides some of the best information on nutrient deficiencies (Stark 1984).

Soil water extractions are made using a series of porous ceramic-tipped water probes set in the soil to the desired depth. When a vacuum is pumped on the tubes, the natural soil solution filters through the ceramic tips with only minor chemical changes. Establishing and maintaining the probes in the soil is costly and time-consuming; once established, however, the water that is pumped from the probe can be analyzed directly for a large number of nutrients at minimal cost. The method is faster and better than artificial soil extracts because it allows analysis of the soil solution that is available to the roots. There are few published data on the range of nutrient concentrations in soil solutions needed to support good growth of different species, while many generalized publications exist for the nutrient concentrations usually found in ammonium acetate extracts of soil (Stark 1982).

Xylem sap analysis is a new technology that allows the forester to evaluate a stand quickly and inexpensively for deficiencies of nutrients and water. Xylem sap stores sugar behind the buds in winter; sap can be analyzed for sugar levels during the winter months. The best time to sample xylem sap is just prior to the growth flush in May or early June on a rainy or cloudy day. Sampling can be done at other times, but it is usually necessary to measure transpiration during summer months.

Winter sap analysis works well as long as the branches are frozen. Sampling should be from branches of one species about 2 ft long from trees ±5 years of the same age in the lower third of the crown (if possible) on the same aspect and collected alternately from test and control individuals during the day. After the branch is cut, it is tested for water potential using a pressure chamber and then extracted at 300 or 350 psi. The extract is diluted and analyzed for 15 nutrients by inductively coupled plasma spectrometer (Stark and Spitzner 1985; Stark and others 1985). In winter, branches can be evaluated for immediately available sugars using analysis for total nonstructural carbohydrates in xylem sap. The extractions require 3 to 6 minutes, and analysis (including total nitrogen) can be completed in about 5 minutes (except for sugar). Although a large body of published results on nutrient levels needed for good growth does not exist, new data on sap nutrients are appearing more frequently. Since the method is fast and cheap, there is usually no problem collecting paired samples from good and poor growth sites.

APPLIED FERTILIZATION METHODS

When nutrient deficiences are determined for forested areas, and natural fertilization levels are inadequate for optimum growth, the technology exists for various methods of application by foresters. Fertilizer can be applied in several ways:

1. Aerial, liquid, dilute
2. Forceful injection into the bole
3. Aerial, pelletized
4. Pelletized or granular, drilled
5. Granular or pelletized, broadcast
6. Organic sludges.

Aerial Liquid Fertilization

When fertilizer is applied to foliage directly as a liquid spray, we can be reasonably certain that it will be taken up by the plant (Soil Improvement Committee 1980). The main problems are drift from wind and excessive concentrations that burn the foliage. Direct aerial sprays put the nutrients where they are needed for quick uptake and use by the tree. Nutrient deficiency in the foliage is often severe, but ion deficiencies in the roots may be even worse.

Aerial application does not put the nutrients where they are needed if the roots are deficient. If the roots are lacking in phosphorus, for example, the energy transfer system may be unable to supply the energy needed for the active uptake of other nutrients if the P is applied aerially away from the roots. Phosphate applied in dilute solution to the needles may be taken up and used by the needles, but the mechanism by which excess phosphorus is transported out of the needles to the roots is not clearly understood. Theoretically, excess phosphate could be moved down to the roots through the phloem.

Foliar applications of the needed nutrients usually correct the problem of nutrient deficiencies in foliage, but they are expensive and short-term. One advantage is that large areas can be treated. However, any aerial application runs the risk of drift to water supplies and subsequent contamination.

Pressure Injection

Pressure injection of fertilizer has some of the same advantages and drawbacks as aerial sprays. The main difference is the point of application. Pressure injection can be in the lower bole or at the root collar. In either case, the nutrients are most likely to be carried upward into the crown, becoming available to the cambium first, the needles second, and then, possibly, the roots (Zimmerman 1983).

Root meristems, cambium, and needles have different nutrient needs at different times. We know some about the relative nutrient needs of various plant parts and the timing of these needs, but not enough to make decisions about the best way to inject nutrients from a physiological point of view. Pressure injection is costly and time-consuming. It is not practical as a field technique in forestry, but it does have value in urban forestry where nutrients are not easily added to roots. The forester has to be certain of an economically significant growth response such as might occur in a seed orchard to justify injection of fertilizer.

Aerial Pelletized Fertilizer

It is not easy to apply nutrients where the trees' roots can easily reach them. Aerial pelletized fertilizers such as urea are commonly used. Aerial application is fast, but not cheap. The pellets released from a plane may be fast-release (readily water soluble) or time-release (slowly water-soluble). Urea pellets are usually readily soluble. Up to 40 percent of the urea applied from the air may volatilize on a hot day if the pellets are intercepted and held by the crown. Rain or wind soon drops the pellets to the ground. As moisture contacts the pellets, the urea goes into solution and is quickly acted on by the enzyme urease that is prevalent in most soils (Nannipieri and others 1985). Urease converts urea to ammonium, which is slowly converted to nitrate by bacteria.

Pelletized or Granular Drilled

When it is essential that the roots of trees receive the fertilizer directly, it is possible to drill holes up to 1 ft deep and pour in small doses of granulated or pelletsized fertilizer. This practice, while effective, is costly because it is labor intensive. It is less effective in areas of high rainfall with coarse-textured or gravelly soils because of excessive leaching losses. Borkert and Barber (1985) discussed the placement of fertilizers in agricultural soils. Older studies addressed fertilizer placement in forests (Brendenmuehl 1968). Soil compaction greatly reduces surface fertilizer movement into soil.

Pelletized or Granular Broadcast Fertilizer

Fertilizer broadcast from the ground is likely to affect the entire ecosystem and is less specific to tree growth than aerial sprays or injections. Ground application of fertilizer, as opposed to aerial application, requires considerable person-hours and is difficult to carry out in steep topography. Tree growth response is not readily predictable with ground broadcast fertilizers.

Organic Sludges

Organic fertilizer and treated sewage sludge are being used more frequently in lowland forests. Steep topography limits the usefulness of this type of fertilizer because of the difficulty of putting the nutrients where they are needed and keeping them there. Low sludge application rates in closed canopy forests can be useful on steep topography. Sludges are good in drier climates because they add nutrients, organic matter, and water.

EFFECTS OF FERTILIZATION

Fate of Fertilizers in Soil

Fungi present in the duff and surface soil take up considerable amounts of nitrogen. Some of the fungi may be mycorrhizal and may transport nitrogen to tree roots. Once the bacteria or fungi capture the nitrogen, it can be taken into other parts of the food chain, by protozoans as they eat bacteria or arthropods eating fungi, or through the gut of earthworms and many other organisms.

If the nitrate (or urea) survives microbial conversion in the surface duff and enters the soil, the soil microorganisms have the first chance to utilize the fertilizer. Denitrifier organisms will convert some forms of nitrogen (nitrate) under conditions of low soil oxygen to N_2O and then to nitrogen gas that reenters the atmosphere. These denitrifiers are usually not abundant in forest soils, but they do cause a loss of usable nitrogen, especially in soils with low oxygen. Most plants can use nitrate, but some require nitrogen in the ammonium form. Still others cannot use ammonium. Bacteria can convert nitrate to ammonium and then to nitrogen gas which is lost into the air. Other bacteria and fungi absorb nitrate for their own growth needs. Once nitrogen is captured by soil microbes, it will not be available for tree growth until it is either released in waste products (as a result of grazing) or the microbes die and decay.

After surviving the microbes, the nitrate is available to grass and forb roots in the surface 4 inches (10 cm) of soil. Grass roots are often dense in the surface soils and are able to screen out large amounts of nitrate. A nitrogen fertilizer may not make it past the surface grass roots. Within the grass root layer are roots of some shrubs, particularly shallow-rooted, rhizomatous shrubs such as *Arctostaphylos* *uva-ursi* and *Vaccinium* spp. These plants do not have dense roots like the grass, but they do have high nitrogen demands.

If the nitrogen fertilizer survives the microbes, surface soil, and grass and shrub roots, it may be available to enter tree roots. Fertilizer treatment may result in no accelerated tree growth in a reasonable length of time (1 to 3 years).

Nitrogen Storage in Soil

In the soil, exchangeable or available nitrogen is stored in two main ways. If nitrogen occurs as the positively charged ammonium ion, it will be held on the cation exchange sites or the negative bonding sites on clays and organic colloids. If nitrogen occurs as a negatively charged anion in the soil, it will be stored on the positively charged anion exchange sites of the soil. Most forest soils have very low anion exchange capacities. Either the anion (NO_3^-) or the cation (NH_4^+) on the exchange sites are in dynamic equilibrium with the soil solution. As the plants take up nitrate from the soil solution, more nitrate ions move off the anion exchange sites and into the soil solution. If prolonged irrigation or leaching from rain occurs, the nitrate ion may be washed beyond reach of the roots to deep soil horizons or to a water table. These leaching losses of ions deplete the system of nutrients needed for tree growth.

An ammonium fertilizer can acidify the soil as can ammonium uptake by plants. As each NH_4^+ is metabolized by nitrifying bacteria to NO_3, two H^+ ions are released into the soil solution. An excess of H^+ ions can saturate the soil solution of acid soils, and the hydrogen ions then knock off Ca, K, Na, Mg, and other cations from the exchange sites. These nutrient ions are likely to be leached from the soil, especially in coarse-textured soils.

Effects of Fertilization on Thinned Stands

When a stand is thinned, more resources (CO_2, water, nutrients, sunlight) are made available to the remaining trees. Fertilizer adds nutrient resources without increasing available water, sunlight, or CO_2. Current theory states that when a stand is thinned, the first response of the trees is to grow a more extensive fine root system. Fertilizing a stand may result in increased root growth initially, but reduced root growth later as more carbon is allocated to the crown and bole. If lack of water or sunlight limit tree growth in a fertilized, unthinned stand, the root stimulation may not occur. Application of the wrong fertilizer may also fail to stimulate root growth. If the crowns of thinned stands are small and thin, they may not be able to produce sufficient hormones to stimulate roots. Once more feeder roots have developed, or ion uptake efficiency has increased, the tree will begin to put on more annual crown growth. With a larger crown area or improved leaf area, the tree will begin to show more rapid annual radial growth. The acceleration of radial growth may occur in 1 year following fertilization in wet climates or may take 3 to 7 years in drier climates.

Optimum Nutrient Research—Sweden

Of particular interest to foresters is the work on optimum forest nutrition in progress at Norrliden and other areas in Sweden (Holmen and others 1976). Foliar analyses are used with fertilizer application (NPK) to maintain constant nutrient levels in foliage over time. The objective is to determine which levels of nutrients will produce optimum growth. Soil acidification studies are also in progress in Sweden, and some plots are under irrigation. Results of fertilizer tests show increased foliar total nitrogen, with reduced Ca, Mg, and Mn from dilution effects. Stem volume growth was related to tree size stocking density and foliar nitrogen for Scotch pine (*Pinus sylvestris*). Urea and ammonium nitrate increased stem volume growth, while ammonium nitrate alone influenced height growth. Sulfuric acid treatment on NPK-fertilized plots inhibited nitrogen mineralization.

The development of Cate-Nelson curves to evaluate N and P deficiency in foliage is of increasing value in prescribing correct fertilizer treatments. These curves make it possible to compare chemical data from foliage of a species to determine if deficiency, sufficiency, or excess nutrient concentrations occur. More species need to be analyzed by these means (nutrient concentration and perneedle nutrient content) to allow more extensive use of this system (CRIFF Report 1986).

Other work in Sweden has concentrated on intensive cultivation of seedlings using programmed daily additions of complete fertilizers to stimulate maximum growth. With this method, daily nutrient additions are adjusted to the daily nutrient demands of the seedlings to optimize growth (Waring, personal communication).

Fertilization Studies—Northwestern United States

Several regional forest fertilizer or fertilizer-thinning studies are in progress in the Pacific Northwest. The Regional Forest Nutrition Research Project has emphasized study of the response of thinned and unthinned stands of second-growth Douglas-fir (*Pseudotsuga menziesii*) to urea (Mandzak, personal communication). Stem growth response may occur 7 or 8 years after treatment with 224 or 448 kg N/ha. In unthinned stands, growth response is inversely related to site index. Ammonium nitrate is a potential substitute for urea in the Northwest.

Light fertilizer application at the time of planting, particularly with species like Douglas-fir that often begin growth slowly, may be beneficial, based on studies in the Northwest on this species (Mandzak, personal communication) and *Pinus radiata* in New Zealand and Australia (Turner 1983). Most forest fertilization programs do not take into account natural mineralization rates or individual species—age demand curves.

By way of summary, the forester has many alternatives to consider in determining optimum nutrient levels. A good understanding of the needs of various tree species, the soil, soil chemistry, and economics is needed to achieve the desired results for any particular piece of ground.

A growing amount of technological information is being presented in a manner that can be used by forest managers with some expertise in soils. Technology is being developed **now** for the time in the **future** when we can afford to use it.

Nutrient Loss Model—NUTROSS

One other common nutrient cycling concern is the possibility of removing too much nutrient from chemically fragile soils during harvest. Our laboratory has developed a model called "NUTROSS" that uses field data from any site and calculates how much nutrient is likely to be lost as a result of harvest at any level of intensity. The method has been tried on three widely different sites and appears to work well. All that is needed from the field is the volume of timber removed by species, size categories removed (slash or boles to a 3-, 4-, or 5-inch top), ammonium acetate extractable and DTPA nutrients in the feeder root zone of the soil (except N), total soil nutrient content, and depth of the feeder root zone. This model assumes that all materials **left** on site will be available to grow those same materials in the next rotation, if they are not removed in harvest. Thus, nutrients in slash, litter, duff, unmerchantable top, understory, and available soil nutrients are used to rate nutrient losses. Losses should not exceed 30 percent of available recyclable ecosystem nutrients for any essential nutrient. If harvestable material does exceed 30 percent of ecosystem nutrients, the site is said to be chemically fragile, and intensive harvest is discouraged. Such sites require special cultural practices such as wider spacing, more fertilizer, or low nutrient-demanding species.

Nutrient Cost Evaluation—FORCYTES-10

Another, more complex approach to evaluating nutrient costs and harvest practices includes an economic evaluation as well as cost/benefit ratios (Feller and others 1983). FORCYTE-10 (Forest Nutrient Cycling and Yield Trend Evaluator) is a computer simulation model of forest biomass production, litter fall, mineralization, nutrient cycling, and nutrient limitations on growth that allows evaluation in response to different management regimes. The model accounts for thinning, fertilization, various utilization levels and rotation lengths on nutrient capital, stand (tree) productivity, and economic performance, as well as an evaluation of energy efficiency. It has been developed largely for Douglas-fir over an array of growth sites. This complex model uses at least 14 sequential programs to run quickly and inexpensively. One drawback is the cost of getting "real data" to use to test such a complex model, but it is definitely a tool for the future and will be available when needed.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Bruce F. Short)—If whole-tree harvest/yarding can have negative impacts on some sites, what effects would broadcast burning have on nutrient-limited sites?

A.—Broadcast burning should do less harm to nutrient availability on a nutrient-limited site than pile burning. The answer depends on how severe the nutrient limitations are. With data that we have used so far in the NUTROSS model, when boles only are removed from chemically fragile soils, the loss of nutrients from broadcast burning is usually low, except with sands or gravels or shallow soils with high precipitation.

Q. (from Lee Harry)—On poor-site lodgepole pine if we whole-tree harvest but still leave lots of sound, dead material, will that help the nutrient status much? Often we can do that more cheaply than lopping tops. Do those old boles leave us many nutrients?

A.—The answer depends on the quality of the soil. That can be judged best by entering real data into NUTROSS. Generally, whole-tree harvest is likely to damage the nutrient balance on a site because of the high nutrient content of foliage and small branches. The boles are relatively poor in nutrients. Large boles over 12 inches in diameter will help, but less than the foliage from a stand **plus** large woody debris which adds nitrogen.

Q. (from Barry Bollenbacher)—Could you comment on the widespread practice on National Forest and industry lands of whole-tree yarding in lodgepole pine stands with site productivities of 50-90 ft^3/acre/yr? This is the normal practice currently in Montana. (Tops are burned at the landings.)

A.—The answer is similar to that for question 2. Burning tops offsite removes significant amounts of nutrients. Whole-tree harvest is normally not justifiable on any lodgepole pine stand.

Q. (from Dennis R. Parent)—Do bole removal and intensive slash disposal (pile and burn) have the same effects as complete tree removal?

A.—Burning on site releases nutrients back to that soil. If the soil can store all of the nutrients released from pile burning, the only harm will be loss of the pile microsite for immediate regeneration. Usually pile burning overloads the soil with nutrients that are, in part, lost through leaching. When a whole tree is removed, those nutrients are lost from that site forever. Whole tree removal is a poorer practice than slash pile burning, but neither are recommended on chemically fragile soil.

Q. (from Ernie Collard)—If leaving tops, roots, etc., on site after harvest is good for four rotations, what do you recommend for the fifth rotation? Fertilization program or a fallow rotation?

A.—We calculate that four rotations with the tops, branches, and needles left on site will allow time for the soil to weather and release enough nutrients to replace the boles removed in the fifth rotation. During the three or four rotations, weathering should enrich the soil to make it a more productive site for trees while the nutrients removed in logs were replaced from the available soil pool. At the end of the four rotations, the soil available pool should have recovered its losses and have additional nutrient reserves to carry the next three rotations. Four rotations is an estimate at best and will be revised when we know more about weathering. Most likely the fifth rotation will not support whole-tree harvest either, but we have no evidence at this time.

Q. (from Neal Forrester)—While whole-tree utilization is not a common practice in the West, logging practices such as tree length skidding and skidding tops to landings are being used more frequently. Do you know of any work done to determine the effects on site nutrients resulting from these practices?

A.—We can program NUTROSS to answer any question of this type. We have estimated nutrient losses for the removal of boles only. (See manuscript by this author.)

Q. (from Bob Naumann)—Can fertilization affect susceptibility of thinned stands to root disease?

A.—This is hard to answer. I suspect that fertilizer can increase the spread of root rot in thinned stands, but I do not have any proof of this.

ESTIMATING THE RESPONSE OF PONDEROSA PINE FORESTS TO FERTILIZATION

Robert F. Powers
Steve R. Webster
P. H. Cochran

ABSTRACT

Ponderosa pine responds well to nitrogen (N) fertilization—particularly when fertilization is combined with weeding. Findings from California and eastern Oregon show that fertilization can improve stand volume growth an average of 30 percent over 5 years. This equates to annual volume gains of from 30 to 75 ft³ per acre for pole-sized trees on average sites. Plantations freed of weed competition grew twice as fast as unweeded plantations following fertilization. Those scalped of topsoil during site preparation showed nearly three times the fertilization response of plantations where topsoil remained intact. The best single index of stand N deficiency (and predictor of fertilization response) was N concentration in foliage from the upper crowns of dominant trees. Deficiencies were pronounced at foliar N concentrations of less than 1.1 percent. Overall, 76 percent of the variation in relative growth response to fertilization could be explained by foliar N concentration, soil C:N ratio, and site index.

INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) is the most widely distributed commercial pine species in North America, and nitrogen (N) is the most common nutrient limiting its growth. Case studies (Cochran and others 1981; Powers 1983) indicate that pine growth can be increased by N fertilization, particularly when fertilization is combined with other silvicultural treatments such as weeding (Powers and Jackson 1978). Forest fertilization is expensive though. Sites will be favored where response is apt to be strong and consistent, and where financial returns are high. Extensive fertilization is unlikely in the Intermountain-Rocky Mountain regions where site qualities are comparatively low, rotations are long, and markets are remote (Long and others 1986). However, the more productive forests of California, central Oregon, and northern Idaho may be another matter.

In his economic analysis of fertilization trials conducted by Cochran (1979) on small-diameter ponderosa pine in central Oregon, Randall (1981) concluded that fertilization could not be justified unless costs were reduced, stumpage prices increased, or growth rates improved substantially. Part of the cost of fertilization concerns the inefficiency of fertilizing stands that have little or no chance of responding to treatment. Thus, there is a need for developing a site-specific means for predicting the likely response of particular stands to fertilization. We believe that a sufficiently large mass of data now exists on ponderosa pine response to fertilization in the Pacific States that a general predictive response model might be possible. Accordingly, we have pooled our data to examine this possibility.

METHODS

All of our ponderosa pine field experiments having at least 5 years' growth response were combined into one data set containing information on 43 study sites—15 in the Oregon Cascade Range, and the remainder in the Coast and Cascade Ranges and Sierra Nevada of California (fig. 1). Study sites encompassed about 7 degrees of latitude, 3,700 ft of elevation, and 56 inches of annual precipitation (table 1). Soils were formed from volcanic, granitic, and metasedimentary rocks and covered a broad array of textures and depths. All soils had been classified to the series level (USDA SCS 1975) and were typical for the pine region in the two states.

Twenty-five of the installations were plantations; the remainder were thinned, even-aged natural stands. Size classes mainly were saplings and poles. Plots, each 0.10-acre or larger, had been treated with urea at one of three

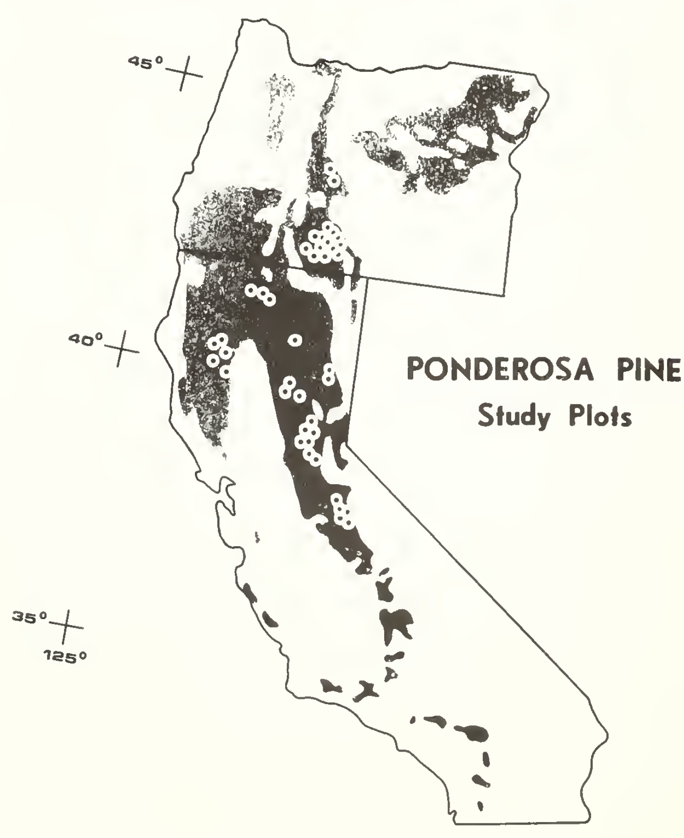

Figure 1—Distribution of 43 fertilization study installations in California and Oregon superimposed on the range of ponderosa pine.

Table 1—Characteristics of ponderosa pine study sites in California and Oregon

Variable	Mean	Range
Latitude (degrees)	39°25'	36°57' - 43°51'
Elevation (ft)	4,580	2,600 - 6,320
Precipitation (inches)	39	17 - 73
Site index (ft at 50 years)	62	35 - 110
Soil C (pct)	3.67	0.94 - 7.06
Total soil N (pct)	0.148	0.050 - 0.413
Mineralizable soil N (ppm)	18	3 - 42
Foliar N, current (pct)	1.22	0.77 - 1.60
Foliar N, 1-year (pct)	1.10	0.70 - 1.40
Volume response to N (pct)	30	-12 - 263

N rates: 0 (control), 200, and 400 lb N/acre with two to four replications per treatment. Thirty-two of the 43 installations received the 400-lb N rate. Eighteen sites, all in Oregon, received additional "full" nutrient treatments (usually P, K, and S). Of these, 14 had both N and full treatments at the same study sites. Six plantations had been manually weeded of brushy species. Except for weed competition, stands were considered adequately (but not overly) stocked and capable of crown expansion. Underbark stem volumes were measured on each plot at treatment and again after five growing seasons using either optical dendrometery or equations based on total height and breast-height diameter. Volume growth was determined by the difference between starting and final volumes of surviving trees, and expressed on a per-acre basis.

Site index was estimated on untreated control plots either conventionally using regional reference curves adjusted to a total age of 50 years, or through height intercept (Powers and Oliver 1978). Surface soil horizons were sampled on untreated control plots for all the California and some of the Oregon sites. These were analyzed for total N and organic C by standard methods, and the 7- to 9-inch depth zone was analyzed for mineralizable N (Powers 1980). Current-year needles were collected in the fall from the upper-third crowns of dominant trees on unfertilized plots and analyzed for total N by modified micro-Kjeldahl procedures. Samples of 1-year-old foliage also were collected on about half the installations. Means and ranges of physical and chemical values are shown in table 1.

Growth increment on plots with substantial variation in initial stocking was adjusted for uniformity using covariance analysis. Because installations differed in tree size and stocking, absolute volume increment was not a satisfactory way of reporting response. Instead, response to treatment was expressed as the proportional change in 5-year volume increment relative to the control treatment at that location (a response of "50" meaning that fertilization increased volume growth by 50 percent). All measured variables were examined for colinearity through a correlation matrix. Sets of independent variables with low colinearity that best explained variation in treatment response were selected from all possible regression subsets using adjusted R^2 and Mallows' *Cp* statistic as selection criteria (BMDP 1981). The most efficient subset was examined further using multiple linear regression of transformed variables to produce an effective estimation equation.

RESULTS

General Findings

Combining data from all stands receiving 0, 200, and 400 lb N/acre treatments indicates that N response increases fairly linearly with fertilization rate (fig. 2). Because the 400-lb treatment was not applied to all stands, subsequent reference to N response concerns only the 200-lb treatment. Analyzing fertilization response for the 14 installations receiving full treatments in addition to N suggests that the greatest response is due to N alone (fig. 3). Other nutrients improved growth by about one-third more than that attributable to N. Foliar analyses (not shown) suggest that the added response is due to S, supporting earlier findings from multiple-nutrient trials (Cochran and others 1981).

Five-year volume gains from N fertilization averaged about 30 percent overall (table 2). Most stands responded positively, with two-thirds showing 5-year growth increases of at least 20 percent. Growth gains were proportionally greater for fertilized stands on soils formed from metasedimentary rocks than on soils of other parent materials. Granitic soils were associated with the highest site indices and the lowest responses to fertilization. Response differences between planted and natural stands were minor, but plantation response was more variable.

Nonuniformity in plantation response can be traced to several possible causes. Several plantations that had not reached crown closure had been invaded heavily by brush

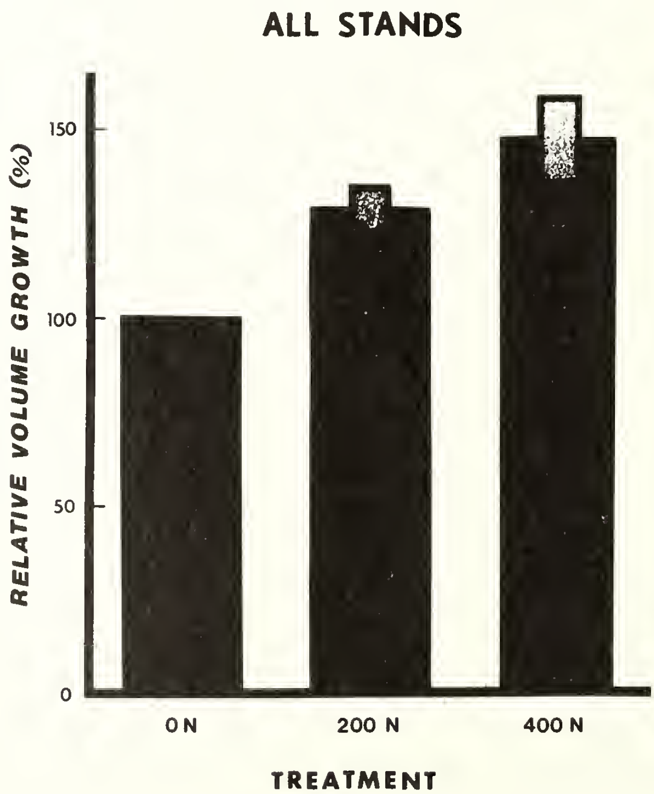

Figure 2—Means and standard errors of 5-year growth response at 32 research installations to N treatments at 0, 200, and 400 lb N/acre as urea. Response is expressed relative to 0 N treatment = 100 percent.

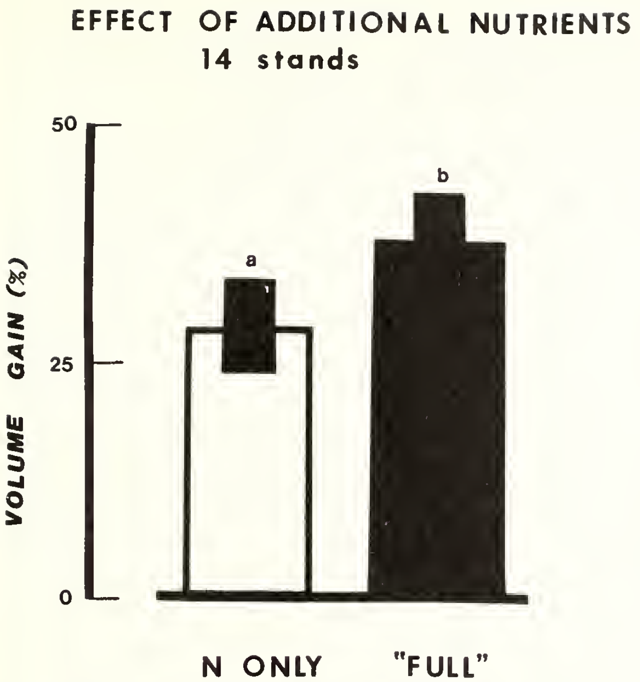

Figure 3—Effect of N and "full" (N + additional nutrients) treatments on volume growth expressed as a percentage gain over that for unfertilized stands. Bars show means and standard errors for 14 paired installations.

Table 2—Relative volume growth response of ponderosa pine stands fertilized with 200 lb N/acre in respect to general stand and site attributes

Stand origin	Condition	No.	Mean site index	Relative growth response to N	
				Mean	S.E.
				- - - *Percent* - - -	
All stands		43	67	29.5	5.6
Planted	All	25	70	27.7	8.7
Natural	Thinned	18	62	32.0	5.6
All stands	Granitic soil	5	85	4.6	5.4
	Volcanic soil	29	62	23.7	4.4
	Metased. soil	9	65	61.7	19.4
Plantations	Weeded	6	59	43.5	24.5
	Not weeded	19	73	22.7	8.8
Plantations	Scalped	19	66	33.5	11.3
	Not scalped	6	88	9.0	4.0

(mainly *Arctostaphylos* Adans. and *Ceanothus* L. species) and grasses. Those freed of weed competition at the time of fertilization averaged about twice the relative fertilization response as unweeded plantations, although variability was great. Also, plantations where topsoil had been scalped into windrows during site preparation showed more than three times the fertilization response as unscalped plantations.

Plantations with both soil and foliar nutrient analyses were examined further. Scalped sites averaged considerably less mineralizable soil N and substantially lower N concentrations in both current and year-old foliage than

Table 3—Soil and site characteristics of established plantations of ponderosa pine where topsoil has or has not been scalped (removed) during site preparation. Basis: 16 scalped and six unscalped sites with both soil and foliar nutrient data

Characteristic	Topsoil scalped		Topsoil not scalped	
	Mean	S.E.	Mean	S.E.
Mineralizable soil N (ppm)	15.5	2.50	24.9	5.30
Foliar N current (pct)	1.13	0.05	1.24	0.06
Foliar N year-old (pct)	1.06	0.06	1.12	0.05
Site index (ft at 50 years)	66.0	4.80	88.0	7.10
Relative growth response (pct)	37.8	13.20	9.0	4.00

unscalped sites (table 3). Site indices were one-third greater where soils had not been scalped, but this may be more an effect of parent material than of topsoil loss. Nearly all of the scalped sites were on volcanics or metasedimentaries, but half of the unscalped sites were on granitics.

Correlations

Comparing our eight measurement variables with relative growth response to fertilization indicates that only C:N ratio in the A horizon, N concentration in foliage of the current and previous year, and site index bear any substantial linear relationship to growth response (table 4). The most strongly correlated variable was N concentration in 1-year-old needles ($r = -0.66$). However, this also was correlated highly with two other useful variables—soil C:N ratio and N concentration in current-year foliage. Consequently, it was not considered further in multivariate analyses. All possible subsets regression confirmed that C:N ratio, N concentration in current-year foliage, and site index were the subset variables producing the lowest Cp statistic and one of the highest coefficients of determination. Site index and foliar N concentration were significantly correlated at $p = 0.05$, although the relationship was fairly loose.

Despite its utility elsewhere (Moore this proceedings; Powers 1983; Shumway and Atkinson 1978), mineralizable soil N was not correlated strongly with fertilization response. Possible explanations include differences in laboratory technique and the need to stratify data by soil temperature regime (Powers 1984). Soil temperatures classified for this data set ranged from mesic to cryic.

Predicting Fertilization Response

The most effective form found for a four-variable equation involving the independent variables soil C:N, foliar N, and site index, and fertilization response as the dependent variable was:

$$Y = 16.1 + 2.14\ \text{C:N} + 271\ (\text{N}-1.35)^2 - 0.74\ SI \qquad [1]$$

$$s = 24.6$$

$$R^2 = 0.76$$

Table 4—Coefficients of linear correlation between variables measured on 43 ponderosa study sites

	Volume response	Site index	Precipi-tation	Latitude	Mineral-izable N	Foliar N 1-yr	Foliar N current	Total N
C:N ratio	[1]0.65**	–0.11	–0.14	0.00	–0.11	–0.71**	–0.39	–0.27
Total N	–.15	–.06	.15	.06	.17	–.11	.13	
Foliar N current	–.63**	.41*	–.42*	–.27	.11	.89**		
Foliar N 1-yr	–.66**	.30	–.28	.22	.08			
Mineralizable N	–.13	.27	.44*	–.08				
Latitude	.10	–.26	.38*					
Precipitation	.06	–.09						
Site index	–.54**							

[1]Linear correlation significant at $p = 0.05$ (*) and $p = 0.01$ (**).

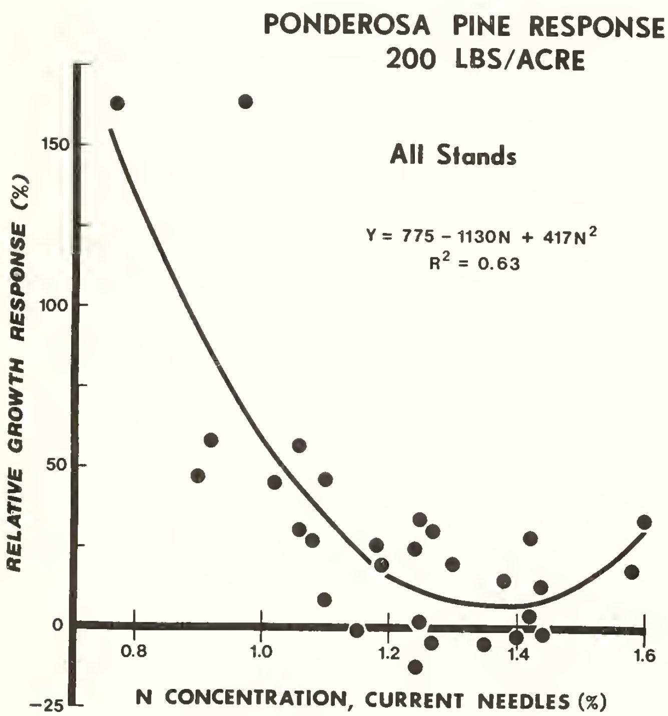

Figure 4—Data and quadratic relationship of foliar N concentration to growth of fertilized stands receiving 200 lb N/acre. Growth is expressed as a percentage change in 5-year volume increment relative to unfertilized stands.

where

Y = 5-year volume growth response to 200 lb N/acre expressed as percentage change from growth on unfertilized plots for the same period and stand

C:N = the ratio of organic C and total N by weight in the fine fraction of the A-horizon

N = the concentration of total N in current-year needles collected in the fall from the upper-third crowns of dominant trees and expressed as percentage dry weight

SI = site index, or the height in feet attained by dominant trees at 50 years total age

and s and R^2 are the estimated standard deviation about the regression line and the coefficient of multiple determination, respectively.

The best single predictor of fertilization response was the quadratic expression:

$$Y = 775 - 1130\,N + 417\,N^2 \qquad [2]$$

$$s = 26.2$$

$$R^2 = 0.63$$

The display of this equation in figure 4 indicates that response predictions may be conservative at very low values of foliar N.

DISCUSSION AND CONCLUSIONS

Ponderosa pine clearly is capable of strong response to N fertilization in the forests of California and Oregon. Average response was essentially linear with fertilizer rate through 400 lb N/acre (fig. 2), suggesting that stands have an even greater capacity to respond than shown here. The average response to 200 lb N/acre was a volume growth increase of about 30 percent, with plots on sedimentary soils responding the most, and those on granitic soils the least. Interestingly, plots on metasediments showed nearly three times the relative growth response as those on volcanics although their site indices were virtually identical (*SI* 65 and 62, respectively). This suggests that N unavailability is a major growth-limiting factor on metasedimentary soils, but that other factors tend to be more important on volcanics.

Relative growth responses to fertilization should be converted to absolute responses to make sound management decisions concerning treatment. Absolute 5-year volume gain through N fertilization can be estimated by the following example: given a site index of 60 ft at 50 years (our average condition for volcanics and metasediments), an average stocking of 260 stems per acre, and a mean stand diameter of 11 inches (Oliver and Powers 1978), 5-year growth of an average plantation should be about 705 ft^3/acre. Fertilization responses on our volcanic and metasedimentary sites averaged 24 and 62 percent, respectively (table 2)—translating to a 5-year fertilization response gain of 169 to 437 ft^3. These estimates seem plausible. For example, one of our pole-sized, *SI* 56 Oregon stands on volcanics had a fertilizer gain of 170 ft^3/acre, and a

California *SI* 70 stand of small poles on a metasedimentary soil produced an additional 375 ft³/acre through fertilization.

Plantations with reduced weed competition showed twice the fertilization response as unweeded plantations, and not merely because site quality was lower in the former (table 2). Six plantations had full-factorial combinations of weeding and fertilization that allowed direct, paired comparisons. There, average volume growth was nearly four times greater from weeding than from fertilization alone, but was over nine times greater when weeding was combined with fertilization. Where summer drought occurs, competition must be controlled before trees will respond well to N fertilization. We doubt that fertilization will boost tree growth enough to shade out competing weed species in established but unweeded plantations of ponderosa pine.

Plantations scalped during site preparation averaged more than three times the fertilization response as unscalped plantations (tables 2 and 3). Results are confounded somewhat because scalping and nonscalping were not actually tested side by side. However, scalping removes fertile topsoil where organic N accumulates (Powers 1980, 1984). Thus, we infer that scalping may lead to sizable reductions in site quality. Controlled experiments are necessary to obtain data free of confounding factors.

Relative growth response of stands to N fertilization can be estimated from knowledge of soil C:N ratio, site index, and foliar N concentration (eq. 1), or nearly as well from knowledge of foliar N concentration alone (eq. 2). Independent data now are needed to validate these models. The true relationship of fertilization response to foliar N concentration probably is not quadratic, but is asymptotic to the N axis at higher values of N. The relatively high fertilization response shown at 1.6 percent foliar N in figure 3 is for a unique stand thinned very heavily for seed production. The large crowns found on such trees have considerable capacity to expand. Because of this, trees such as these generally will respond to N fertilization even though N concentrations in current-year foliage are high (Miller and others 1981; Powers 1984). We conclude that trees testing at or below 1.1 percent N in current-year, upper-crown needles at the end of the growing season are experiencing N deficiency.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Bill Peterson)—What are the differences—particularly leaf display and retention—between evergreen and deciduous trees in their response to N fertilizer?

A.—The first effects of improved N nutrition are larger, darker green leaves because of better growth and higher chlorophyll content. On sites where lack of N is more of a limiting factor than moisture, leaves are retained somewhat longer than usual. For evergreens, this means that leaves might be retained for a few months to a year longer, so that crowns appear fuller than those of unfertilized trees. For deciduous trees, crowns will be fuller, but the effect may persist for only one or two seasons. Because their foliage isn't perennial, deciduous trees lack the capacity of evergreen trees to store fertilizer N in their biomass for continued internal cycling and reuse.

Q. (from Bruce Greco)—What are the significant effects of continued "pile and burn" activities on drier ponderosa pine sites?

A.—About 300 to 500 lb N/acre might be present in the forest floor and slash following logging or type conversion on a dry ponderosa pine site. Generally, about ten times more than this is present in the mineral soil. If a piling operation is "clean," only the aboveground material goes into the piles for burning. Depending on burning intensity, between 50 and 80 percent of the N is volatilized. This means that between 150 and 400 lb N/acre might be lost from an average site during burning. The remainder is converted to NH_4^+ and enters the soil during the next rain. If you assume N input in precipitation averages between 2 and 5 lb N/acre/year, an 80-year rotation would replace most or all of the burning loss. Remember that intense slash burning is probably a one-time event in the life of a stand, so the impact should not be particularly noticeable over a rotation. Impacts may be much more severe if topsoil is piled along with the slash, however.

Q. (from Gerd Eichel)—Are you confident that your results apply to all soils, or would soils derived from recent glaciation be different? Shouldn't we analyze the soil first to discover which elements are deficient?

A.—None of our study sites had soils derived from recent glacial materials. Therefore, we can't be certain that responses would be similar on such soils. Based on findings from the Douglas-fir region however, stands on soils of recent glacial deposits respond more strongly and consistently to N fertilization than those on other soil types. Concerning soil analysis, reliable tests simply have not been established for western forest trees. The beauty of foliar analysis is that the tree integrates all the factors of site, including nutrient availability. Either nutrients are in the tree in adequate amounts, or they are not. In practice, one would screen for as many nutrients as they could afford that would likely be limiting growth, and the laboratory results would be compared against established standards to determine the main limiting nutrient.

Q. (from John Joy)—Did animal damage (particularly porcupine) increase in fertilized stands of pine?

A.—We did not detect increased animal damage of any type.

Q. (from K. Higginbotham)—When (at what age) is the best time to fertilize?

A.—Biologically, the "best" time is just before nutrient concentrations in tree foliage approach suboptimal levels, but this requires repeated sampling and knowledge of "optimal" (not "critical") concentrations. Practically, the "best" time is just before crowns have closed. This is the time when trees are relying almost entirely on the soil for supplying their nutrient needs and building more crown. After crown closure, crown mass doesn't change much and as much as half of the annual demand for N is met internally through recyling from senescing foliage and twigs.

Q. (from Craig Cowie)—On deficient soils, is one fertilizer treatment enough? If not, how often would you refertilize?

A.—Generally, N fertilization responses last between 5 and 10 years before fertilizer N gets tied up in the soil or humus, or is leached away. The main thing that N does is increase crown size. Thus, the "fertilizer effect" might be expected to last for at least as long as crowns can continue to expand (as long as there's some place to store the fertilizer N). The practical thing to remember is that fertilization should result in some usable product. One might fertilize small poles just after a precommercial thinning and capture the investment in a commercial thinning at the next stand entry. Depending on foliar N concentration, the manager might then fertilize again, or wait until the next commercial thinning before final harvest.

Q. (from David Crampton)—Would you elaborate on why needles formed in the previous growing season (1-year-old foliage) seem more reliable for N diagnosis than current-year needles?

A.—Although essentially all of the N content of a needle is organic N, about half is soluble in the phloem—meaning that it can be translocated within the tree from regions of relatively low growth activity to regions of high activity. During a growing season, needles formed in that season have an unusually high demand for N because chlorophyll and other N-containing compounds are being formed concurrently with cell expansion. In essence, current-year needles have first-crack at whatever soluble N is available. If this demand can be met by root uptake, fine. But if the soil is infertile and uptake rate can't keep pace with demands made by new foliage, the deficit may have to be met by N reserves in older foliage. Thus, the first signs of N stress will be reflected in lowered N concentrations in older foliage as N is translocated from those needles to more active growing points. One-year-old needles are sensitive sampling units because they produce the bulk of the carbohydrate that's used in stem growth and will show low N concentrations sooner than younger needles.

Q. (from Don Wood)—Foliar nitrogen concentration seems to be a good measure of N status of the tree and potential response to fertilization. Are there services available to field foresters for conducting chemical analyses? If so, what are the costs?

A.—Many commercial laboratories are available for chemical analyses. Some are good, some not so good. Costs generally run between $8 and $12 a sample, depending on the number of samples to be run. Agricultural departments of land grant universities may provide such services at little or no cost. Your local agricultural extension agent should steer you toward a reliable facility.

Q. (from Rolan Becker)—Do you foresee fertilization of immature stands as ever being practical in the Northwest?

A.—Under present management strategies, no. However, certain zones may be dedicated in the future to intensive forest management. If so, the strategy will be to grow trees to a commercially optimal size as rapidly as possible. In certain cases this may involve repeated applications of mixed fertilizers beginning with stand establishment. Research is already under way to evaluate the biological possibilities, including interactions of improved nutrition with water use and susceptibility to insect damage.

RESPONSE OF DOUGLAS-FIR, GRAND FIR, AND WESTERN WHITE PINE TO FOREST FERTILIZATION

James A. Moore

ABSTRACT

The major factors influencing tree growth response to nitrogen fertilization seem to be stand density and soil physical and chemical properties. Stands of moderate density show the greatest absolute and relative response to fertilization. As pretreatment available nitrogen increases response to nitrogen fertilization decreases, and there are significant differences in treatment response by soil parent material. Lack of nitrogen seems to limit tree growth almost everywhere in the intermountain Northwest; however, on some sites, other factors such as moisture and other mineral nutrients also may limit growth. Growth response to fertilization peaks at about 4 years after treatment, and is still significant in years 6 to 8. The "best" application rate seems to be 200 pounds of nitrogen per acre.

INTRODUCTION

This will be a brief review of what we know about nitrogen fertilization in the intermountain Northwest.

I will cover:

1. Does lack of nitrogen limit tree growth in the intermountain Northwest?
2. Are there other factors that explain differences in response to nitrogen fertilization?
3. What application rate seems to be preferred? Results from Douglas-fir will be used to illustrate the above three points.
4. What is the duration of response to nitrogen fertilization? Based on longer term results for grand fir in north Idaho.

Answers to the first questions are provided by results from a study of Douglas-fir by the Intermountain Forest Tree Nutrition Cooperative (IFTNC). This is an organization composed of 12 industrial, Federal, and State forest land management organizations in Washington, Oregon, Idaho, and Montana. The host institution is the College of Forestry, Wildlife and Range Sciences, University of Idaho.

There are 94 Douglas-fir installations with stands averaging 30 to 80 years old, distributed in six geographic regions of the Cooperative: western Montana, northern Idaho, central Idaho, northeastern Oregon, central Washington, and northeastern Washington. There are a minimum of six plots at each installation (each plot is at least 0.1 acre in size) for a total of 572 permanent plots. Stocking control treatments (if any) were conducted more than years (an average of 8 years) prior to fertilizer application Therefore, this is **not** a thinning-by-fertilizer study. Although the stands were thinned, the Cooperative wanted range of densities—so some stands are overdense even though they may have been thinned previously. The fertiizer treatments were 200 lb and 400 lb of nitrogen applied as urea in the fall (IFTNC 1987).

DOES LACK OF NITROGEN LIMIT TREE GROWTH IN THE REGION?

Figure 1 shows the cumulative distributions (C.D.F.'s) for foliar nitrogen concentrations for current year foliage collected during the dormant season 1 year after fertilization from the third whorl down from the top of the tree.

The vertical line indicates 1.4 percent foliar nitrogen concentration. This value is estimated to be an inadequat level for coastal Douglas-fir. This example is for basalt, but it is typical for all parent materials.

For all stands, the average untreated foliar nitrogen concentration was 1.12 percent. This is very low. More than 90 percent of the stands were below the inadequate level of 1.4 percent.

When the stands were treated with 200 lb nitrogen per acre, foliar N increased to an average concentration of 1.3 percent but more than one-half remained below 1.4 percent. When treated with 400 lb of nitrogen, the average foliar N concentration increased to 1.75 percent and only about 20 percent of the stands were below 1.4 percent.

Almost every stand showed substantial increase in folia N after treatment. Therefore, nitrogen uptake did not seem to be a problem even with the wide variety of site ar stand conditions included in the sample. Nitrogen does seem to be very low in the region, and we would expect significant growth response to nitrogen fertilization!

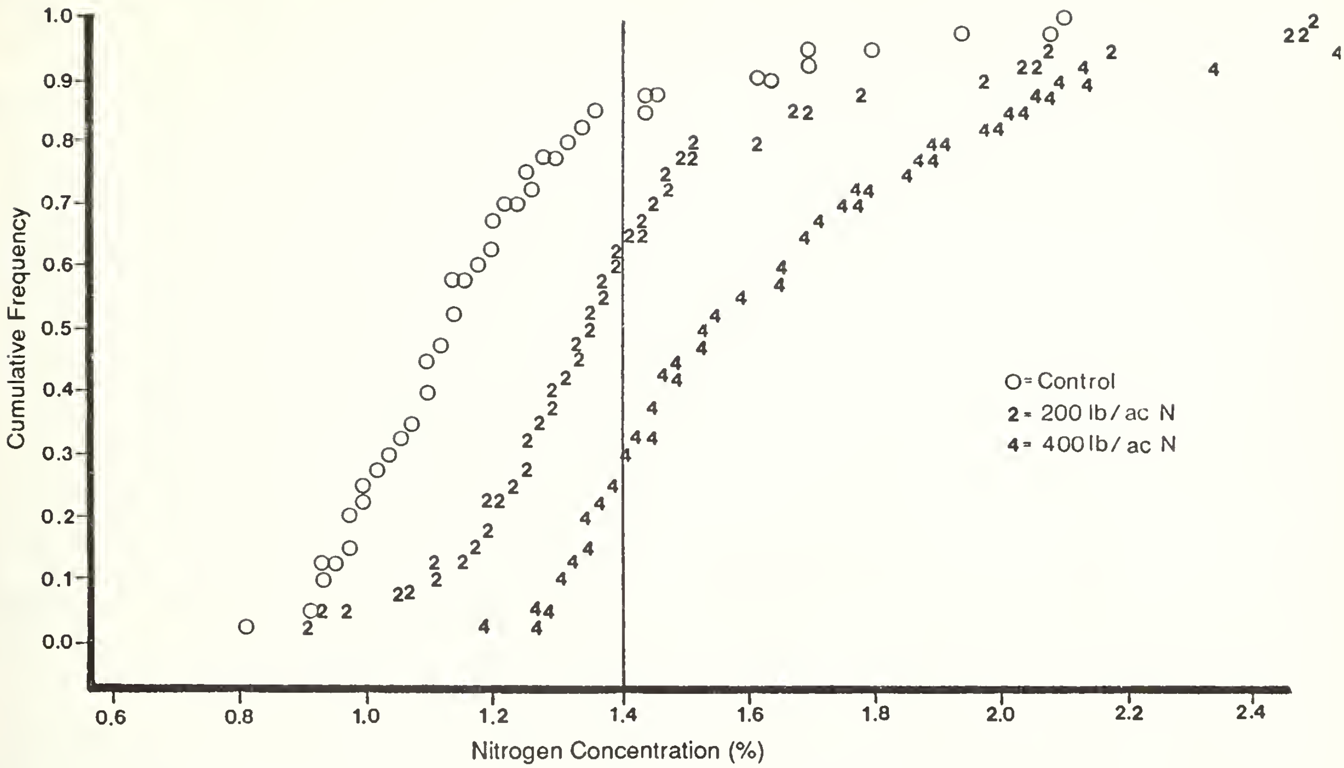

Figure 1—Cumulative distribution of foliar nitrogen concentration following nitrogen fertilization.

WHAT APPLICATION RATE SEEMS TO BE PREFERRED?

After 2 years there was, overall, a significant response (IFTNC 1987). Two hundred pounds of nitrogen per acre produced an average growth response of 2.4 ft^2/acre (28 percent) and the response to the 400-lb treatment was 3.0 ft^2/acre (35 percent). There were significant differences in growth response by geographic region: northern Idaho and central Washington showed the greatest response, while northeastern Oregon and Montana were less than average (although still significant). Response was most variable in the Montana region. Response to the 400-lb treatment was significantly greater than to the 200-lb treatment only in northern Idaho and central Washington. If nitrogen were applied to all these stands we would expect these significant average responses; however, response was highly variable. Some stands did not respond at all (about 15 percent) and some showed more than twice the average.

Fortunately, much of the variation in response to nitrogen fertilization can be explained by differences in stand density, soil parent material, and pretreatment mineralizable nitrogen (Min-N) rate.

In general, as stand density at the time of fertilization increases, predicted treatment response decreases. However, there is a significant interaction between stand density and soil parent material. The interaction is such that maximum response to fertilization occurs at different densities depending on parent material.

The ash/metasediment is typical to illustrate the relationship between initial stand density and response to treatment. Basal area per acre growth for the untreated control plots is greatest at approximately 130 ft^2/acre for this parent material. Basal area growth response to 200 lb of nitrogen per acre is greatest at the lowest initial basal areas sampled, but the curve is relatively flat over the range of densities sampled. Response to the 400-lb nitrogen treatment peaks at a stand density of about 120 ft^2/acre. However, 2-year response is predicted to be greater than 4 ft^2/acre even at an initial basal area of 175 ft^2 (IFTNC 1987).

As previously mentioned, soil parent material (or soil forming process) was also an important variable in predicting response to urea fertilization. The average percent response by parent material is listed below:

Parent material (process)	200 lb	400 lb
	Percent	
Granite	21	32
Ash-loess	40	45
Basalt	29	31
Glacial till	27	32
Ash/metasediments	28	41
Valley fill	–3	–1
Colluvium	48	77
Alluvium	39	27
Sandstone	63	74

Sandstone and colluvium produced the highest percentage response to both nitrogen treatments, and valley fills showed no response at all. Granites were below average, but treatment response was significant.

The third significant variable for predicting response to nitrogen fertilization was pretreatment levels of mineralizable nitrogen (Min-N). This index of soil nitrogen availability was estimated using the anaerobic incubation technique described by Powers (1980).

There is an inverse relationship between 2-year basal area per acre growth response and Min-N. Stands with low levels of pretreatment Min-N produced significantly higher responses than those with high Min-N.

ARE THERE OTHER FACTORS THAT EXPLAIN DIFFERENCES IN RESPONSE TO NITROGEN FERTILIZATION?

It appears that on some sites the availability of other mineral nutrients may be inadequate to support increased growth after nitrogen fertilization. Examination of the foliar content and concentrations of other nutrients before and after nitrogen fertilization (using the same foliage samples described previously) reveals some interesting patterns. Nutrient ratios (balances) were often substantially changed 1 year after the nitrogen treatments (IFTNC 1987). In some situations both foliar nutrient concentration and content were significantly reduced. If concentration fell below inadequate levels suggested for coastal Douglas-fir, then response to nitrogen fertilization was significantly less than expected. The patterns of change in foliar concentrations of other nutrients were different for certain soil parent materials. Potassium was the element most frequently falling below an inadequate foliar concentration (6,000 ppm); this particularly occurred on ash-loess, glacial till, and valley fill parent materials. Copper, boron, and iron foliar concentrations occasionally were below inadequate levels after nitrogen fertilization.

WHAT IS THE DURATION OF RESPONSE TO NITROGEN FERTILIZATION?

Grand Fir

We don't know for sure, but there are some long-term results (14 years after treatment) available from 12 grand fir stands located in northern Idaho. These fertilization trials were originally installed by University of Idaho researchers Howard Loewenstein and Dave Scanlin (Shafii 1988). Recent (1985) remeasurement of these stands and subsequent data analysis were funded by Potlatch Corporation through the IFTNC. In Shafii's study the treatments were: thinned only, thinned plus fertilized, fertilized only, and no treatment. The fertilizer treatments were 200 lb of nitrogen per acre applied in the form of urea. Unlike the previously described Douglas-fir experiment, the fertilization treatments were applied at the same time as the thinning.

The net annual basal area response to fertilization in thinned grand fir stands was 0.4 ft²/acre (11 percent) during the first 2-year period after treatment (Shafii 1988). This was statistically significant, but much less than the Douglas-fir during the first 2-year period. The response difference is more likely due to thinning shock in the grand fir stands than species differences. Response to fertilization peaked during years 3 and 4 (0.9 ft²/acre, 22 percent) and began to decline during the third 2-year period. Although response to fertilization was less in years 5 and 6 than in years 3 and 4, growth on the thinned and fertilized plots was still significantly greater than on the thinned-only treatments (0.6 ft²/acre, 11 percent) during this period. By years 7 and 8, response was no longer significant. During the last 6 years of the period (years 9 through 14), average growth of the thinned and fertilized plots was actually less than the thinned-only treatments. However, this difference was not statistically significant. Growth response was highly variable between stands during the last 6 years of the study, probably because the stands received thinning treatments of different intensities. Some of the stands were heavily thinned and others thinned only lightly. The lightly thinned stands rapidly reoccupied the available growing space after fertilization. Thus the duration of fertilization response was shorter than in stands with more available growing space.

Urea fertilization in the unthinned portion of the same grand fir stands produced different patterns of response over time. Response was significant and much higher (1.5 ft²/acre, 36 percent) than in the thinned stands during the first 2 years following fertilization. The level of response was more like that discussed earlier for Douglas-fir. This is circumstantial evidence supporting the thinning shock explanation in the thinned grand fir stands. Response during years 3 and 4 was substantial (1.7 ft²/acre, 57 percent), but by years 5 and 6 was no longer significant. There was no significant response to fertilization during the remainder of the 14-year period.

These results show that duration of response to nitrogen fertilization is shorter in unthinned stands than in thinned stands. However, remember that these results are for total net basal area growth per acre and that fertilization may have other effects on stand growth. For example, nitrogen fertilization may result in proportionally more growth response for large trees in a stand with consequent increased mortality in smaller size classes. These possible changes in tree size distributions can be masked when looking at stand averages. The influence of fertilization on stand dynamics is the subject of on-going research.

Western White Pine

There is little information available on the response of western white pine to nitrogen fertilization, probably because blister rust has greatly reduced the number of suitable white pine stands. Scanlin (1980) reported an approximate 30 percent response to 200 lb of nitrogen per acre 6 years after treatment in two young (approximate age 10 years) white pine stands located in northern Idaho. Graham and Tonn (1985) reported no significant response after 10 years to the same nitrogen treatment in one

18-year-old white pine stand in the Priest River Experimental Forest. Urea was the nitrogen source in both studies.

SUMMARY

1. Nitrogen is below adequate levels throughout the region.
2. Growth response to nitrogen fertilization is variable. Much of the variation in response can be accounted for by: (a) stand density; (b) soil parent material; (c) pretreatment mineralizable nitrogen.
3. Two hundred pounds of nitrogen per acre seems to be a good treatment.
4. Duration of response is about 6 years (at least in grand fir stands) and probably depends on stand density.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Susan Stout)—Although Dr. Powers made clear the need for crown room to optimize fertilizer response, don't you risk "thinning by fertilization" in stands thinned 8 years earlier? I wonder if a relative density measure would have even more explanatory power than initial basal area, by accounting simultaneously for density and average tree size?

A.—If the phrase "thinning by fertilization" means "accelerating crown differentiation by fertilization," then the answer is yes if the stands had reoccupied the growing space. There is some preliminary evidence that the larger trees in a stand respond proportionally more to fertilization than the smaller trees. This can accelerate mortality rates in smaller size classes, and, of course, is more noticeable in denser stands. This may be happening in the longer term grand fir study and is currently under investigation. The more extensive Douglas-fir trials have not been established long enough to see a fertilization effect on stand dynamics. If fertilization does cause a significant change in tree size distributions, then the value of the additional increment due to fertilization would be greater than is represented by stand totals, since larger trees are worth more given the same total volume.

The second part of the question deals with the measures of stand density used in the analysis. Several relative density measures were tested: Stand Density Index (Curtis 1982) and Crown Competition Factor (Krajicek and others 1961). There was no significant difference in the variation explained by these terms and basal area per acre. Since all the measures performed equally well, we chose to express the results using the traditional basal area.

Q. (from Rob Mrowka)—In habitat types with a brush understory such as vine or mountain maple, do you have any data that would suggest we can still expect a reasonably good response to fertilization following a commercial thin?

A.—A qualified yes. Some of the Intermountain Forest Tree Nutrition Cooperative's Douglas-fir test sites in central Washington do have vine or mountain maple in the understory, and they showed good growth response to fertilization. However, there are additional data available on the composition and quantity of the understory plant community that have not yet been analyzed. Graduate student Jim Mital is conducting this analysis as part of his Ph.D. research project. (For additional discussion of the influence of competing vegetation on fertilization see the answer to the next question by Mr. Deboi.)

Q.(from Gary Deboi)—Bob Powers said that fertilization without brush control was not worthwhile. Have trials in Douglas-fir and other trials in the Pacific Northwest or Inland Empire shown similar results? Any guesses or assumptions?

A.—The results that Bob Powers presented were for young stands where the trees had not yet established dominance on the sites and were still under heavy competition from the brush. I think that similar stands in our region would show similar results. The results I presented were for older stands (approximate age 30 to 80) that were already well above competing vegetation, and for the range of conditions sampled by the Cooperative, the understory community does not seem to have as much influence on fertilization response as in juvenile stands. I am not saying no influence, just not as much as in juvenile stands.

Q. (from Kris Hazelbaker)—You have used the foliar nutrient limitations of coastal Douglas-fir for interior Douglas-fir. How valid do you feel that transfer is, and is work being done to validate figures for interior Douglas-fir?

A.—Using the foliar nutrient values developed for coastal Douglas-fir has provided us with useful ballpark estimates for the inadequate levels for most mineral nutrients. The nitrogen values seem to be good. However, there is some circumstantial evidence that the inadequate levels for some of the other nutrients for Douglas-fir growing on some soils in the intermountain Northwest may be somewhat less than those estimated for coastal Douglas-fir. Let me quickly add that this is a very complex subject and more work needs to be done. The work of the IFTNC could be termed "empirical validation" of these foliar nutrient values; but to really answer the question a different kind of experiment would need to be conducted. I'm not aware of any current work in the region to experimentally determine inadequate levels for interior Douglas-fir foliar nutrient concentrations.

NUTRITION AND FERTILIZATION OF LODGEPOLE PINE

Gordon F. Weetman

ABSTRACT

A review of recent fertilization trials with lodgepole pine in North America is presented. Fertilizer work with both jack pine and lodgepole pine suggests a close similarity in response between the species, which actually interbreed. Lodgepole pine appears to be particularly responsive to nitrogen additions; phosphorus deficiencies may be induced by nitrogen additions. Responses as high as a 50 percent increase in volume increment over a 10-year period have been found with applications of nitrogen over 150 kg/ha. Some case study data are presented. Priorities and testing protocols for operational fertilization also are presented.

INTRODUCTION

One of the earliest studies of lodgepole pine in the United States (Clements 1910) contains the following statement:

> All of the evidence obtained in the present study indicates that competition is wholly a question of available water and light. In exhausted soils and those poorly aerated, both nutrients soils and air play a part in competition. In natural habitats, however, such as those of the lodgepole forests, where all the nutrient salts taken from the soil are ultimately returned to it, and where the loose texture of the gravel permits thorough aeration, these factors are negligible.

Today we know that the role of "nutrient salts" is not so negligible and actually many lodgepole pine are responsive to nutrient additions. However, our understanding of lodgepole pine nutrition and fertilization is much better than is indicated by the sparse North American literature. This is because:

1. Lodgepole pine (*Pinus contorta*) as a hard, two-needle pioneer pine species is apparently very similar in its nutritional requirements to other pines of this type, notably jack pine (*P. banksiana*)—with which it interbreeds naturally in Alberta—and Scots pine (*P. sylvestris*). There is evidence to suggest that lodgepole pine will respond in the same way as these two species to soil nutrient additions (especially nitrogen [N]) and to soil nutrient deficiencies.
2. Much work has been done in Britain, Ireland, and Scandinavia on lodgepole pine nutrition and fertilization.

This paper reviews some of our understanding of these species, outlines some current studies, and presents some recent fertilization response data. Nursery nutrition of lodgepole pine will not be covered.

The species is famed for its extraordinarily wide ecological amplitude and low competitive ability. Outside of its altitudinally defined interior North American range (ssp. *latifolia*), where it forms vast forests, *P. contorta* is forced off the richer sites by more competitive species and occurs on extreme sites (muskegs, dunes, rocky sites, and serpentine soils) as ssp. *contorta* (shore pine). In an extreme case (ssp. *bolanderi*) it occurs as dwarf trees on very nutrient-poor acid podzols (Critchfield 1978, 1980). Its ability to tolerate and successfully grow on extremely nutrient-poor sites is borne out by mineral nutrition studies. Swan (1972a, 1972b) found its nutritional requirements similar to those of Scots and slash pine (*P. elliottii*). Table 1 presents foliar nutrient concentration standards from three sources. Morrison (1974) reviewed literature on the interpretation of foliar nutrient status data. A microcomputer program using published data to provide interpretation of the nutritional status of foliage samples for macro- and microelements has recently been developed (Ballard and Carter 1986). Color photographs of visual deficiencies in lodgepole pine are presented in Binns and others (1980).

Work on nutrient cycling in the last decade has recognized two phases in stand development (Miller 1981; Royal Society 1982).

Phase I—Prior to Canopy Closure

At this phase, the trees are very dependent on soil supplies and almost any nutrient may be limiting, especially when lodgepole pine is planted or occurs on extreme sites or soils. Precise and early diagnosis is clearly desirable. Lodgepole (shore) pine planted on acid impoverished mineral and organic soils in Britain and Ireland can grow with low levels of available N and potassium (K) if phosphorus (P) is applied. This characteristic of lodgepole pine has permitted the establishment of very extensive stands on oligotrophic peats in Britain and Ireland. Lodgepole pine planted on peats in the coastal belt of Norway has shown frost damage and shoot dieback due to low foliar boron concentrations (less than 3 ppm); a situation readily alleviated by borax additions to bring the concentrations up to 10 ppm (Braekke 1979). "Elimination" fertilizer trials to identify the nutrient needs of lodgepole pine planted on ombrogenous and soligenous peats have successfully yielded the appropriate fertilizer prescription, usually involving N, P, and K plus perhaps some micronutrient addition (Braekke 1977a, 1977b). Such studies in the United Kingdom and Scandinavia have demonstrated dramatic growth rates for fertilized lodgepole pine with balanced nutrition (Tamm 1985). Mean annual increments of 12-15 $m^3/ha/yr$ are attainable—values reflected in the United Kingdom Forestry Commission yield tables for lodgepole pine growing on good sites (Hamilton and Christie 1971).

Table 1—Published interpretations of foliar macronutrient concentrations for lodgepole pine

Nutrient element	Foliar concentrations, pct dry mass				
	Very severely deficient[1]	Severely deficient	Slight to moderate deficiency[2]	Adequate	Source[3]
N	0.00-1.05	1.05-1.20	1.20-1.55	>1.55	I
	[4]-	-	[5]≤1.20	[5]≥1.70	II
	-	-	<1.10	≤1.40	III
P	-	0.00-0.09	0.09-0.15	>0.15	I
	-	-	[5]≤0.07	[5]>0.17	II
	-	-	<0.12	≥0.14	III
K	0.00-0.35	0.35-0.40	0.40-0.55	>0.55	I
	-	-	[5]≤0.30	[5]≥0.60	II
	-	-	<0.30	≥0.50	III
Ca	-	0.00-0.05	0.05-0.10	>0.10	I
	-	-	[5]≤0.06	[5]>0.10	II
Mg	-	0.00-0.06	0.06-0.10	>0.10	I
	-	-	[5]≤0.07	[5]≥0.09	II
	-	-	(<0.03	[6]>0.05)	III

[1]Categories are a modified version of those of Ballard and Carter (1983); data from other sources were fitted into this on the basis of associated equivalences according to the qualitative terms used by authors.
[2]For sources other than Ballard and Carter (1983), values given may also include more severe deficiencies than indicated by this category.
[3]Sources are as follows: I=Ballard and Carter (1983); II=Swan (1972a and b); III=Binns and others 1980).
[4]Dash implies no explicit statement possible for the relevant categories. Please see footnote 2 also.
[5]Values are lower and upper limits, respectively, of Swan's (1972a and b) "transition zone from deficiency to sufficiency"; includes shore pine data.
[6]Bracketed values are tentative only.

Similar dramatic response for lodgepole pine with balanced nutrition is no doubt attainable in North America, particularly for shore pine in the coastal environment. In Europe lodgepole pine is used for major planting programs on the poor soils made available for forestry.

Not only does lodgepole pine respond dramatically to balanced nutrition, but Scandinavian experience has shown that for unfertilized soils, it grows much faster than Scots pine (Hagner 1985). For the same level of nutrition it is apparently photosynthetically more efficient than Scots pine. Massive use has been made of lodgepole pine in Swedish planting programs.

Whether or not N fertilizer will improve growth rates prior to canopy closure depends on the rates of N mineralization on the site. For peatlands, the rates are often too low to satisfy modest demands of planted trees. The plantations themselves may result in improved N-mineralization rates of peats (Williams and others 1979). The form of added nitrogen appears to make little difference based on studies in Scotland (MacIntosh 1982) and British Columbia (British Columbia Ministry of Forests 1986). In North America, N may be limiting particularly if organic matter reserves or cation exchange capacities are low in mineral soils. A key feature may be the length of the period of the flush of increased nutrient availability following fire or cutting (Assart effect). Capture of this flush by trees often occurs rapidly in fire-regenerated stands with serotinous cones, but may be missed on cutovers with delayed site preparation and regeneration.

Literature on nutritional studies of this species before canopy closure is limited. A 1981 test of 17 stands of young, precommercially thinned lodgepole pine in the interior of British Columbia used first-year needle weight and graphical diagnosis of foliar analysis to screen for response to a factorial test of levels of N fertilization with and without P and K (Weetman and Fournier 1982, 1986).

Over half the stands were strongly responsive, with 20 percent plus increases in unit foliage needle weight (fig. 1). Work with other species, notably jack pine (Camire and Bernier 1981; Timmer and Morrow 1984; Weetman and Algar 1974), has shown first-year needle weight response to be highly correlated with subsequent volume response. A systematic series of 11 fertilizer trials in young lodgepole pine stands has been established by the British Columbia Ministry of Forests in the interior of the Province (Brockley 1983, 1986). There is some evidence that N fertilization of young lodgepole pine attracts more girdling by snowshoe hares and squirrels.

It may be that many young lodgepole pine stands suffer from nutrient deficiencies. Since lodgepole pine grows on such an enormous variety of sites, it is probable that many trees may be deficient in nutrients, almost certainly on organic soils, and probably on soils of unusual chemical composition. Lack of nitrogen may limit growth on soils of low organic matter content. Since precommerical thinning is expensive, but often required to produce sawlog-sized trees, systematic testing by foliar analysis, screening trials, and conventional fertilizer trials may be warranted on stands not yet closed.

Phase II—After Canopy Closure

Although before canopy closure there is a shift of nutrients from soil to tree, once the canopy is closed, the tree's demands on the soil rapidly reduce, because the cycles within the tree and through the tree-litter system are then fully charged. The cycle within the tree is based on the recovery and reuse of nutrients prior to the death of old tissues, including those of the leaf before abscission, and can be up to 85 percent efficient. What is discarded, except that left in heartwood, is, to a greater or lesser extent, available to roots and mycorrhizal fungi from the litter layer.

These cycles may be very tight and, when supplemented by inputs from the atmosphere in rain or from other sources, may, for elements such as K and magnesium (Mg), enable the tree to become virtually independent of soil sources of supply. For other elements, however, notably N and, to lesser extent, P, rather slow release from the decomposing litter means the tree may have to continually recharge the cycle from native soil sources. For N this immobilization in humus can lead to the development of late-rotation N deficiency, a phenomenon that, because it has attracted a lot of research attention, has led to the belief that deficiency of N is the major nutritional problem in forests (Miller 1982).

This belief has been supported by the few reported fertilizer trials in closed stands, recently reviewed by Brockley (1983). These include one trial reported from Oregon (Cochran 1975, 1979), one study from British Columbia (Boyd and Strand 1975), an exploratory study

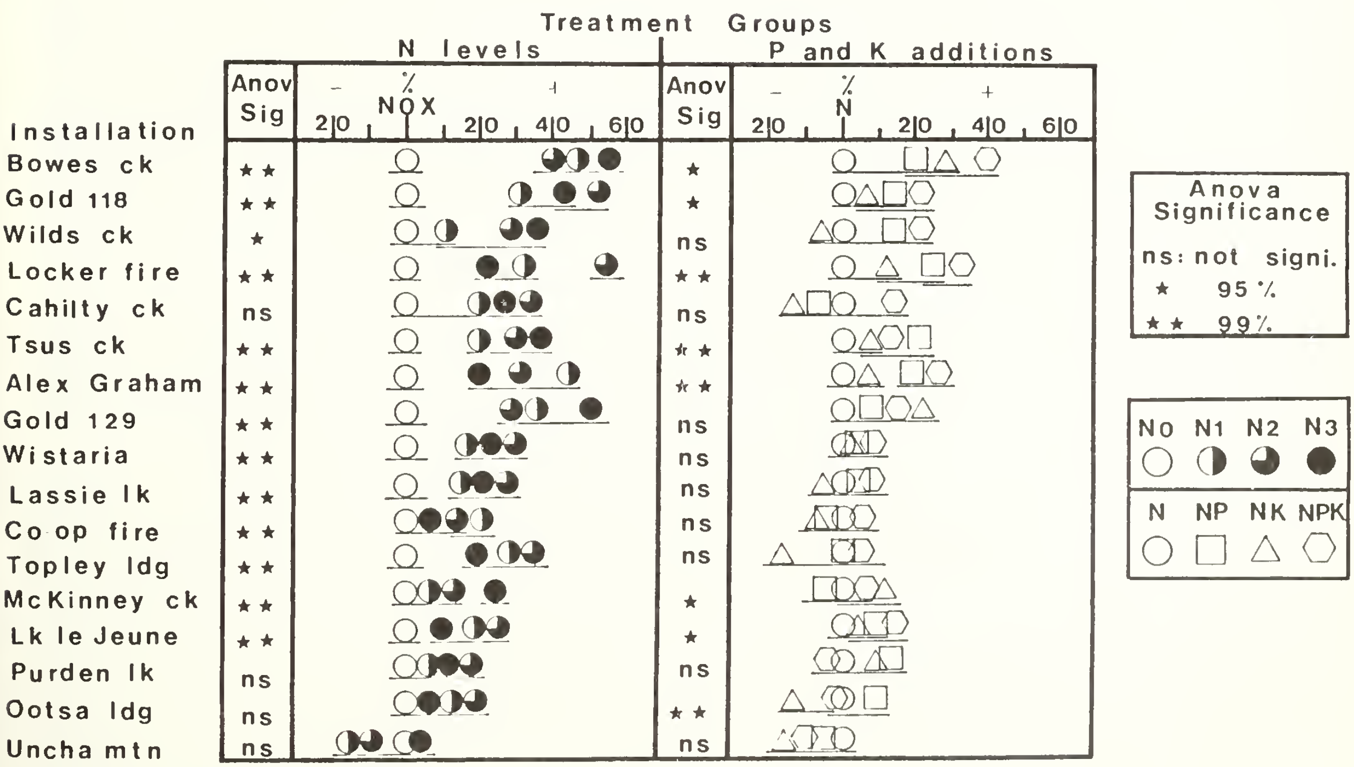

Figure 1—Relative first-year needle weights by treatment groups, statistical significance of two-way analysis of variance, and Student-Newman-Keuls multirange tests for 17 lodgepole pine fertilizer screening trials in British Columbia.

(Bella 1978), and a full-fledged fertilization experiment in 30- and 70-year-old stands on two soil types in Alberta (Yang 1984a, 1984b).

In Oregon, a single, mixed NPS treatment (N 672, P 336, and sulfur [S] 101 kg/ha) was compared to an unfertilized control in a thinned, 40-year-old pole-sized stand growing on pumice soil. Four-year and 8-year growth response was reported by Cochran (1975, 1979). Eight-year volume response averaged 18.8 m^3/ha (+79 percent).

Another Oregon study was established by Weyerhaeuser Corporation again on volcanic soils. Treatments consisted of (1) control, (2) N at 207 kg/ha, (3) N at 414 kg/ha, and (4) N at 414, P 90, K 98, and S 78 kg/ha. The experiment was conducted on both ash and pumice soil types. Three-year volume responses as large as 12.0 m^3/ha (+87 percent) were reported by Cochran (1979).

In the sparse North American literature, sulfur nutrition has received notable attention. Because soils in central Oregon, the Cascade Mountains, and western Alberta are reportedly low in S (Rennie 1974; Will and Youngberg 1978), S has often been added in fertilization trials of lodgepole pine (Bella 1978; Cochran 1975; Yang 1984a, 1984b). The mechanism of S nutrition in lodgepole pine growth is not clear, although Turner (1979) found that a constant ratio of 0.030 was maintained between organic S and total N in coniferous needles. Further investigations on interactions of S and N in lodgepole pine stands are needed.

The lone British Columbia study was undertaken by Crown Zellerbach Corporation near Kelowna. The research consisted of two parts: (1) an initial screening trial that indicated lack of N was the only factor limiting growth on the study site (Boyd and others 1975; Strand and Lin 1969), and (2) a study to test the effect of N fertilization, chemical thinning, and fertilization plus thinning on the growth of 40- and 80-year-old stands (Boyd and Strand 1975). N at rates of 1, 112, and 224 kg/ha as urea was applied to thinned and unthinned research plots. Thinning with MSMA (monosodium acid methanearsonate) was conducted at the time of fertilization. Four-year basal area growth response averaged 0.88 m^2 (+32 percent) and 0.28 m^2/ha (+19 percent) for the 40- and 80-year-old stands, respectively. Four-year volume growth response averaged 4.06 m^3/ha.

An exploratory study in Alberta (Bella 1978) in which a 70-year-old, medium site lodgepole pine stand was thinned for fenceposts and then fertilized with NPS (N 112 and 673 as urea-ammonium, P 56 and 168, S 28 and 84 kg/ha) showed that growth increased about 7 m^3/ha (30 percent gain in merchantable volume over 7 years due only to N [P and S were not significant]).

Closed jack pine stands have also shown a consistent response to N applications. The addition of urea (225 kg N/ha) to natural stands produced on average growth of 8.5 m^3/ha over 5 years (Foster and Morrison 1983). It is reasonable to expect similar response in lodgepole pine. Whether moisture or N is the primary factor limiting growth in closed stands is probably a site-specific phenomenon. Moisture is not a major limiting factor in most jack pine stands, but it may be in many lodgepole pine stands.

The problem of identifying and predicting response of closed stands to fertilizer additions still requires field trials; there is no sure way to identify responsive stands with confidence solely by soil analysis (such as N-mineralization rate) or foliar analysis. Screening trials using single tree fertilizer additions and foliar analysis offer a fast, inexpensive way to identify potentially responsive stands in one growing season (Weetman and Fournier 1982). Provided lodgepole pine is rooted in mineral soil, it is unlikely that P and K are major limiting elements in any soil types (Bella 1978; Yang 1984a, 1984b).

The upper limits of lodgepole pine productivity should be explored by various fertilization strategies (Axelssen 1983). There is every reason to expect that, as with Scots pine, stand productivity is directly related to N availability which in turn is controlled by N-mineralization and fertilization rates. Lodgepole pine grown close to optimum nutrition conditions should display a change in carbon allocation with increased bolewood efficiency and improved photosynthetic rate. It is unlikely that height growth is as good a response parameter in pine as diameter growth. The current information suggests that the potential for growth improvement through better nutrition is very great in lodgepole pine.

Recent Work in British Columbia

A decision to spend $20 million on forest fertilization over a 5-year period has provided funding for operational fertilization of interior lodgepole pine stands. However, most stands in the interior have received no stocking control and are usually very dense. To assist managers in making fertilizer decisions, a fertilization workshop was held in 1986 (British Columbia Ministry of Forests 1986). Results were reviewed from a series of screening trials in 1980 and a network of 11 recent conventional installations, plus studies of squirrel and hare damage and apparent boron deficiency problems.

Brockley (1986) came to the following conclusions:

1. Results indicate that lack of nitrogen is a major growth-limiting factor in young, juvenile-spaced lodgepole pine stands in the British Columbia interior. When other nutritional and nonnutritional factors are not limiting or near-limiting, lodgepole pine can be expected to respond favorably to nitrogen fertilization.
2. There is considerable variation in the responsiveness of juvenile-spaced lodgepole pine to nitrogen fertilization. Prefertilization assessment of foliar nitrogen status alone will not give a reliable indication of potential responsiveness to nitrogen application. In many areas, marginal boron or sulfur nutrition is indicated. Nitrogen fertilization may induce deficiencies of these nutrients, and others, thereby limiting response.
3. Preliminary results indicate that stands thinned at the time of fertilization respond similarly to previously thinned stands. However, the former may be more susceptible to snow-press following fertilization.
4. In certain areas, young juvenile-spaced lodgepole pine is very susceptible to feeding attack by red squirrels. Risk of damage is apparently significantly increased by

fertilizing juvenile-spaced stands. Damage to crop trees may restrict the beneficial effects of nitrogen additions and may have a negative impact on subsequent yield and investment value. Therefore, stands in which squirrel damage is noted during the pretreatment survey should be assigned lower priorities for operational fertilization.

Yole (1986) prepared the following statement for the Prince Rupert region of British Columbia:

> Most current fertilization work suggests that fertilization response should be greatest under the treatment combination of spacing and fertilization. Fertilization at the time of spacing should receive first priority, followed by spaced stands less than 3 years, and fertilization just prior to scheduled thinning. Obviously the fertilization schedule will closely follow the spacing schedule. One of the main problems in the Prince Rupert Region are the relatively few hectares of juvenile-spaced Pl stands (approximately 200 ha) available for fertilization treatment.

Table 2 summarizes the broad prioritization of stand and site conditions presently considered in an operational fertilization program in the Prince Rupert region. The following scheme (Figure 2) has been proposed by Yole (1986) to locate and recommend stands for research and operational fertilization.

Table 2—Priority of lodgepole pine stand conditions for operational fertilization

Factor	First priority	Second priority	Third priority
Treatment	Precommercial thinning and fertilization, no rehab option	Precommercial thinning and fertilization, rehab option possible	Commercial thinning and fertilization
Reasons	Shorten rotation length, improve volume and health	Improve health then consider improving volume	Improve crop tree volume
Age class	203	less than 4	3 and greater
Ecosystem association	SBSe/01 SBSe/04 SBSe/06	SBSe/03 SBSe/04	SBSe/03 SBSe/05
Density			
prespacing	4-8,000 sph	10-15,000 + sph	4,000 sph
postspacing	1,100-1,600 sph	1,600-2,000 + sph	300-800
Forest District	Lakes Morice (Bulkley)	Lakes (Morice)	Lakes Kispiox Kalum (Morice)

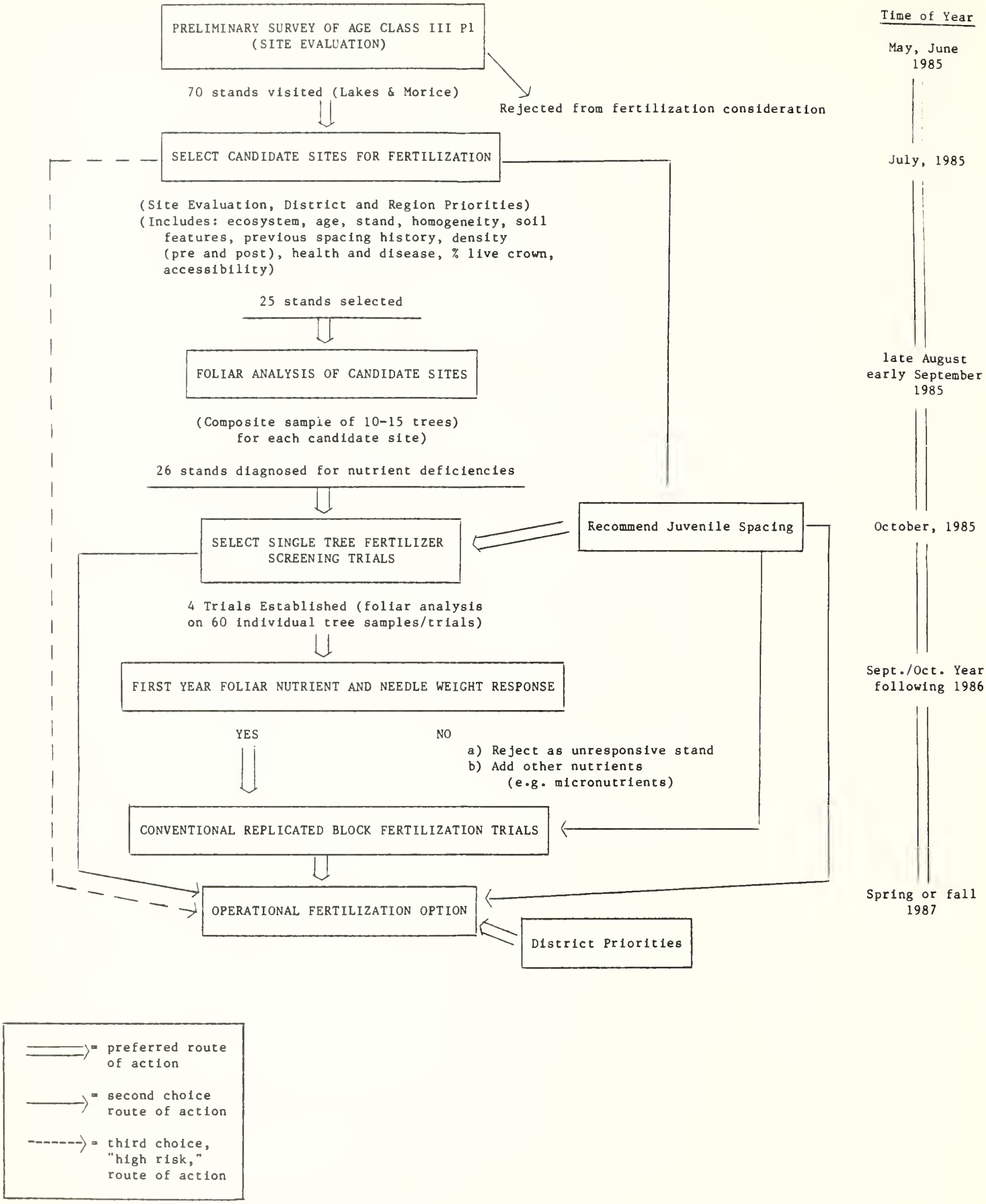

Figure 2—1985 scheme to locate and recommend stands for research and operational fertilization (from Yole 1986).

PRACTICAL QUESTIONS

1. Will nutrient removals by whole tree harvesting reduce soil fertility? This may occur in poor sites; particularly those low in organic matter. It is less probable on rich sites if it occurs once per long rotation.

2. Will slash burning result in fertility losses? There appear to be no long term nutrient balance studies on the species. Avoid organic matter loss on poor sites (Feller 1982).

3. How should stands be tested for fertilizer response? There are many ways ranging from screening trials to formal factorial fertilizer/thinning experimental designs. Obtain good advice and replicate. The 1979 Forest Fertilization Conference proceedings (Gessel and others 1979) is very helpful.

4. Should lodgepole pine be fertilized at the time of planting? Broadcast fertilization may result in increased vegetative competition, particularly grass, for the planted trees. It may not be necessary on fresh cutovers and fires with high levels of nutrient availability. On old cuts and burns, and on poor sites low in organic matter, it may be helpful. Nutrient demands of planted trees are low, but nutrient supply is very dependent on the soil type. Very few trials have been done in North America.

5. Should fertilization immediately follow precommercial thinning (PCT) or be done later? Some current studies suggest that fertilization should follow PCT to build tree crowns.

6. Will fertilization improve insect or disease resistance? There is some evidence that it does. Waring and Pitman (1983) found significant resistance to mountain pine beetle when canopy density was reduced and nitrogen nutrition improved. In jack pine resistance to sawfly defoliation has been found.

7. What is the best time of the year to fertilize? The conventional time is before bud flush in the spring.

8. What is the current status of lodgepole pine fertilization? It is entirely experimental with most of the current trials in Canada.

9. What additional studies are needed? More cooperative screening trials and formal testing of the closed stands for response to nitrogen; identification of limiting nutrients in young stands; generation of fertilization and thinning growth response data.

CONCLUSIONS

1. Lodgepole pine can grow on sites with extremely low nutrient availability. The species has very modest nutrient demands, but responds dramatically to improved nutrient status.

2. It can be successfully established and, by use of customized fertilizer additions to achieve balanced nutrition, made to grow very quickly on nutritionally poor sites, until some other factor becomes limiting.

3. Nutritional requirements and foliar analysis diagnosis values are well established.

4. Stands before crown closure, relying primarily on soil nutrition, may show deficiencies in many elements, depending on the soil type.

5. After stand closure, nitrogen deficiency can usually be suspect. Response to nitrogen additions as high as a 50 percent increase in stand volume increment over a 10-year period have been found with applications of N over 150 kg/ha.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Al Barclay)—What are the implications of fertilizing Pl (a) shortly after juvenile thinning takes place; (b) shortly (6 months - 1 year) prior to thinning?

A.—Fertilization following thinning should accelerate the rate of crown development provided the stand is known to be responsive. Fertilization 6 months prior to thinning (one growing season ahead) will result in fertilizer uptake into the trees which will be cut and remain as slash. There should be a dilution and lengthening in the response period.

IMPACT OF SPECIES COMPOSITION ON SITE PRODUCTIVITY IN THE NORTHERN ROCKY MOUNTAINS

David A. Hamilton, Jr.
William R. Wykoff

ABSTRACT

Analysis of growth rates of individual trees demonstrates that differences in growth are only weakly related to stand species composition. Simulations of stand development using the Stand Prognosis Model suggest that stands treated to favor shade-intolerant species are more productive at age 60 than are similar stands treated to favor tolerants. By age 150 stands treated to favor tolerants frequently equal or surpass in productivity stands treated to favor intolerants.

INTRODUCTION

Research tells us that species and individual tree and site characteristics affect growth rate; thus, it might seem reasonable to assume that site productivity may vary with the combination of species growing on the site. From a management standpoint, knowledge of such relationships would clearly be valuable in determining which species to favor in a precommercial thinning or which species to plant on any given site. However, literature is ambiguous regarding the strength of such relationships.

Typically, site productivity is measured by some component of stand dry matter production. This could include cubic foot volume to a specified merchantability standard, board foot volume to a specified merchantability standard, or some component of biomass production (for example, bole, above ground, total tree), all at a specified time since stand establishment. For this paper, we define productivity as total gross cubic foot volume observed at 60, 100, and 150 years since stand establishment.

Factors other than potential volume productivity should also be evaluated when alternative management strategies are being considered. These include answers to questions such as the following:

1. What are the relative risks of encountering insect or disease problems when management favors a given species or combination of species?
2. What are the impacts of alternative species compositions on the productivity of resources other than timber that are included in multiple use management plans?
3. What are the economic implications of favoring alternative species in a management strategy?
4. What are the effects of alternative species compositions in maintaining site productivity over several rotations?

In this study we do not specifically answer these questions but emphasize the important role they should play in the final selection from among alternative management strategies.

Tajchman and Lacey (1986) suggest that traditional methods of classifying sites to evaluate productivity are inadequately supported by basic research on growth processes. They conclude that this shortcoming leads to a need for studies that can improve our understanding of the basic physical and biological processes affecting growth and thus site productivity. A brief review of the vast body of literature on tree physiology suggests that our understanding of growth is somewhat better than these authors suggest; however, their point that any evaluation of site productivity must be based on the physiological processes affecting growth is valid.

Species clearly differ in their capacity to produce dry matter. Differences frequently have been related to differences in efficiency of photosynthesis. It appears that very shade-tolerant conifers (for example, hemlock and true firs) produce the highest annual rates of dry matter per acre . Such species usually maintain more foliage than less shade-tolerant trees, resulting in higher crown ratios and thicker foliage canopy (Smith 1962). This may partially explain the observation that some less tolerant species appear to survive in the understory if the overstory is made up of other intolerants but seem to drop out of the understory if the overstory is made up of tolerants. Another inference that might be drawn from the relatively heavy crowns of tolerants compared to the crowns of intolerants is that, in fact, tolerants are just as productive or more productive than intolerants but that more of the biomass production is directed into crown development and less into stem growth.

Spurr and Barnes (1980) discuss the relationship between tree physiology and tolerance. They indicate that intolerant species have high rates of both photosynthesis and respiration. Although intolerants thus use strong light more efficiently, they experience significantly greater reductions in photosynthesis than do tolerants when grown in shaded conditions.

Tolerant species in general have lower rates of respiration than do intolerants and are therefore more competitive when grown in shaded conditions. Although tolerants tend to also have lower rates of photosynthesis that result in relatively slow bole growth under most environmental conditions, they possess physiological characteristics (such as an ability to open stomates in dim light and to open them rapidly to take advantage of intermittent light) that further enhance their ability to compete in shaded conditions.

Spurr and Barnes (1980) summarize this discussion by stating that, in the understory, tolerants frequently outperform intolerants, particularly in height growth. In the open, however, intolerants are usually superior. A further consideration in an analysis of differences in productivity by species is the fact that tolerant species usually mature later and live longer than intolerants. Thus, any comparison of productivity of alternative species or combinations of species may depend greatly on the stand age selected for the evaluation.

Photosynthetic capacity may seem a likely indicator of the relative productivity of a species on a given site. However, it has been shown to vary not only between species but also among varieties, clones, or provenances of the same species. Correlations between photosynthetic capacity and growth of trees have varied from strongly positive to negative (Kramer and Kozlowski 1979). This type of variation has been attributed to the following:

1. Basic differences in physiologic processes resulting in differences in tree development.
2. Longer growing seasons for some species or varieties compensating for lower rates of photosynthesis.
3. Differences in seasonal patterns of photosynthesis.
4. Differences in the relationship between rates of photosynthesis and respiration.

Daniel and others (1979) suggest that site quality is determined by factors such as soil depth, soil texture, soil profile characteristics, mineral composition, slope, aspect, microclimate, and tree species. Success in improving site productivity through management depends on the ability to match species to the environmental characteristics of the site. This can be accomplished by treatments that modify the site so that it is more nearly optimal for the existing species or by selecting species that are likely to be more productive on the existing site.

Smith (1962), however, points out that frequently the techniques for controlling species composition are neither cheap enough nor effective enough to allow the manager complete freedom of choice on species composition. Similar comments could also be made about techniques available for modifying environmental characteristics of the site. As Spurr and Barnes (1980) state, "We should never forget that growth is a function of the effect of the environment on the genotype, and that site factors alone can never account for all the variation in growth rates found between different species or even between races or different sexually regenerated individuals within a single species."

In any effort to modify site productivity, we also need to consider differences in the value of species as well as differences in overall productivity. The best species composition in terms of gross wood productivity may not be the composition that yields the highest value.

Carmean (1975) reports that studies conducted in many regions evaluate the correlation between site indices based on alternative species. In the Northern Rocky Mountains, Copeland (1956) determined the relationship between site indices for western white pine, western larch, Douglas-fir, and grand fir. Deitschman and Green (1965) reported relationships between white pine, western larch, lodgepole pine, Douglas-fir, grand fir, and western hemlock.

However, evaluations of productivity of alternative species based on comparisons of site index can be very misleading and should in most cases be avoided. Carmean (1975) and Spurr and Barnes (1980) both indicate that it is necessary to look beyond site index at a specified index age to accurately evaluate overall productivity of alternative species on a given site. Short-lived, generally intolerant species may exhibit rapid early height growth and thus have a higher site index at index age 50 than longer lived, generally tolerant species. Over a 100-year or longer rotation, tolerant species may maintain height growth longer than the intolerants and eventually surpass them. Differences in the ability of some species to maintain height growth at higher densities further limits the value of comparative site indices as a means of comparing species productivity.

Individual site characteristics may result in growth curves that vary considerably from the curve assumed by the site index equation. If soil depth is shallow, growth may be normal only until soil depth becomes limiting for a species. Conversely, if roots encounter an enriched horizon or a deep water supply, growth may suddenly accelerate.

Watt (1960) evaluated the impact of species changes on growth of stands in the western white pine type. The component of western white pine in this type ranges from 19 percent to 96 percent. Watt concluded that observed variation in site index in this type is not related to differences in species composition; however, he did indicate that there are differences in growth by species at various times in stand development. The more intolerant species such as lodgepole pine and western larch grow more rapidly than western white pine at young ages.

By age 70, Douglas-fir and larch begin to drop out of the stand (Douglas-fir because of susceptibility to root rots, larch because of increased competition) and western white pine gains in importance. Farther into the rotation the more tolerant grand fir, western hemlock, and western redcedar become more prominent in the stand, primarily because of their ability to maintain rapid growth under favorable conditions. Watt concludes that the greater the proportion of western white pine and grand fir in a stand, the greater will be the volume produced.

An analysis carried out by Haig (1930, 1932) was designed to determine if the variation between observed stand basal area and the yield table value for basal area or observed stand cubic foot volume and the yield table value for volume could be explained by variations in species composition. He used multiple linear regression to evaluate the relationship between observed basal area expressed as a percent of the yield table value and the independent variables age, site index, mean stand diameter at breast height (d.b.h.), and species composition (expressed as percentage of western white pine, western larch, Douglas-fir, grand fir, western hemlock, western redcedar, and other species). The resulting multiple correlation coefficient (R^2) was 0.16. When age and site index were dropped from the analysis, R^2 was reduced to 0.07.

A similar analysis looked at the relationship between observed cubic foot volume expressed as a percent of yield table volume and the independent variables mean stand d.b.h and species composition. The resulting R^2 was 0.07. On the basis of these analyses, Haig suggested that relationships between species composition and unexplained variation in stand volume or basal area were very weak or were masked by other uncontrolled factors affecting growth. On the basis of this work, Haig concluded that his "composite yield table is considered accurate, therefore, for all western white pine stands regardless of their composition."

The diameter increment, height increment, and mortality models that are used by the Stand Prognosis Model (Hamilton 1986; Stage 1975; Wykoff 1983; Wykoff 1986; Wykoff and others 1982) to predict stand development are comprised of species-dependent and species-independent relationships. By examining these component models, we gain some insight into relative productivity of individual species or groups of species on a variety of sites. This analysis is complicated somewhat in that diameter increment is a predictor in models for other tree attributes. The effect of site and stand characteristics on predictions of diameter increment will thus indirectly affect predictions for other attributes.

In the height increment model there is a species constant and a species-dependent d.b.h. term. All other effects are independent of species except that d.b.h. increment is a predictor and varies considerably by species relative to most stand and tree attributes. Ignoring the effects that are attributable to diameter increment, intolerant species such as larch and ponderosa pine attain the largest height increments at small diameters, and the rate of change in height increment relative to diameter is large when compared to more tolerant species such as western white pine, grand fir, and western redcedar. As d.b.h. increases, the predicted increments for tolerant trees approach and sometimes exceed predictions for intolerant trees.

The influence of species on mortality rate is also fairly straightforward. Again ignoring the effects attributable to diameter increment, species effects are limited to a species-dependent constant. Western redcedar, western hemlock, spruce, grand fir, and Douglas-fir have the lowest mortality rates; western larch and lodgepole pine, the highest. Thus, the more tolerant species have lower expectations of mortality.

For diameter increment, all model parameters are independently estimated for each species. Thus, it is difficult to assess the relative performance of species under different stand and site conditions without simulation. In general, the diameter increment response surface for tolerant species relative to d.b.h., relative size, and stand density is fairly flat when compared to the surface for intolerant species. In young stands, where density is not a major factor, species such as larch and ponderosa pine attain larger diameter increments than western redcedar or western hemlock that are in a similar competitive position. As the stand matures and stand density increases, the relative performance of these species gradually reverses.

We have used the Stand Prognosis Model to integrate the component increment models for a wide variety of stand and site conditions. In the remainder of this paper, we examine whether the species-related differences discussed previously translate into differences in stand productivity that can be associated with varying species composition.

ANALYSIS

Growth Rates on Permanent Sample Plots

The calibration term calculated by the Stand Prognosis Model is a measure of how each species on a site is growing compared to how the model predicts trees of that species should grow on the site. Our first analysis used calibration terms calculated for each species for each measurement period on a set of 102 permanent sample plots located in northern Idaho and western Montana. These plots have been remeasured at 5- to 10-year intervals for up to 20 years. The analysis was designed to determine if variations in calibration terms could be explained by differences in species composition (for example, do grand fir grow differently when competing with other grand fir than when competing with other species?).

The relationship between calibration terms and species composition was evaluated by estimating the regression coefficients in the following equation:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_8 X_8 \qquad (1)$$

where

Y = calibration term for a species in a time period
β_i = least squares regression coefficient for species i
X_i = arcsin of the square root of the percent of species i in the stand

and

species 1 is western white pine (*Pinus monticola*)
species 2 is western larch (*Larix occidentalis*)
species 3 is Douglas-fir (*Pseudotsuga menziesii*),
species 4 is grand fir (*Abies grandis).*
species 5 is western hemlock (*Tsuga heterophylla*),
species 6 is western redcedar (*Thuja plicata*),
species 7 is lodgepole pine (*Pinus contorta*),
species 8 is other.[1]

A model was fit for each combination of species and time period. Analysis of variance was carried out for each model and *t*-tests for each estimated regression coefficient were calculated.

In most time periods, the models for larch, Douglas-fir, grand fir, and western hemlock explained a significant portion of the variation in calibration terms at the

[1] Includes subalpine fir (*Abies lasiocarpa*), ponderosa pine (*Pinus ponderosa*), Engelmann spruce (*Picea engelmannii*), and mountain hemlock (*Tsuga mertensiana).*

5 percent significance level; however, there are few consistent patterns of significance over time. For example, in eight of nine time periods, the model for Douglas-fir explained a significant amount of variation. In these Douglas-fir models, coefficients for proportions of all species except those grouped into the "other" category were significant in at least one time period. However, the only variables with significant coefficients in more than one time period were percentage of western white pine in two periods and percentage of lodgepole pine in three periods. The most consistency was found in western hemlock models. In six of the eight time periods in which there were adequate data to fit a model, the model explained a significant amount of variation. In five of these models the coefficient for percentage of western redcedar was significant, and in four of the models the coefficient for percentage of western larch was significant.

The most consistently significant coefficient in all models was the coefficient for percentage of western larch. This coefficient was significant in 21 percent of the models and was negative in all but one instance. Thus, it appears that other species tend to grow more slowly than expected when larch is a major component of the stand. A possible explanation of this result is that western larch is more prevalent at the harsher end of any site classifications used by the Stand Prognosis Model. Under this hypothesis, the higher the frequency of western larch, the harsher the site is likely to be and, therefore, the slower the growth of all species on the site.

All significant coefficients in western larch models in any time period are negative, possibly because the density effect is poorly represented in the western larch diameter increment model in the Stand Prognosis Model.

In the western hemlock models discussed previously, it is interesting to note that the five significant coefficients for percentage of western redcedar (a tolerant species) are all positive, whereas the four significant coefficients for percentage of western larch (an intolerant species) are all negative. We could conclude from this result that western hemlock growing in competition with western redcedar grows more rapidly than when growing in competition with western larch. This would agree with our previous hypothesis that higher frequencies of western larch are more likely on the harsher phases of any site classification. Alternatively, we could conclude that a dense overstory of larch reduces available light and thus the growth of western hemlock, but that when grown with western redcedar, the hemlock and cedar share the same crown levels and the hemlock receives adequate light for more vigorous growth.

Because this study was an analysis of data obtained as a sample of existing conditions, we have no basis for making inferences about cause and effect relationships. The results of the analysis do, however, support a conclusion similar to the one made by Haig (1932). It appears that there are some weak relationships between species composition and the growth of individual species. To more clearly describe these relationships, it would be necessary to conduct a series of studies in which species composition is controlled in a designed experiment on experimental units established on similar sites.

Simulations of Stand Yield

Because of the lack of data available to analyze questions about the impact of species composition on site productivity, we used the Stand Prognosis Model to simulate expected differences in productivity when species composition is controlled. Stands were generated by the Regeneration Establishment Model (Ferguson and Crookston 1984) to represent a range of conditions that a manager might expect to encounter. Half the stands were located in the St. Joe National Forest in *Pseudotsuga menziesii / Physocarpus malvaceus* (PSME/PHMA), *Abies grandis / Clintonia uniflora* (ABGR/CLUN), *Tsuga heterophylla / Clintonia uniflora* (TSHE/CLUN), or *Abies lasiocarpa / Clintonia uniflora* (ABLA/CLUN) habitat types (Pfister and others 1977). The other half of the stands were located in the same habitat types in the Lolo National Forest except that TSHE/CLUN was replaced by *Thuja plicata / Clintonia uniflora* (THPL/CLUN). Stands in each habitat type in the St. Joe were simulated at elevations of 2,500 ft, 3,500 ft, and 4,500 ft except for ABLA/CLUN, which was simulated at only 3,500 ft and 4,500 ft. In the Lolo, elevations were 3,500 ft, 4,500 ft, and 5,500 ft except for ABLA/CLUN, which was simulated at only 4,500 ft and 5,500 ft. All stands were assumed to be level (zero slope and aspect).

Species composition was controlled either by precommercial thinning to favor certain species or by planting desired species. In either case the regeneration establishment model is used to introduce additional natural regeneration to the stand during the 20 years following thinning or planting. This simulates the reinvasion effect observed in many stands following early thinnings (Deitschman and Pfister 1973). Thus, the primary advantage of thinning or planting is to give the selected trees a competitive advantage over any regeneration established following the thinning or planting.

Stands were planted at a density of 600 trees per acre. Equal numbers of each species were planted on a site. Thus, 200 trees per acre of each species are planted when three species are to be planted and 300 trees per acre of each species are planted if only two species are to be planted. On those stands where species composition was controlled by precommercial thinning of the natural regen-eration, stands were thinned to 600 trees per acre. This removed the effect of differences in stems per acre from the analyses.

The species composition of natural regeneration varied by habitat type (h.t.) and National Forest. The major species in the ABGR/CLUN h.t. in the St. Joe were grand fir, Douglas-fir, lodgepole pine, and western white pine. Larch replaced western white pine in this habitat type in the Lolo. Grand fir, western redcedar, western white pine, Douglas-fir, lodgepole pine, and western hemlock were the major species in the TSHE/CLUN h.t. in the St. Joe. In the THPL/CLUN h.t. in the Lolo, the major species were grand fir, western redcedar, larch, and Douglas-fir. Regeneration in ABLA/CLUN in the St. Joe consisted of grand fir, Douglas-fir, western white pine, and subalpine fir. Larch again replaced western white pine in this habitat type in the Lolo. In all habitat types in the Lolo and in

TSHE/CLUN in the St. Joe, Engelmann spruce began to appear in the stands in significant amounts at higher elevations.

An analysis of variance with factorial effects was used to evaluate differences in productivity. Main effects were species composition and elevation.

Except for a stochastic component of the diameter increment model, the portions of the Stand Prognosis Model that influence our results are deterministic. Thus, replication of the experiment will not provide degrees of freedom for estimating error. Interaction terms may be used as the error term; however, the resulting tests of hypotheses are not statistically valid. The analysis does provide a means of making objective comparisons of alternative management strategies concerning the impact of species composition on productivity.

The regeneration establishment model is not calibrated for the PSME/PHMA habitat type. Therefore, the only alternatives examined for this habitat type were differences in species planted. All two- and three-way combinations of ponderosa pine, Douglas-fir, and western larch were planted. In the ABGR/CLUN habitat type, two-way combinations of ponderosa pine, Douglas-fir, grand fir, and western larch were planted. In addition, natural regeneration alternatives were considered. Species composition was controlled on naturally regenerated stands by precommercial thinning to favor either tolerant or intolerant species. For this purpose Douglas-fir and Engelmann spruce are moderately tolerant, grand fir and subalpine fir are tolerant, and western hemlock and western redcedar are very tolerant. Other species are considered to be intolerant. The natural stand was also simulated with no thinning.

Both planted and natural stands were also analyzed in THPL/CLUN, TSHE/CLUN, and ABLA/CLUN habitat types. Western larch, Douglas-fir, and grand fir were planted in THPL/CLUN habitat type. Western white pine, Douglas-fir, and grand fir were planted in TSHE/CLUN habitat type. Western larch, Engelmann spruce, subalpine fir, and lodgepole pine were planted in ABLA/CLUN habitat type.

The results of this analysis are presented in detail in tables 1 and 2. Elevation had no impact on the relative productivity rankings and thus is not reported as a separate effect in the tables. There are several general conclusions that can be drawn. At age 60 most planted stands have higher cubic foot volume than do the natural stands; thinning stands to favor intolerants results in more volume than thinning to favor tolerants. The advantage of planted stands might be explained in part by a shorter regeneration period and in part by better control of species composition. By age 100, some of the combinations of planted species have lost their advantage over natural stands. By age 150, many of the differences in productivity have disappeared. Most natural stands thinned to favor tolerants have either equaled or exceeded the productivity of stands thinned to favor intolerants. The only exception to this is ABLA/CLUN habitat types in the St. Joe , where the natural stand thinned to favor intolerants is the highest producing alternative at both age 100 and age 150. This effect appears to be explained by careful examination of the species compositions of the stands. Western white pine is practically nonexistent at age 150 in the stand thinned to favor tolerants, whereas it makes up approximately 40 percent of the stand (75 per-cent by volume) thinned to favor intolerants. When free to grow, western white pine is one of our more productive species. Apparently thinning to favor western white pine gives it enough competitive advantage to remain a dominant component of the stand at least to age 150.

DISCUSSION

For the most part, these two analyses have reinforced what others have observed or suggested to be the impact of species composition on individual tree growth and stand productivity. The first analysis suggests that although some weak relationships exist between species composition and variations in the growth of individual trees, our understanding of these relationships is not thorough enough to significantly improve our capability to predict differences in growth between species. This conclusion is similar to that made by Haig (1932) based on his analysis of a portion of the same data.

The second analysis confirms the general conclusion of others (Watt 1960; Spurr and Barnes 1980; Carmean 1975) that at young ages intolerants tend to be more productive than tolerants, whereas later in the rotation, treatments favoring tolerants tend to equal or surpass treatments favoring intolerants in productivity. This analysis also supports Watt's (1960) recommendation to plant western white pine and grand fir in the "white pine type." Further, it suggests that in most cases the gains in productivity experienced early in a rotation that are attributed to planting appear to be maintained at least to age 150.

In this paper we have considered the impact of species composition on stand productivity. This is only one of several factors the resource manager should consider when making decisions concerning which species to favor on any particular site. Economic factors must also be considered. If the highest yielding species is western hemlock but the market value for hemlock is very low, there may be little justification for managing to favor hemlock. Similarly, if the market demand is for large-diameter trees for veneer, there may be little reason to consider relative productivity at age 60.

The relative risk of encountering insect or disease problems when a given species is favored must also be evaluated. Although western white pine is one of our most highly productive species in northern Idaho, insect and disease problems, including blister rust and mountain pine beetle, resulted in regional management guidelines that actively discriminated against western white pine from the mid-1960's until some time around 1980, when blister rust-resistant planting stock became available.

Today resources other than timber play an increasingly important role in the planning process. Thus, management strategies favoring alternative species composition must also be evaluated for their impact on the productivity of resources other than timber such as wildlife habitat, watershed protection, or recreational values. Differences in the impact of species on soil nutrients is an additional

Table 1—Simulated differences in productivity by habitat type, species composition, and stand age in the St Joe National Forest

	Age (yrs)					
	60		100		150	
Habitat type	Species[1] planted or favored	Volume	Species planted or favored	Volume	Species planted or favored	Volume
		Ft³/acre		*Ft³/acre*		*Ft³/acre*
PSME/PHMA	PP,DF	7,063[2]	WL,PP	10,846	PP,WL,DF	12,773
	PP,WL,DF	6,704	PP,DF	10,843	WL,PP	12,718
	WL,PP	6,592	PP,WL,DF	10,784	PP,DF	12,547
	DF,WL	3,147	DF,WL	5,956	DF,WL	7,265
ABGR/CLUN	GF,PP	8,714	GF,PP	13,502	GF,PP	15,532
	PP,DF	8,696	PP,DF	13,249	PP,DF	15,302
	DF,GF	4,896	INTOLERANTS	9,054	NATURAL	12,979
	WL,DF	4,742	NATURAL	9,007	INTOLERANTS	12,707
	WL,GF	4,000	DF,GF	8,673	TOLERANTS	12,588
	INTOLERANTS	3,805	WL, GF	8,371	WL,GF	12,073
	NATURAL	3,748	WL,DF	8,209	DF,GF	11,303
	TOLERANTS	1,560	TOLERANTS	7,469	WL,DF	10,282
TSHE/CLUN	DF,WP	7,348	GF,WP	13,471	GF,WP	18,046
	GF,WP	7,117	DF,WP	12,460	DF,WP	15,989
	GF,DF,WP	6,820	GF,DF,WP	11,901	GF,DF,WP	15,569
	GF,DF	5,705	NATURAL	10,408	NATURAL	14,922
	NATURAL	4,977	INTOLERANTS	10,255	INTOLERANT	14,440
	INTOLERANTS	4,560	GF,DF	9,788	TOLERANTS	13,175
	TOLERANTS	2,161	TOLERANTS	8,056	GF,DF	12,740
ABLA/CLUN	WL,S	4,854	INTOLERANTS	10,883	INTOLERANTS	15,708
	S,AF	4,807	NATURAL	10,129	NATURAL	13,904
	WL,AF	4,730	WL,S	9,610	WL,S	13,410
	NATURAL	4,710	S,AF	9,268	WL,AF	12,640
	LP,S	4,703	WL,AF	9,084	LP,S	12,571
	LP,WL	4,547	LP,S	8,859	S,AF	12,432
	LP,AF	4,504	LP,WL	8,282	TOLERANTS	12,054
	INTOLERANTS	4,286	LP,AF	8,031	LP,WL	12,012
	TOLERANTS	2,053	TOLERANTS	7,426	LP,AF	11,152

[1]Planted species abbreviations are PP(ponderosa pine), DF (Douglas-fir), WL (western larch), GF (grand fir), WP (western white pine), S (Engelmann spruce), AF (subalpine fir), and LP (lodgepole pine). INTOLERANTS designates a naturally regenerated stand tninnned to favor intolerants, TOLERANTS designates a naturally regenerated stand thinned to favor tolerants, and NATURAL designates an unthinned naturally regenerated stand.

[2]Values connected by vertical line are not significantly different at the 5 percent significance level when tested by Duncan's new multiple range test.

factor that must be evaluated in selecting preferred species composition.

The hypotheses we have presented are based primarily on inventory data that describe conditions as they exist today. Such data are useful for developing relationships but cannot be used as the basis for making cause and effect inferences. Thus, we are unable to do more than hypothesize the impact on productivity of management strategies that favor alternative species compositions. Only by using an experimental design to control or explain some of the other sources of variation in productivity, such as site factors and density, can we make valid tests of these hypotheses.

Such an experiment should be long term (permanent plots measured for at least 30 years) and should be extensively replicated because of the uncontrollable sources of variation affecting productivity (for example, climate, insect and disease hazard). We feel this study suggests that such a major research effort might be difficult to justify.

Table 2—Simulated differences in productivity by habitat type, species composition, and stand age in the Lolo National Forest

Habitat type	Age (yrs) 60: Species[1] planted or favored	Volume	100: Species planted or favored	Volume	150: Species planted or favored	Volume
		Ft³/acre		*Ft³/acre*		*Ft³/acre*
PSME/PHMA	PP, DF	3,737[2]	WL, PP	7,667	WL,PP	10,552
	WL,PP	3,648	PP, DF	7,475	PP, DF	10,267
	PP, WL, DF	3,600	PP, WL, DF	7,365	PP, WL, DF	10,207
	DF,WL	1,766	DF,WL	4,109	DF,WL	5,888
ABGR/CLUN	PP, DF	5,489	GF,PP	10,717	GF,PP	14,671
	GF, PP	5,408	PP, DF	10,386	PP, DF	14,098
	WL, DF	3,101	DF, GF	6,381	WL, GF	9,292
	DF, GF	2,997	WL, DF	6,320	DF, GF	9,238
	WL, GF	2,683	WL, GF	6,233	INTOLERANTS	9,090
	INTOLERANTS	2,227	INTOLERANTS	5,979	NATURAL	8,898
	NATURAL	2,205	NATURAL	5,752	WL, DF	8,849
	TOLERANTS	1,962	TOLERANTS	5,599	TOLERANTS	8,817
THPL/CLUN	WL, DF	3,354	WL, DF	6,203	DF, GF	8,756
	DF, GF	3,073	DF, GF	6,106	WL, DF	8,442
	WL, GF	2,813	WL, GF	5,820	WL, GF	8,325
	NATURAL	2,273	NATURAL	5,484	NATURAL	8,242
	INTOLERANTS	2,118	INTOLERANTS	5,197	INTOLERANTS	7,881
	TOLERANTS	914	TOLERANTS	4,139	TOLERANTS	7,877
ABLA/CLUN	LP, WL	2,940	S, AF	5,924	S, AF	8,763
	LP, S	2,938	LP, S	5,870	LP, S	8.288
	LP, AF	2,802	WL, S	5,637	WL, S	8,228
	WL, S	2,644	LP, AF	5,588	TOLERANTS	8,062
	S, AF	2,578	LP, WL	5,530	NATURAL	8,008
	WL, AF	2,539	WL, AF	5,380	WL, AF	7,820
	NATURAL	2,256	NATURAL	5,306	LP, AF	7,803
	INTOLERANTS	1,698	INTOLERANTS	4,708	LP, WL	7,500
	TOLERANTS	992	TOLERANTS	4,318	INTOLERANTS	7,255

[1]Planted species abbreviations are PP(ponderosa pine), DF (Douglas-fir), WL (western larch), GF (grand fir), WP (western white pine), S (Engelmann spruce), AF (subalpine fir), and LP (lodgepole pine). INTOLERANTS designates a naturally regenerated stand thinnned to favor intolerants, TOLERANTS designates a naturallly regenerated stand thinned to favor tolerants, and NATURAL designates an unthinned naturally regenerated stand.
[2]Values connected by vertical line are not significantly different at the 5 percent significance level when tested by Duncan's new multiple range test.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Dennis R. Parent)—Are there any research plots of pure species in the Inland Empire area with data that back up your simulations? If not are there any plans to establish such plots? Are you comfortable with the ability of the Prognosis Model to detect such species growth differences as you were looking for? Did you do any simulations of pure stands versus mixed stands?

A.—To test the simulation results, we would have to have available a set of permanent sample plots in which the species compositions to be evaluated were growing on a series of plots that were similar in all factors affecting growth (both controllable [for example, site factors, density] and uncontrollable [for example, climate, insect or disease hazard]). The existence of uncontrollable factors affecting growth means that the experiment would have to be replicated extensively. Unfortunately, such studies do not exist (as far as I know) in the Inland Empire. As new permanent sample plots are established, the need for this kind of information should be considered as an additional objective.

The Stand Prognosis Model has been developed to simulate our best understanding of how stands in the Inland Empire develop over time. Thus, in the absence of hard data, simulation using the Stand Prognosis Model represents our best source of information about the impact of varying species composition on productivity.

In this analysis we did not evaluate differences between mixed and pure stands. Pure stands were not considered because they are extremely difficult to maintain in a pure state over a rotation and because of the dangers from insect and disease hazards that are accentuated by monocultures.

Q. (from Fred Hall)—The Forest Service Pacific Northwest Region (R-6) Ecology program has solid data to show major differences in species growth by plant association (habitat type). Therefore your generalization may not be universally valid. For example in R-6—ABCO-PIPO/CAPE:

SI_{100} = ABCO 94, PIPO 89, and
GBA = ABCO 241, PIPO 104, and
Ft^3/acre/year index* = ABCO 92, PIPO 33 (Hopkins 1979)
*SI(GBA).004 = Ft^3 index

A.—It is not our intention to imply that there are no differences in productivity that can be attributed to species composition. In our simulations, any stands on *Pseudotsuga menziesii / Physocarpus malvaceus* or *Abies grandis / Clintonia uniflora* in either the Lolo or St. Joe National Forests on which ponderosa pine was one of the planted species showed significantly higher productivity than for any alternative at all three stand ages. At 150 years, the plantation of western white pine and grand fir on *Tsuga heterophylla / Clintonia unifora* in the St. Joe National Forest showed significantly higher productivity than any alternative.

Your measure of productivity is somewhat troubling. By basing the measure on Site Index at index age 100 and

Growth Basal Area, you essentially have an estimate of productivity at a single point in time (index age). The physiology literature fairly strongly suggests that differences exist in tree development between many species. Thus, the species with optimal productivity at index age may not necessarily be the same species showing maximum productivity at either earlier or later ages.

Q. (From Bob Pfister)—Several years ago a University of Idaho economic study used Prognosis to compare ponderosa pine and Douglas-fir yields on Douglas-fir and grand fir habitat types in the Moscow area. These projections suggested almost a doubling of yield of one species over the other. Would it be valuable to expand these simulation tests to those sites and species where other researchers have suggested major productivity differences by species choice?

A.—As we indicated in our response to Fred Hall's statement, our simulations do show significant differences in productivity that can be attributed to varying species composition. A rereading of the productivity study you refer to suggests that it is not a good source of information concerning the impact of species composition on productivity. Sites are identified only as high, moderate, or low with the site planted to ponderosa pine identified as high and those with significant Douglas-fir identified as moderate. There is no indication as to whether the sites are similar in habitat type or other site characteristics. Biological comparisons of productivity are based on maximum mean annual increment. Documented differences in tree development by species strongly suggest that different species will reach maximum mean annual increment at different ages. Such differences make this a very suspect measure of differences in productivity. Even if species reach maximum mean annual increment at the same age, there is no assurance that development over time will be similar. Thus, comparisons of productivity at a single point in time may be very misleading.

PHYSIOLOGICAL AND MORPHOLOGICAL RESPONSES OF NORTHWEST FOREST TREE SPECIES TO THINNING AND FERTILIZATION

John H. Bassman

ABSTRACT

Stand cultural treatments should bring a variety of physiological processes into ranges optimal for maximum tree growth. This requires an understanding of how cultural treatments affect physiology. This paper reviews the effects of thinning and fertilization on physiological processes of several Northwest tree species.

Fertilization and thinning increase leaf production, leaf area, and the ratio of leaf area to sapwood basal area. Fertilization increases shoot growth but thinning may decrease it initially ("thinning shock"). Combinations of thinning and fertilization are synergistic with respect to increased growth. Both thinning and fertilization increase the unit leaf rate (biomass production per unit leaf area) of the plant. Fertilization increases leaf nitrogen concentrations and leaf chlorophyll, with concomitant increases in photosynthetic rates and other gas exchange processes. Thinning causes higher light intensities, higher foliage temperatures, reduced water stress, and as a result, higher photosynthetic rates.

INTRODUCTION

The purpose of stand culture is to direct tree and stand growth toward economic or social purposes as set forth by management objectives. Genotype-environment interactions control growth by acting on internal physiological processes; that is, Kleb's concept (Kramer and Kozlowski 1979). Silviculturists control (to varying degrees) or modify both genotype and environment to affect tree and stand growth. The degree to which physiological processes are affected ultimately determines the degree of impact on tree growth. The objective of cultural treatments then should be to bring a variety of physiological processes into a range that is optimal for maximum tree growth. This, in turn, depends on a thorough understanding of the impacts of cultural treatments on physiology.

Genotype and environment affect physiology in complex ways. Levels and rates of one process generally affect levels and rates of other processes; bringing one process into optimal range may not necessarily affect other processes in a positive fashion (Daniel and others 1979). For example, light available to a tree may be increased by removing adjacent vegetation. This should have the impact of increasing photosynthesis and growth. However, such increased exposure may also increase evaporative demand resulting in increased water stress and subsequent stomatal closure, and may instead lead to reduced photosynthesis and growth. Species-specific understanding of such interaction effects is important to select cultural treatments for maximum growth.

Cultural treatments alter the physical and chemical environment of targeted plants. To be successful, the changes must meet the physiological requirements of selected trees (Daniel and others 1979). This paper reviews effects of thinning and fertilization on physiological responses of Northwest tree species. Thinning and fertilization are likely to be the most widely used cultural operations applied to development of future forests of the Mountain West. Since many reports in the literature address both practices simultaneously, they will be so considered here. Studies relating to seedlings were not considered; gross growth responses (such as basal area, diameter, volume) are covered in detail elsewhere in this volume. Also, much of the fertilization literature pertaining to physiology derives from studies of coastal Douglas-fir. In water-limited habitats characteristic of the Inland West, responses are likely to be different.

GROWTH

Stem Growth

Nitrogen fertilization alone generally results in an immediate improvement in height growth and branch elongation. In 20-year-old Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*), fertilization with 200 or 400 lb N per acre as NH_4NO_3 increased height growth 30 percent the first year and 50 percent the second year over controls (Brix and Ebell 1969). Such stimulation is short-lived, lasting only 4-5 years (Brix 1981b; Brix and Ebell 1969). Branch growth behaves similarly (Brix 1981a).

In contrast, the initial response to thinning alone is often a reduction in height growth. This so-called "thinning shock" has been documented repeatedly in Douglas-fir (Brix 1981b; Crown and others 1977; Harrington and Reukema 1983; Miller and Reukema 1977) and in other conifers as well (Berry 1965; Bickerstaff 1946; Braathe 1957; Burns and Brendemuehl 1978; Day and Rudolph 1966, 1972; Jack 1971; Piene 1981; cited in Harrington and Reukema 1983). Thinning shock is generally of short duration, with subsequent recovery of and improvement in height growth (Crown and others 1977; Hall and others 1980; Harrington and Reukema 1983). Harrington and Reukema (1983) reported that height growth was linearly related to growing space with best height growth at wider spacings 15 to 25 years following thinning of a 27-year-old

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Douglas-fir stand. Severity and duration of thinning shock is partially related to severity of thinning (Crown and others 1977; Harrington and Reukema 1983) and may be more common on medium to poor quality sites (Harrington and Reukema 1983). Effects are also more pronounced in the upper part of the crown (Reukema 1964). Diameter growth may be unaffected, increased, or decreased (Harrington and Reukema 1983; Miller and Reukema 1977; Reukema 1964). The physiological basis for thinning shock may be reduced photosynthetic capacity caused by loss of shade leaves that have been suddenly exposed to full sun (Donner and Running 1986).

The combination of thinning and fertilization tends to be synergistic. Heavy thinning combined with high rates of nitrogen fertilization produce the best growth (Brix 1981a; Miller and Reukema 1977).

Leaf Production

Both thinning and nitrogen fertilization increased foliage biomass in 24-year-old Douglas-fir (Brix 1981a) (table 1). Heavy thinning (T_2 = two-thirds of initial basal area removed) alone or heavy fertilization alone (F_2 = 448 kg N/ha) resulted in 90 percent increase in foliage dry weight compared with controls. The combination of heavy thinning and fertilization (T_2F_2) resulted in a 271 percent increase. These increases result from increased leaf size, number of needles, number of shoots, and number of needles per shoot (Brix 1981a; Brix and Ebell 1969). Increased production began the year of treatment, was maximum the second or third year, and tapered to control levels by years 4 to 7 (Brix 1981a). Thinning and fertilization also change distribution of foliage in the tree (fig. 1). Fertilization alone increased the height in the crown with maximum foliage; thinning alone reduced the height of maximum foliage. The latter was due in part to increased retention of lower branches (Thompson and Barclay 1984). Maximum foliage weight and an intermediate pattern of distribution resulted from combined fertilization and thinning (Brix 1981a).

For Douglas-fir, thinning and fertilization together increased individual tree leaf area, the combination resulting in nearly twice the leaf area of each treatment applied separately (Brix 1981a) (table 2). Because thinning increases crown projection area and reduces crown overlap, leaf area index (LAI) for both individual trees and for the stand is reduced. Fertilization alone increases both tree and stand LAI (Binkley and Reid 1984; Brix 1981a).

Thinning and fertilization tend to increase the ratio of leaf area to sapwood basal area (Binkley and Reid 1984; Brix and Mitchell 1983). The combination of heavy thinning and heavy fertilization produces the highest ratio. Brix and Mitchell (1983) suggested that this is inconsistent with "pipe model" theory, which contends a functional and constant relationship of foliage area to sapwood area (Waring and others 1982; Whitehead and Jarvis 1981). Higher ratios of leaf area to sapwood area have been reported to occur as a result of increasing fertility (Binkley 1984; Binkley and Reid 1984). Brix and Mitchell (1983) found foliage area/sapwood area ratios changed for various levels in the crowns of Douglas-fir in response to thinning and fertilization. This contrasts to data for subalpine tree species (Kaufmann and Troendle 1981; Long and others 1981).

Table 1—Total needle weight (kg) per tree 7 years after thinning and fertilizing 24-year-old Douglas-fir. T_0 = no thinning; T_2 = two-thirds of initial basal area removed; F_0 = no fertilization; T_2 = 448 kg N/ha (from Brix 1981a)

Treatment	Mean dry weight per tree
	Kilograms
T_0F_0	3.83 + 0.42a[1]
T_2F_0	7.32 ± 0.42a
T_0F_2	7.26 ± 0.12
T_2F_2	14.80 ± 0.28

[1]a = standard error.

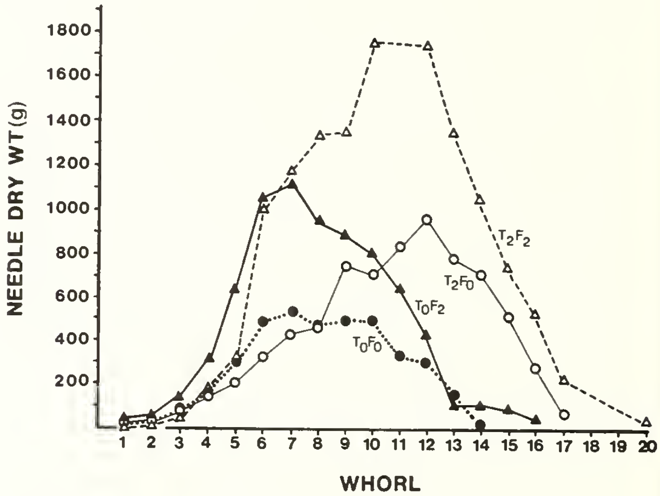

Figure 1—Distribution of needle dry weight within the crown 7 years after thinning and fertilizing 24-year-old Douglas-fir. T_0 = no thinning; T_2 = two-thirds of initial basal area removed; F_0 = no fertilization; F_2 = 448 kg N/ha. Redrawn from Brix (1981a).

Table 2—Total needle surface area (one side) per tree, crown projection area, leaf area index (LAI) for sample trees, percent crown closure, and LAI for stand surrounding sample trees 7 years after thinning and fertilizing 24-year-old Douglas-fir (from Brix 1981a)

Treatment	Needle surface area	Crown projection area	LAI for trees	Crown closure	LAI for stand
	------ m^2 ------			*Percent*	
T_0F_0	25.19a[1]	3.56a	7.08b	84b	5.92b
T_2F_0	42.90b	8.27b	5.18a	59a	3.04a
T_0F_2	48.65b	5.02a	9.80c	90b	8.79c
T_2F_2	92.92c	11.74c	7.93b	81b	6.43b

[1]Data in the same vertical column not followed by the same letter are significantly different (P = 0.05).

Biomass Production

Both thinning and fertilization increased biomass production in Douglas-fir (Barclay and others 1986; Brix 1983), although the fertilization response may be short-lived (3-4 years) (Brix 1983). Barclay and others (1986) reported net production of stemwood over 9 years was roughly 40 percent greater in heavily fertilized treatments (T_0F_2 = 448 kg N/ha) than controls (T_0F_0). Combination of heavy thinning (T_2 = two-thirds basal area removed) and heavy fertilization resulted in 57 percent greater biomass than controls. Thinning and fertilization also shift the distribution of biomass within the tree. Thinning tends to decrease proportion of biomass allocated to wood, bark, and dead branches while increasing portions in live branches, foliage, and increasing butt flare (Barclay and others 1986; Thompson and Barclay 1984). Fertilization increases the proportion of biomass in branches, but has little effect on other components (Barclay and others 1986; Thompson and Barclay 1984).

PHOTOSYNTHESIS

Net Assimilation

Thinning and fertilization increase total production and unit leaf rate (ULR=biomass production per unit leaf area) or efficiency (Barclay and others 1986; Binkley and Reid 1984; Brix 1983). Brix (1983) reported that increased foliar efficiency accounted for 20, 36, and 27 percent of stemwood response to thinning, fertilization, or a combination, respectively. The remainder could be attributed to an increase in foliage biomass (fig. 2). Heavy fertilization (470 kg/ha ammonium nitrate) of a 35-year-old Douglas-fir stand produced 60 percent greater leaf area and 40 percent greater stem growth per unit leaf area, resulting in a doubling of stem growth over a 5-year period 13 to 18 years after treatment (Binkley and Reid 1984). Increased efficiency from thinning may result primarily from physical changes; leaves may be exposed to higher light intensities and/or increased availability of water. Increased ULR resulting from fertilization is most likely due to increased foliar nitrogen (see below; Barclay and others 1986).

Photosynthetic Rates

Thinning increases light penetration, leaf temperatures, and possibly turbulent air transfer resulting in greater leaf-to-air CO_2 gradients. On sites where water is not limiting, this can result in increased photosynthetic rates, but for purely physical reasons (Donner and Running 1986).

Fertilization treatments have increased photosynthetic rates in Douglas-fir by as much as 78 percent, but the degree of response depends on light conditions (Brix 1971, 1981b; Keller and Koch 1962). Brix (1971) found photosynthetic rates to be stimulated only when light intensities were greater than 2,000 foot-candles. The combination of thinning (which improves light conditions) and fertilization can be expected to produce the greatest photosynthetic response (Brix 1981b). Photosynthetic response to fertilization alone apparently lasts only several years (Brix 1971).

Brix (1971) reported that leaf nitrogen content may be doubled in current shoots by the end of August following a spring application of ammonium nitrate to 24-year-old Douglas-fir. A significant relationship between foliar nitrogen concentration and rate of photosynthesis has been demonstrated (Brix 1981b). Maximum net photosynthesis occurs at a leaf nitrogen concentration of 1.74 percent (fig. 3). Higher and lower levels of leaf nitrogen result in reduced photosynthetic rates (Brix 1981b; Keller

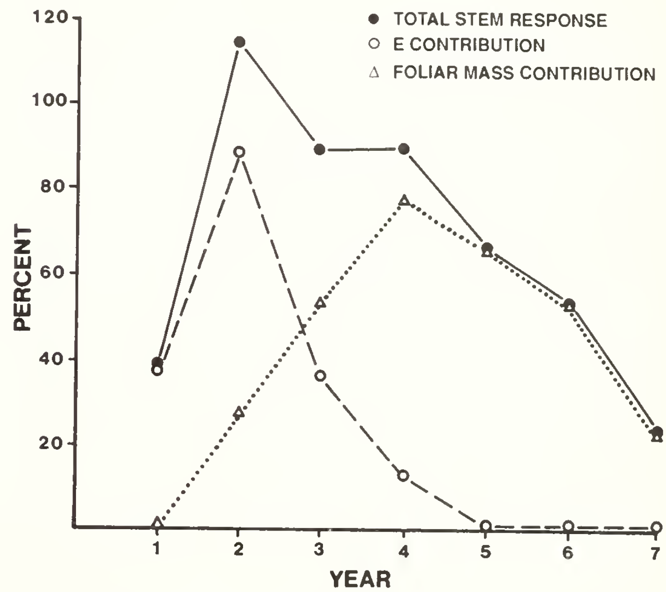

Figure 2—Stemwood growth response to T_0F_2 treatment, percent above control, and contribution of E (production per unit leaf area) and foliage biomass to the response following treatment of 24-year-old Douglas-fir. Redrawn from Brix (1983).

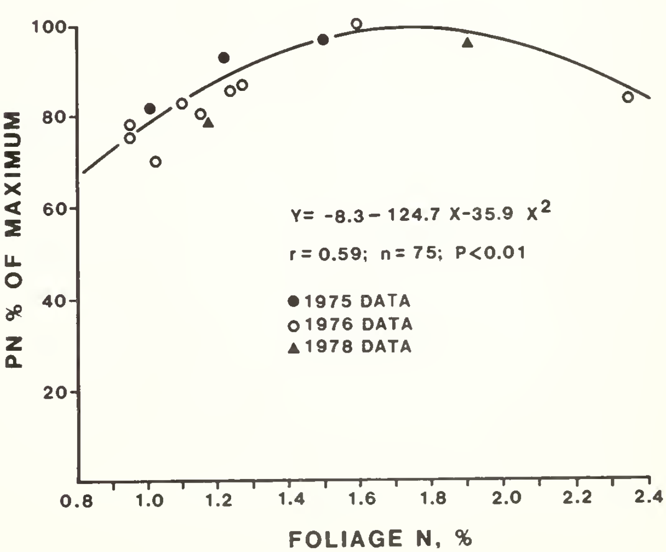

Figure 3—Rate of net photosynthesis (PN) for current shoots in the year of fertilization with respect to foliar nitrogen concentrations. Different symbols represent means for trees treated in different years. Rates are expressed as a percentage of the highest treatment mean (attained with 448 kg N/ha ammonium nitrate). Redrawn from Brix (1981b).

1972). It is significant that other fertilization studies indicate maximum diameter growth for Douglas-fir with foliage nitrogen concentrations of 1.75 percent (cited in Brix 1981b; Gessel and others 1969). Source of nitrogen (ammonium nitrate or urea) is apparently unimportant to the response after the first year (Brix 1981b).

At least a portion of the increased photosynthetic rates resulting from fertilization can be attributed to increased leaf chlorophyll content. Brix (1971) showed that chlorophyll concentrations in leaves were increased 130 percent by nitrogen fertilization for current year shoots, 80 percent for 1-year-old shoots in mid-August following an April application of ammonium nitrate. Levels remained elevated (compared to controls), but declined the second year. Other explanations for the photosynthetic response to fertilization suggested by Brix (1981b) include: (a) increased activity of carboxylating enzymes (Natr 1975; Osman and Milthorpe 1971); (b) reduced diffusion resistance through stomates and mesophyll cells (Natr 1975; Ryle and Hesketh 1969); and (c) improved utilization of assimilates, such as a sink effect (Sweet and Wareing 1966).

WATER RELATIONS

Water may be the most important factor limiting production in the Inland Mountain West (Bassman and Black 1984). Responses to thinning and fertilization most certainly will be affected by, and affect, water availability. Indeed thinning may have its most important effect by increasing water availability.

This was demonstrated in a study reported by Donner and Running (1986). The effects of thinning on development of seasonal leaf water stress in 50-year-old lodgepole pine stands on three sites in western Montana were evaluated. At each site, stands were thinned to varying densities and compared to adjacent controls. Predawn leaf water potentials were usually more negative (greater water stress) in controls than in any of the thinned units during the two summers subsequent to treatment (fig. 4). Leaf water potentials were proportional to basal area removed; the highest density stand had the most negative leaf water potentials. Similarly, plots with the greatest basal area showed the greatest rate of seasonal soil moisture depletion. Thus, increased water availability in thinned plots resulted in more favorable leaf water potentials. Similar results were reported for 18-year-old red pine (*Pinus resinosa* Ait.)(Sucoff and Hong 1974). Donner and Running (1986) suggested thinning increases available soil moisture by reducing canopy interception of precipitation and by reducing transpiring leaf area.

Donner and Running (1986) found that leaf water potentials during the summer averaged 0.3 megaPascal higher in thinned plots. Simulations using their DAYTRANS/PSN ecosystem model suggested 21 percent greater seasonal photosynthesis could occur in these trees as a result of this more favorable water potential, combined with increased radiation. Estimated carbon budgets indicated a substantial portion of the increased photosynthate would be allocated to stem growth.

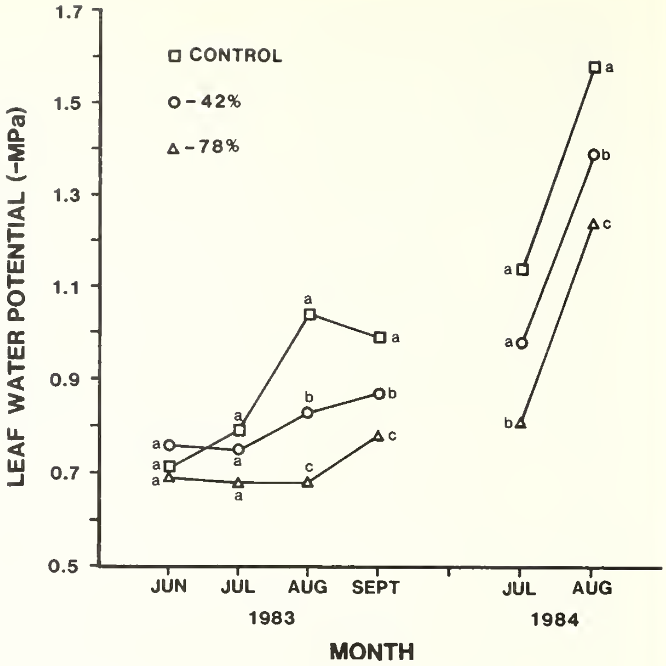

Figure 4—Seasonal trends in predawn leaf water potential at the West Dry Fork study site, Montana. Treatments indicate percentage of basal area removed. Each point is the mean of 10 measurements. Redrawn from Donner and Running (1986).

SUMMARY

Increased growth resulting from thinning and fertilization derives from different, but parallel physiological influences. Fertilization increases production of new foliage and increases the photosynthetic efficiency of foliage. The latter derives from increased foliar nitrogen which serves to increase leaf chlorophyll content. It may also increase activity of carboxylating enzymes and reduce leaf conductance. Thinning increases retention of older foliage. Increased photosynthetic rates derive from increased light and temperature. Thus both practices increase growth by causing crown expansion and increasing photosynthetic rates. In the Inland Mountain West, water availability is the most important factor limiting productivity. Thinning increases available moisture by reducing transpiring leaf surface area and canopy interception of precipitation. Resulting decreases in moisture stress increase photosynthetic production which is likely to be directed to stem growth.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Jim Vandenburg)—What is a megaPascal anyway, and why is the water potential in a thinned stand better than in the control?

A.—A megaPascal (MPa) is a unit of pressure. It is the International System of Units pressure unit that replaces pounds per square inch (psi) and the bar. One MPa is equivalent to 1,000 kPa which is about equivalent to 10 bars. Thinning reduces stand leaf area and so reduces transpiring tissue as well. Thus there is less competition for available moisture and reduced soil moisture depletion over the growing season. The end result is lower water stress in the trees remaining, and this has a positive impact on growth.

Q. (from Roy Strang)—Your data on responses to thinning and fertilizing (Brix' plots) were from the coast. What differences from his findings do you expect in the dry continental interior climate?

A.—There is little doubt that nitrogen deficiency is an important limitation in the interior areas as well as the coast. The availability of water, however, is the overriding factor controlling growth. Turgor pressure is needed not only to maintain cellular functions, but in the growth process as well. When water is limited stomata close to reduce water loss and maintain turgor. This also prevents most photosynthesis since CO_2 must enter the plant by the same pathway as water vapor departs. So no matter how much fertilizer is applied, plants must have an adequate water supply to benefit from the added nutrients. The evidence suggests thinning as an important measure to increase water supply to remaining plants. Thus to get maximum benefits from fertilization in the interior areas, it should be accompanied by thinning to the extent available moisture can be increased. Still, water stress will not be completely alleviated. And thinning, by increasing exposure of foliage, may induce a certain amount of water stress, too. Thus I would expect growth responses to remain less than for coastal situations. In addition, there is probably a certain amount of "genetic inertia" for interior species and varieties. That is, they have become adapted to a water-limited environment through generations of natural selection. This probably imparts some conservatism in terms of water use that cannot be completely overcome by cultural measures but which might be improved on by artificial selection and breeding.

Q. (from Verlin L. Smith)—In your presentation you inferred that for a single treatment as much or more gain is achieved through fertilization than thinning, but other studies show the greatest gain is from stocking control by thinning. Why the differences?

A.—Fertilization and thinning affect growth processes in different ways. For example, fertilization stimulates production of new foliage, especially in the upper crown. Thinning, however, increases retention of lower branches. Thus both result in trees with larger crowns (more leaf surface area) and a greater ability to manufacture the carbohydrates needed for growth. I don't think the data I presented showed fertilization always eliciting a greater response than thinning. It depends on the process and, for some of these, fertilization does result in a greater response than thinning. What is probably more important is the time over which growth is enhanced. Fertilization responses tend to be short lived. Unless fertilization is repeated at 5- to 10-year intervals, the growth stimulation is not sustained. By contrast, thinning responses are longer lived, depending on the extent of release and the time interval until competition begins to limit growth again. So, over the long run, stocking control by thinning may very well provide the greatest gain.

RESPONSE OF ADVANCE REGENERATION TO RELEASE IN THE INLAND MOUNTAIN WEST: A SUMMARY

Ward W. McCaughey
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ABSTRACT

Future Forests in the Inland Mountain West are often today's advance regeneration. Forest stands containing advance regeneration concern forest managers because of uncertainty of response to overstory removal. This paper summarizes literature on the relationship of growth response of advance regeneration to overstory removal for 11 coniferous species. The tree species, tree condition, and site characteristics determine the time a tree needs to adjust to overstory removal. Advance regeneration must control transpirational losses while developing needles adapted to increased sunlight. Conditions favorable to release are cool/moist sites, good vigor prior to release, large crown ratios, and no logging damage. Increased diameter growth for most species can be expected within a year or two after release; height growth response usually takes longer.

INTRODUCTION

One of the biggest challenges of managing our future forests is how to utilize advance regeneration. By definition advance regeneration is understory trees that became established naturally before harvest cutting. The amount and acreage of advance regeneration are unknown for managed lands in the Inland Mountain West, but advance regeneration is more common than we probably realize. Advance regeneration was present on 11 to 46 percent of stocked plots within randomly sampled cutover stands in Oregon, Idaho, and Montana (table 1). Five studies are summarized in table 1 to show the percentage of advance regeneration in operationally harvested stands. Averages are calculated using stocked plots to show the amount of growing stock in regenerating stands. The percentage of stocked plots containing at least one advance tree varies by study location, site preparation, residual overstory density, habitat type, and other site factors. These studies indicate a substantial portion of regenerating stands have advance trees that survived both harvest and postharvest treatment.

Advance and subsequent regeneration often become established on the same plot. Here the manager can wait to see which trees express dominance before choosing crop trees. Some plots may be stocked with only advance regeneration. Then the alternatives are limited to relying on growth of the advance trees or investing time and money to obtain subsequent regeneration. Table 2 shows the percentage of stocked 1/300-acre plots containing only advance regeneration from three studies conducted in northern and central Idaho and western Montana (Ferguson and Stage 1982; Ferguson and others 1986; Carlson and others 1982). Data were analyzed from 9,896, 1/300-acre plots established in clearcuts, shelterwoods, and selection cuts ranging in age from 3 to 15 years old. The average percentage of stocked plots containing only advance regeneration is shown by regeneration method, site preparation, and overstory climax species. The highest percentages of plots containing only advance regeneration occur on plots with no site preparation, followed by mechanically scarified plots and then burned plots. The percentages shown in table 2 may seem high. Part of this is because

Table 1—Percentage of stocked plots with advance regeneration from five studies in the Inland Mountain West. Stocked plots may also contain subsequent regeneration

Reference	Study location	Percent advance	Number of stocked plots	Plot size
Seidel 1979	Northeast Oregon	11	642	milacre
Seidel and Head 1983	Eastern Oregon	32	811	milacre
Ferguson and others 1986	Northern Idaho	46	2,968	1/300 acre
Carlson and others 1982	Western Montana	40	1,560	1/300 acre
Ferguson and Stage 1982	Central Idaho	40	716	1/300 acre

Table 2—Percentage of stocked 1/300-acre plots containing only advance regeneration. Averages are displayed by regeneration method, site preparation, and overstory climax species. Stand ages range from 3 to 15 years and the number of plots per cell varies from 58 to 343. (Site preparation designation was determined on the majority of a plot receiving that treatment)

Overstory climax species	Regeneration method and site preparation					
	Clearcut and seedtree			Shelterwood and selection		
	None	Mech	Burn	None	Mech	Burn
Douglas-fir	32.3	8.3	3.4	66.1	33.8	47.4
Grand fir	38.0	13.3	6.8	66.2	48.2	34.9
Western redcedar	22.2	9.8	6.6	46.0	36.4	15.4
Western hemlock	18.4	4.5	0.6	46.0	24.7	23.5
Subalpine fir	41.3	13.7	5.9	69.1	30.6	15.4

percentages are calculated using only stocked plots. Also site preparation was recorded as the treatment that covered the largest percentage of the plot, and it is possible for advance trees to survive on untreated portions of the plot. The percentages in table 2 still show that advance regeneration is common in cutover forests of the Inland Mountain West and reveal where concentrations are likely to be high. Percentages increase for shelterwood and selection systems.

Data used to develop table 2 were separated by age of cut to examine changes in the percentage of stocked plots containing only advance regeneration with increasing time since harvest (fig. 1). Plots with mechanical and burn preparation are combined for comparison to plots with no site preparation. Both curves in figure 1 show a rapid decline in percentage of plots stocked with advance regeneration only and level off after 5 to 6 years following release. The rapid decline is due to subsequent regeneration becoming established combined with some mortality of released trees. The average percentage of plots stocked only by advance regeneration for the 6- to 15-year postharvest period is 37 for no site preparation and 11 for mechanical/

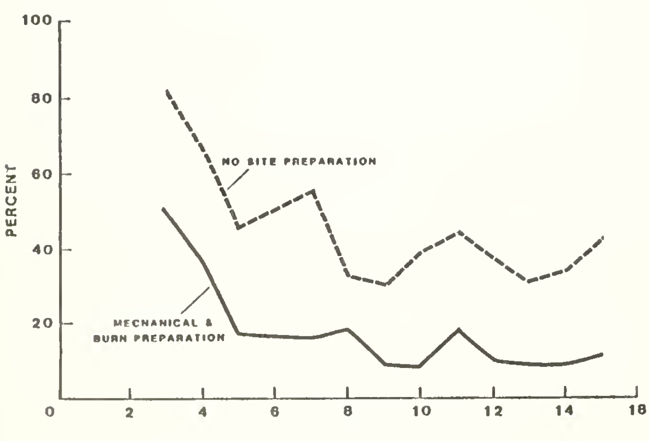

Figure 1—Percent of 1/300-acre plots stocked solely by advance regeneration and by time since release for no site preparation versus mechanical/burn preparation.

burn. The values in figure 1 do not account for factors such as aspect, elevation, overstory density, or habitat type, but they do indicate that a good proportion of plots will be stocked solely by advance regeneration in stands up to 15 years old.

Large amounts of advance regeneration exist within current timber stands in the Inland Mountain West. The amount and diversity of understory trees present after logging depend on the original stand and on the silvicultural system used. Since establishment of regeneration following harvesting is uncertain, utilizing advance regeneration for a variety of multiple-use objectives is becoming a viable silvicultural option.

Controversy has centered on the expected response of advance regeneration to release. Advance growth provides immediate growing stock, shade for subsequent seedlings, esthetics, hiding cover for wildlife, and some soil protection. Therefore, it is important to understand response to release for various tree, site, and stand conditions.

RELEASE CHARACTERISTICS

Site and tree characteristics and the degree of physiological shock are key factors influencing release response of suppressed trees. Information from the literature is presented on tree and site factors influencing release response of 11 moderately tolerant to very tolerant conifers (table 3). These species comprise a majority of the advance regeneration found within Inland Mountain West forests. Each species will be discussed separately with respect to general characteristics, growth responses, and release interactions with insect and disease problems.

Abies

BALSAM FIR

General Characteristics—In western North America, balsam fir (*Abies balsamea* [L.] Mill.) ranges from Alberta's Athabaska River to the central prairie Provinces of Canada (Halliday 1943). It is very shade tolerant and

Table 3—Species list

Balsam fir (*Abies balsamea* [L.] Mill.)
White fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.)
Grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.)
Subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.)
Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)
White spruce (*Picea glauca* [Moench] Voss)
Black spruce (*Picea mariana* [Mill.] B.S.P.)
Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco)
Western redcedar (*Thuja plicata* Donn ex D. Don)
Western hemlock (*Tsuga heterophylla* [Raf.] Sarg.)
Mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.)

commonly grows with black and white spruce (*Picea mariana* [Mill.] B.S.P. and *Picea glauca* [Moench] Voss) and tamarack (*Larix laricina* [Du Roi] K. Koch.). Balsam fir is slower growing than its associates, and the wood is considered inferior in quality. In Quebec, Hatcher (1960, 1964) found fir seedlings able to survive 50 years of suppression. Once released, they attained growth rates comparable to nonsuppressed seedlings.

Release Interactions—There are several diseases that can affect quality and vigor of balsam fir. Most rots begin in balsam fir as early as 40 years of age and increase as trees get older. The fungus *Stereum sanguinolentum* (Alb. & Sch.: Fr.) Fr. causes decay, entering the tree through stubs and broken tops caused by logging damage (USDA FS 1965). There is no reliable indicator of this rot, although drier sites tend to have the greatest incidence (Basham and others 1953).

Balsam fir is a host species of both eastern and western spruce budworm (*Choristoneura* spp.) throughout Canada and the Lake States (USDA FS 1965). Budworm can kill understory balsam fir, but usually reduces vigor of understory fir unless persistent feeding occurs. To reduce budworm damage on advance regeneration, even-aged silvicultural systems that remove most or all of the overstory should be used (Schmidt and others 1983).

Response to Release—Balsam fir will increase height growth in response to reduction in competition. Height growth rates of balsam fir increased steadily over a 4-year period after release from shrub competition, were five times greater than nonreleased fir 9 years after release, and showed no evidence of slowing (Baskerville 1961). The greatest and most rapid release response occurred on balsam fir between 1 and 4 ft tall at the time of release.

No information is available on release response of balsam fir diameter growth.

WHITE FIR

General Characteristics—In the Inland Mountain West, white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.) is most frequently found between 7,000 and 9,000 ft elevation, producing trees up to 125 ft tall and 3 ft in diameter (Maul 1965). White fir hybridizes with grand fir in interior forests of Oregon, Idaho, Washington, and northern California. This species is moderately tolerant of shade, being less tolerant than grand fir but more tolerant than Douglas-fir (Minore 1979).

Release Interactions—White fir can be infected by several heart and butt rot fungi such as Indian paint fungus (*Echinodontium tinctorium* Ell. & Ev.), *Heterobasidion annosum* (Fr.) Bref., *Pholiota adiposa* (Fr.) Kumm., and *Armillaria mellea* (Vahl.: Fr.) Quel. (USDA FS 1965). The heart rot, Indian paint fungus, infected 22 percent of white fir advance regeneration in four stands on the Fremont National Forest in Oregon (Aho 1977).

Defoliating insects reduce vigor and can kill understory white fir. Two insects that defoliate white fir are the Douglas-fir tussock moth (*Orgyia pseudotsugata* [McD.]) and the western spruce budworm (USDA FS 1965).

Response to Release—Gordon (1973) reported height growth response was delayed 2 to 5 years, larger trees grew the best, and few trees died after release. Those trees that died had logging damage or tended to be less than 1 ft tall. In another study, the three most important variables predicting postrelease growth were prerelease growth, crown ratio, and pattern of prerelease height growth (Helms and Standiford 1985). Trees with good vigor prior to release grew best after release, although some trees with poor prerelease height growth responded with some of the best postrelease growth. Trees with good prerelease growth responded soonest following release. Postrelease growth was better as prerelease crown ratio increased. The pattern of 5-year prerelease height growth was also important. Trees with decreasing patterns of growth prior to release grew more poorly than trees with constant or increasing prerelease growth rates.

GRAND FIR

General Characteristics—Mature grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.) trees are the least abundant seed producers of associated species in northern Idaho, and grand fir seeds have a low germination percentage (Haig and others 1941); yet advance grand fir regeneration is common throughout the range of this species (Dolezal 1982; Ferguson and others 1986; Seidel 1979; Seidel and Head 1983). Grand fir is rated as being tolerant of shade (Haig and others 1941; Minore 1979) but is well-adapted to growing in full sunlight, producing yields almost as high as western white pine (Foiles 1965). Natural regeneration of grand fir is best under a shelterwood (Boyd 1969), and about 30 to 40 percent crown ratio is needed for adequate growth (Stroup 1964).

Release Interactions—Heart and root rots are considerations in releasing grand fir. East of the Cascade Mountains, Indian paint fungus is a major heart rot in grand fir. For example, Indian paint fungus infected 26 percent of 1,090 grand fir trees in 11 study areas in the Blue Mountains of Oregon and Washington, accounting for 71 percent of the total board foot volume decay (Aho 1977). *Armillaria mellea* and *Phellinus weirii* (Murr.) Gilbertson are important root rot fungi that attack grand fir (Hubert 1955). Several insects attack grand fir. The worst defoliators are the western spruce budworm and the Douglas-fir tussock moth. Both insects defoliate grand fir and cause mortality if defoliation persists for several years.

Response to Release—Even though the transition from a suppressed understory tree to conditions of full sunlight is difficult, few grand fir die after overstory removal. In the study of 2,427 released grand fir and Shasta red fir (*Abies magnifica* var. *shastensis* Lemm.) in central Oregon, only 0.3 percent died during the first 5-year period since release while 2.9 percent died during the second 5-year period (Seidel 1977, 1983). Most of the trees that died were less than 3 ft tall. In another study of 115 released grand fir trees in central Oregon, Seidel (1980a) reported 0.9 percent mortality during the first 2 years since release and an additional 6.0 percent in the next 3 years.

Growth responses of individual trees vary widely, but there are similar trends among various studies. Both height and diameter response can be immediate (Seidel 1977, 1980a, 1983; Weir and Hubert 1919) or be delayed up to 3 years (Ferguson and Adams 1980; Seidel 1985). Delays of up to 4 years are reported under shelterwood regeneration methods (Seidel 1985). Growth after release follows a sigmoid-shaped curve in that trees respond with increasingly larger annual growth, eventually tapering off by about 10 years time after release. The sigmoid-shaped response curve is similar for both height and diameter growth.

In Oregon, important predictors of response to release include crown ratio, crown diameter, prerelease height growth, and residual basal area (Seidel 1980a, 1985). Mathematical equations developed by Seidel (1980a) predict height and diameter growth response of released grand fir in northeast Oregon. In northern Idaho, equations developed by Ferguson and Adams (1980) indicate several tree, site, and stand variables including prerelease height growth, time since release, tree age at release, height at release, habitat type, logging damage, slope, aspect, residual basal area, and competing regeneration-size trees, are helpful in predicting response of released grand fir.

Prerelease growth reflects the degree of suppression by the overstory, thereby negating the need to measure prerelease overstory density. Trees exhibiting better growth prior to release have larger increments following release. Larger crowns are positively correlated with larger growth responses following release. Seidel (1983, 1985) recommended a 40 to 50 percent live crown ratio at the time of release.

Poor response to release is associated with older regeneration, tall trees having low vigor (as expressed by slow prerelease growth or small crown ratios), warm/dry habitat types, southerly aspects with steep slopes, and logging-damaged trees. Seidel (1985) reported that growth of released grand fir regeneration is not as good under a shelterwood cutting as in a clearcut. But Ferguson and Adams (1980) indicated that during the first few years after release, some residual large trees or regeneration-size trees may be beneficial in moderating site conditions until regeneration adjusts to the new environment. This effect may not be beneficial if the overstory is too dense, the clumps of regeneration-size trees are too crowded, or if either of these two sources of competition is retained too long.

SUBALPINE FIR

General Characteristics—Advance subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) shows increased growth following overwood removal (Crossley 1976; Herring 1977; Herring and McMinn 1980; Johnstone 1978; McCaughey and Schmidt 1982). Subalpine fir is very shade tolerant and is typically found in association with Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), western white pine (*Pinus monticola* Dougl. ex D. Don), western larch (*Larix occidentalis* Nutt.), grand fir, western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) throughout most of the Rocky Mountains (USDA FS 1965). It is slower growing than Engelmann spruce in both height and diameter growth and is considered inferior in timber quality to most of its associates.

Release Interactions—There are several disease and decay problems to consider when releasing subalpine fir. Indian paint fungus conks indicate substantial decay within subalpine fir (Smith and Craig 1968). Decay is negligible up to age 50 but is considerable by age 160. Of decays found in subalpine fir, 43 percent were attributed to Indian paint fungus, 32 percent to bleeding conk (*Stereum sanguinolentum*), and 5.1 percent to *Resinicium bicolor* (Alb. & Schw.: Fr.) (Smith and Craig 1968). Most of these decays enter the tree through broken branches or areas of the bole damaged by logging. Logging damage provides access for the decay fungi *Stereum sanguinolentum* and *Amylostereum chailletii* (Pers.: Fr.) Boid. Logging-damaged subalpine fir have poor crop tree potential due to associated decay (Herring 1977). Herring (1977) and Smith and Craig (1968) recommend elimination of residual subalpine fir showing incidence of serious logging damage.

Subalpine fir is a preferred food for the western spruce budworm in mixed spruce-fir stands and can reduce the vitality or even kill understory trees (Carlson and others 1982; Schmidt and others 1983). Understory subalpine fir should be examined for budworm damage and growth characteristics before considering saving it. To reduce budworm feeding on released regeneration, most if not all of the overstory should be removed (Schmidt and others 1983).

Response to Release—Subalpine fir responds well to overstory removal. Mean height growth of advance subalpine fir in British Columbia was nearly nine times that of natural regeneration 21 years after release (Herring and McMinn 1980). A small part of the difference was attributed to the "head start" of the advance regeneration and because natural regeneration occurred where excessive scarification had caused site deterioration. In Utah, Wyoming, and Idaho subalpine fir responded to release with increased height growth while nonreleased advance regeneration maintained a slow growth rate (McCaughey and Schmidt 1982). Equations developed by McCaughey and Schmidt (1982) predict height growth of released subalpine fir. Johnstone (1978) developed an equation to predict the height of subalpine fir at a particular year after release for trees in west-central Alberta. Independent variables in Johnstone's equations are the number of years since release and the height of trees at the time of release.

Height growth response may be delayed for several years following overstory removal. Delays in height growth response to release may range from 3 to 5 years in British Columbia (Herring 1977) to 1 to 7 years in the intermountain region of the United States (McCaughey and Schmidt 1982). Height growth rates can decline for the first few years after release before showing accelerated growth rates (Johnstone 1978; McCaughey and Schmidt 1982).

Diameter growth of subalpine fir increases dramatically following overstory removal. Ten-year diameter growth can increase from 150 to 650 percent over prerelease growth rates (Crossley 1976). In west-central Alberta mean annual diameter increment increased from 0.05 inches before release to 0.126 inches 20 years after release (Johnstone 1978).

Diameter response usually occurs from 1 to 5 years after overstory removal and generally precedes height growth response. Diameter growth response at stump height was nearly immediate for a 176-year-old subalpine fir (Crossley 1976). This immediate release response was evident at half-tree height, which dispels the notion that release is confined to the lower bole. In west-central Alberta subalpine fir diameter growth responded to release at all levels of the bole within the first 5 years after logging (Johnstone 1978).

Picea

ENGELMANN SPRUCE

General Characteristics—The Engelmann spruce-subalpine fir forest type is found at higher elevations within forested zones of the Rocky Mountains. Engelmann spruce is moderately shade tolerant. Advance spruce trees release soon after overwood removal and subsequently outgrow their common associates (Garman 1957).

Release Interactions—Diseases reduce the quality of advance Engelmann spruce trees by the time they reach harvest size. Decay in spruce is caused by several wood rotting fungi: *Inonotus cincinatus* (Fr.) Gilb., *Coniophora puteana* (Schum.: Fr.) Karst., *Phellinus pini* (Thore: Fr.) A. Ames, *Chactoderma luna* (Rom.) Parm., and *Fomitopsis pinicola* (Schwartz: Fr.) Karst. (Hornibrook 1950). Two other fungi have also been linked to rot in Engelmann spruce: *Coniophora puteana* and *Chrysomyxa arctostaphyli* Diet. (USDA FS 1956). The rots are usually associated with older spruce; therefore, evidence of disease should be examined before saving 70-year-old or older advance regeneration.

The western spruce budworm causes loss of vigor of understory trees, and tree mortality will occur if defoliation persists for several years (Carlson and others 1982, 1983; Schmidt and others 1983).

Response to Release—Height growth rates of Engelmann spruce usually increase following release from overstory trees. Response can occur in the first year following release but may be delayed for 2 to 6 years (McCaughey and Schmidt 1982). This is 1 to 2 years behind its common associate, subalpine fir.

The amount of residual overstory influences height growth response of Engelmann spruce in the intermountain region of the United States (McCaughey and Schmidt 1982). Height growth response was greatest when the overstory was totally removed and was proportionately less in partial cuts. The greatest height growth increases occurred in taller spruce. Ten years after logging, spruce height growth was still accelerating but how long this will continue is unknown (McCaughey and Schmidt 1982). Equations developed by McCaughey and Schmidt (1982) predict height growth of released Engelmann spruce in the intermountain region. In British Columbia both total height and current annual height increment of 21-year-old spruce indicate that some advance regeneration would be of merchantable size decades before natural regeneration (Herring and McMinn 1980).

There is little information available on diameter growth response to overstory release for Engelmann spruce. Spruce probably follows a pattern similar to its associate subalpine fir with accelerated diameter increment preceding height growth response.

WHITE SPRUCE

General Characteristics—White spruce is a shade-tolerant species that can survive 40 to 50 years of suppression and still respond well to release (Baker 1949; Lees 1966; Steneker 1967). It can form pure stands but generally grows in association with black spruce and balsam fir in northern Canada, and subalpine fir and Engelmann spruce in the northern United States and southern Canada (Garman 1957). In Saskatchewan white spruce falls behind in height growth and remains an understory tree unless released from associated hardwoods such as aspen (*Populus tremuloides* Michx.)(Cayford 1957).

Release Interactions—Growth response is affected by the vigor of white spruce at the time of release. Spruce budworm can reduce spruce diameter growth and vigor after several years of heavy defoliation (Blais 1958). Budworm damage assessments should be conducted before decisions are made concerning saving white spruce advance regeneration. Older advance white spruce may have heart rots such as *Phellinus pini* and should be eliminated from the stand if they exist (USDA FS 1965).

Response to Release—Baskerville (1961) and Berry (1982) found that white spruce responded to overstory release with increased height growth within the first 5 years after harvest. In contrast, Johnstone (1978) reported that spruce height growth declined in west-central Alberta during the first 5-year period after overstory removal, but attained its prerelease height growth rate by the 10th year.

In New Brunswick shorter advance regeneration responded with greater height growth following release than did taller trees (Baskerville 1961). In Alberta, release was observed for all sizes of spruce and was unrelated to tree age (Johnstone 1978). An equation developed by Johnstone (1978) predicts the height of white and black spruce after release. The number of years since release and the tree height at the time of logging were important independent variables. Length of suppression has not been an important variable in most studies. Berry (1982) found that white spruce that had been suppressed for 27 years still responded to release with increased height growth.

Diameter growth of white spruce less than 70 to 75 years old will increase after release from overstory competition. Competition should be reduced on at least three and preferably four sides of each advance tree before there is significant response (Frank 1973). Crossley (1976) found a significant increase in growth at stump height during a 10-year period following release. The average annual increase in rate of diameter growth after release was 477 percent over a 10-year period for white spruce, but averaged 792 percent during the last 5 years.

Tree age of white spruce does not appear to be related to diameter response following release for trees younger than 75 years old (Crossley 1976; Johnstone 1978). Release cuttings stimulated only minor radial stem increment on 75- to 100-year-old spruce in spruce-aspen stands in Saskatchewan (Steneker 1974).

BLACK SPRUCE

General Characteristics—Throughout western North America black spruce ranges from midlatitudes in Canada northward to Alaska. It is considered a shade-tolerant species and is found in association with tamarack, white spruce, balsam fir, jack pine (*Pinus banksiana* Lamb.), and lodgepole pine (USDA FS 1965). The ability of black spruce to reproduce by seed germination, layering of lower limbs, and sprouting from near-surface roots can create large quantities of advance regeneration (Horton and Lees 1961; Place 1955).

Release Interactions—Black spruce is susceptible to windthrow because of shallow roots and the moist soil conditions it is found in (LeBarron 1948). Butt rots are common in black spruce greater than 70 years old. The most common rot organisms are *Phaeolus schweinitzii* (Fr.) Pat., *Stereum sanguinolentum*, *Armillaria mellea*, *Phellinus pini*, and *Fomitopsis pinicola* (Lorenz and Christensen 1937). Black spruce is not a preferred host of spruce budworm except when budworm populations are at epidemic levels (Blais 1957). Decisions concerning advance regeneration should take insect and disease problems into account prior to making silvicultural prescriptions.

Response to Release—Release from competition can stimulate height growth of black spruce. In Alberta, advance black spruce increased growth after overstory removal to a rate nearly equal that of open grown spruce. Height growth declined during the first 5-year period but increased by the 10th year after logging (Johnstone 1978). Johnstone (1978) developed an equation to predict the height of advance black spruce following release. The independent variables are the number of years since release and the height of the advance regeneration at the time of release. Richardson (1979, 1982) found that there was no height growth response the first 2 years after overstory removal but height growth increased 4 years after release. No relationship between growth response and tree age was found in studies by Johnstone (1978) or Stettler (1958).

There is a small percentage increase in diameter growth 5 years after release but a very high annual percentage increase during the 6- to 10-year period (Crossley 1976; Johnstone 1978). Johnstone (1978) found that diameter response is evident at all levels of the bole, but no relationship exists between diameter growth response of black spruce and tree age at time of release.

Pseudotsuga

DOUGLAS-FIR

General Characteristics—Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) forests cover about 20 million acres (8 million ha) in the States of Montana, Idaho, and eastern Washington (USDA FS 1983). There are millions of additional acres where Douglas-fir is an associate with western larch, grand fir, and lodgepole pine. Douglas-fir is intermediate in shade tolerance but is commonly found as advance regeneration. Young seedlings and saplings will respond to release from overstory competition (USDA FS 1965).

Release Interactions—The western spruce budworm can reduce tree vigor by defoliating understory Douglas-fir (Carlson and others 1982; Schmidt and others 1983). Douglas-fir is also defoliated by the Douglas-fir tussock moth. The tussock moth can cause complete defoliation within 2 months during severe outbreaks (Wickman 1978).

Young Douglas-fir has decay problems caused by *Phellinus pini*, *Fomitopsis cajanderi* (Karst.) Katl. et Pouz., and *Phaeolus schweinitzii* (USDA FS 1965). These heartwood rots reduce both tree vigor and tree value. *Phellinus weirii* can kill Douglas-fir of all ages (Childs 1960) causing reduction of stocking long after release. Another disease that reduces height and diameter growth of Douglas-fir is dwarf mistletoe (*Arceuthobium douglasii*) (Hawksworth 1978). Managers should evaluate crowns and root rot incidence on advance growth prior to making a silvicultural decision.

Response to Release—Douglas-fir height growth will increase quickly when released from overstory competition (Helms and Standiford 1985; Weber and Tesch 1985). In California, height growth response occurred 2 to 4 years after release, and trees that grew the fastest prior to release responded the quickest. Three factors found to be important in predicting postrelease height growth are the prerelease height growth, live crown ratio at time of release, and whether the 5-year prerelease annual height growth was decelerating, constant, or accelerating (Helms and Standiford 1985). In southwestern Oregon, Douglas-fir advance regeneration responded well even after 50 years of suppression. Trees developed large crowns for the first 3 years after release and then began to increase height growth (Weber and Tesch 1985).

Douglas-fir will respond to release by increasing diameter growth. Three prerelease tree variables that help predict postrelease diameter growth are diameter growth rate, diameter, and height (Helms and Standiford 1985). Prerelease height and diameter growth rate are important indicators determining whether advance Douglas-fir should be retained. Trees with greater prerelease height and diameter growth respond more than slower growing trees.

Thuja

WESTERN REDCEDAR

General Characteristics—Western redcedar (*Thuja plicata* Donn ex D. Don) is a high-value species throughout its range. The wood is light and easy to work and has a high natural resistance to decay (Minore 1983).

Redcedar is rated as being very tolerant of shade (Haig and others 1941; Minore 1979). Advance individuals can come from seed but in mature stands are more often "veglings," originating from layering of branches or fallen saplings (Parker 1979). Juvenile redcedar does not compete for dominant crown positions as well as associated conifers in the Inland Mountain West, prompting Haig and others (1941) to state that "redcedar makes the slowest early growth, and never achieves dominance in a young stand." A regeneration height growth equation developed by Wykoff and others (1982) quantifies this observation. Among associated species, redcedar has the slowest growth rate over time.

Release Interactions—Koenigs (1969) noted a high incidence of root rots 20 years after releasing a western redcedar stand. *Armillaria mellea* was found on 41 percent of released trees compared to 12 percent on nonreleased trees. Diameter growth response was initially good but rapidly declined between the fifth and 10th years due to root rot. A later study of 15 released western redcedar stands did not find this decline in growth rate or indications of increased root rot problems (Graham 1982).

Response to Release—Pole-size or larger western redcedar respond well to release (Graham 1982; Leaphart and Foiles 1972). Good prospects for release are associated with northerly slopes and larger (but younger) trees on habitat types where redcedar is the climax species.

Regeneration-size redcedar does respond with increased height growth after overstory removal, but growth rates are low compared to associated species and redcedar soon loses its competitive advantage. Deitschman and Pfister (1973) reported on a stand in northern Idaho where the overstory was removed and regeneration thinned to favor white pine and redcedar. The redcedar averaged 4.5 ft tall. Reinvasion by western hemlock and grand fir was substantial, and within 10 years after release these two species were as tall as the released redcedar. Meanwhile, the released white pine responded well and grew twice as fast as other species.

Tsuga

WESTERN HEMLOCK

General Characteristics—Western hemlock was once considered to be a "weed" or "inferior" species in the Inland Mountain West (Koch 1923; Neff 1928). Today, western hemlock is managed for timber production because of good growth and ease of establishment. Western hemlock is very tolerant of shade (Haig and others 1941; Minore 1979) and is considered to be the climax species in habitat types where it grows in the Inland Mountain West (Cooper and others 1985; Daubenmire and Daubenmire 1968; Pfister and others 1977). Because of this species' shade tolerance, advance regeneration is common.

Release Interactions—Indian paint fungus is a serious heart rot in western hemlock. Both decay incidence and defect increase with tree age (Aho 1977). The behavior of this fungus makes it a major consideration when releasing hemlocks and true firs.

Etheridge and Craig (1976) explained important factors leading to decay in western hemlock by Indian paint fungus. Infection occurs on stubs of shade-killed branchlets. About 40 years of suppressed growth is necessary to produce such conditions. After the stub heals over, the fungus can become dormant for up to 50 years. Infections are reactivated by mechanical injury such as logging scars, broken tops, broken branches, or frost cracks. Indian paint fungus was isolated only from branchlet stubs of suppressed trees. The length of time stubs were exposed before healing over was positively correlated with infection, suggesting that quick healing of branch stubs lowers susceptibility.

Other authors essentially agree with the findings of Etheridge and Craig—Aho (1977) for grand fir, Filip and Aho (1978) for white fir, Herring and Etheridge (1976) for Pacific silver fir (*Abies amabilis* Dougl. ex Forbes), and Smith and Craig (1970) for subalpine fir.

Response to Release—Possibly a greater proportion of released hemlock die than do other species discussed in this paper. For example, Tucker and Emmingham (1977) estimated that 95 percent of western hemlock died the year of release in a south-facing clearcut in Oregon. They estimated that 50 percent died in a shelterwood cutting at the same site. Needles of released western hemlock abscised prematurely, and needles formed the first year after release were about half normal size. Released hemlock in shelterwoods retained more prerelease crown and produced sun needles after release. Tucker and

Emmingham recommended a shelterwood cutting, allowing 3 to 5 years before final overstory removal.

There is evidence that tall western hemlock are slower to respond and have slower growth after release than do shorter trees. Hoyer (1980) showed, from a sample of four trees, that the taller the tree at release, the slower the postrelease height growth. Hoyer's tentative conclusion was that hemlock trees less than 30 ft tall will release and closely match site index curves for western Washington. Trees taller than 30 ft may not release well, thereby leading to an underestimate of site productivity. Additional evidence comes from Oliver (1976), who found that taller hemlock trees take longer to respond to release. Weir and Hubert (1919) noted the effect of shock on released hemlock in northern Idaho. Following release, diameter growth response follows a sigmoid shape with increased growth up to about 7 years after overstory removal.

MOUNTAIN HEMLOCK

General Characteristics—In the Inland Mountain West, mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.) is found in western Montana and northern Idaho northward through southeastern British Columbia. It is associated with whitebark pine (*Pinus albicaulis* Engelm.), subalpine larch (*Larix lyallii* Parl.), Engelmann spruce, and subalpine fir (USDA FS 1965). Shade-tolerant mountain hemlock seedlings and saplings can survive long periods of suppression, resuming normal growth when competition is removed (USDA FS 1965). Mountain hemlock will reproduce by layering, thus increasing the amount of advance regeneration present within stands (Cooper 1931).

Release Interactions—Heart rots on older trees should be examined before decisions are made concerning use of advance growth. Indian paint fungus reduces yields, and *Phellinus weirii* may kill mountain hemlock in central Oregon (USDA FS 1959). Dwarf mistletoe (*Arceuthobium compylopodum forma tsugonsis*) reduces vigor in mountain hemlock (Gill 1935), reducing potential for release.

Response to Release—Advance mountain hemlock responds well to release from overstory competition. In Oregon, mountain hemlock showed a marked increase in height growth over prerelease rates (Seidel 1985). Height growth rates increased the first year after release, continued accelerating for almost 15 years, and then leveled off. Postrelease height growth is directly proportional to live crown ratio and inversely proportional to overstory stand density. Fifteen years after release mountain hemlock was growing at a periodic annual growth rate of 6.2 inches, nearly five times the prerelease height growth rate (Seidel 1985).

Mountain hemlock responds soon to release from overstory competition with increased diameter growth. Diameter growth is directly proportional to live crown ratio and inversely proportional to overstory stand density. Diameter response begins within the first 5 years after release, accelerates from years 6 to 10, and levels off during the 10- to 20-year period after release (Seidel 1985). Diameter growth response is greatest in clearcuttings, somewhat less in shelterwood cuts, and does not change significantly over time in undisturbed areas. In clearcuts mountain hemlock grew nearly 0.2 inches in diameter annually for up to 20 years after release (Seidel 1985).

DISCUSSION

Today's decisions on silvicultural prescriptions will affect forest stands for many years. Tree, stand, and site factors must be taken into consideration to determine the best management strategy for a stand. Several factors complicate the decision of whether to retain advance regeneration. First is our imperfect knowledge of response to release. Second is differences in objectives of land owners. While one owner may be willing to leave advance regeneration, another owner may not. Third, even within an ownership, prescriptions will vary. One site might be good for releasing advance regeneration; another site might produce better yields if given a different prescription.

Featuring advance regeneration in the next rotation may or may not be the proper silvicultural prescription. There are several advantages in saving advance regeneration. Trees that respond to release with increased height and diameter growth provide immediate stocking and, because of their initial size, reduce rotation length. Site preparation and planting costs are reduced. Often, advance regeneration either stocks sites that are difficult to regenerate or provides shade for subsequent natural regeneration. Maintaining a continuous "green" forest helps provide hiding cover for wildlife and improves the esthetic appearance of a stand. Soil erosion is also reduced.

There are also disadvantages to saving advance regeneration that should be considered. By featuring advance regeneration, stand succession is accelerated toward climax, increasing susceptibility to insect and disease problems (Schmidt and others 1983). Advance trees are typically shade-tolerant species, and most are host to the Douglas-fir tussock moth and the western spruce budworm. Stem and root rots are common in older suppressed trees or in logging-damaged trees. Logging damage is often hard to prevent. Another disadvantage of saving advance trees is that disgenic practices may be encouraged. Advance trees are often saved even though they may never produce a commercial product. Contracts requiring protection of large amounts of advance regeneration may increase logging costs.

For timber objectives advance regeneration should be relied on only where growth after release is adequate and there is little risk of trees harboring future problems such as defect and decay. Advance regeneration that does not respond well to release or takes too long to adjust should not be counted in regeneration surveys (Ferguson 1984). Such trees do not meet the intent of the National Forest Management Act of 1976 or State forestry practices acts because projected yields will not be met. Alexander (1974) recommended accepting advance regeneration when it has good form, is able to make vigorous growth when released, and is free of defect or mechanical injury, no matter what its size. Ferguson (1984) has developed guidelines for defining acceptable advance regeneration.

There are three general recommendations common to the 11 species discussed in this summary paper. If releasing advance regeneration for future crop trees is the management objective, avoid logging damage to advance trees, favor the most vigorous trees, and wait 2 to 5 years before evaluating release response.

Avoiding logging damage to advance regeneration decreases the number of passageways for diseases such as *Stereum sanguinolentum, Phellinus pini,* and *Armillaria mellea.* Logging activities can also cause deformed boles, root wrenching, and soil compaction. Gravelle (1977) discussed ways to reduce logging damage to advance regeneration.

Trees growing the best prior to release generally have the highest postrelease growth rates. Trees having live crown ratios greater than 50 percent respond with greater height and diameter growth than trees with low crown ratios. It is important to examine foliage color and density when evaluating the potential of advance regeneration.

Wait 2 to 5 years after logging before evaluating release response of advance regeneration. Nearly all 11 species responded to release in the 2- to 5-year period after release. Advance trees must adapt to increased levels of light. Release response is highly variable, not only between species but also within a species on a specific site. For example, McCaughey (1983) found that Engelmann spruce of the same age did not have similar postrelease height growth and some spruce did not respond while others increased annual height growth by nearly five times prerelease growth rates. Advance regeneration is often found in dense clumps. After waiting 2 to 5 years, slow-growing trees can be thinned from the clump to further release and evenly space the more vigorous trees. Growth rates of released trees should be compared to growth of planted or natural subsequent trees. Seidel (1980b) provided methods for such a comparison.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Ruben Escatell)—To minimize wounding of advance true fir regeneration, what is the maximum basal area per acre allowed to be removed in an overstory removal?

A.—Most studies on this subject indicate the more volume removed, the greater the wounding and destruction of advance regeneration, but there are so many factors affecting damage to regeneration caused by overstory removal that no universal rule applies. The incidence of wounding varies with season of the year, size of advance regeneration, size of removed trees, logging equipment, and terrain. Concerned equipment operators are very important, but silviculturists must participate in planning, training, and supervision.

A buffer of regeneration is often recommended to compensate for reduction in stocking caused by overstory removal. Thus it seems reasonable to correlate the amount of overstory removed with reduction in stocking so that the amount removed does not reduce stocking below the desired level. Since there are so many variables affecting damage to regeneration, this correlation has not been developed. An alternative would be to monitor the stand during logging and quit when the minimum stocking level is reached, but this seems impractical for most ownerships at this time. Gravelle (1977) summarized studies dealing with damage to advance regeneration and has suggestions for reducing damage.

Q. (from John Anderson)—Did you look at effect and degree of sunscald on advance regeneration following overstory removal?

A.—Our paper does not summarize tree physiology information that relates to release response of advance regeneration. Many authors examine the physiological effects of release. For example, Tucker and Emmingham (1977), studying western hemlock, provided excellent insight into the effects of sunscald. When shade-adapted needles are suddenly exposed to increased light levels, chlorophyll is subject to destruction. This, along with other factors, causes early abscision of needles and sun needles formed the year after release are smaller than normal. The literature they cited suggests most conifers respond similarly. The degree of sunscald is less if trees are somehow partially shaded. This has led to recommendations such as more than one entry for overstory removal, leaving culls and snags standing for a few years after release, and not thinning the released stand for 2 to 5 years. Ferguson and Adams (1980) and Helms and Standiford (1985) reviewed other physiological responses to release.

PROSPECTS FOR MANAGEMENT PREVENTION OF DISTURBANCES IN FORESTS OF THE MOUNTAIN WEST

Karl J. Stoszek

ABSTRACT

Reviewed are trends, accomplishments, and concerns in forest protection of the mountain west region of America. Once a specialty field focusing on direct controls of destructive agents, forest protection became recognized as an integral part of silviculture and management. Accomplishments include development of distrubance-hazard rating capabilities and silvicultural pest-hazard reducing measures, and use of pheromones in survey and controls. Problems remain with the consequences of fire exclusion, frost, root rot, and animal damage in young cultures. Emphasized is the need for silviculture that enhances the productive capacity of soils and maintains a structurally and physiologically healthy forest. Outlined are planning measures for the integration of forest protection concerns into silviculture and management considerations.

INTRODUCTION

In this paper I review the development trends in forest protection of the Mountain West, highlight accomplishments in forest protection as well as some of the gaps in our knowledge, and discuss the silvicultural opportunities for preventing or reducing the negative effects of disturbances.

I emphasize that the occurrence and severity of physical and biotic disturbances in the forest do not reflect so much the whims of nature as the structure and health of the forest. The key to reducing the negative impacts of disturbances is to develop and maintain structurally and physiologically sound forests. In this context, the paper serves as an introduction to the other papers on forest protection in this symposium.

FOREST PROTECTION TRENDS

Developments in forest protection of the Mountain West reflect developmental changes in forest management and, lately, increasing environmental concerns of the public. During the era of extraction-oriented timber management, the emphasis was on prompt control of wildfire, sanitation-salvage of high-value trees at risk to insect attack, detection and chemical control of defoliator outbreaks, and attempts to eradicate introduced pest organisms. The goals were clear: protect the forest from natural and man-caused disturbances until harvest.

Virtually no attention was given to possible long-term effects of logging and forest protection actions on structure, vigor, and developmental dynamics of cutover stands and of stands where fire and biotic disturbances have been suppressed. Little attention was paid to effects on site productivity, water quality, and other forest resources, largely because of a general lack of public concern (the forest resources appeared limitless). The basic reason for this attitude was ignorance. There was little foresight or concern, then, over the long-term consequences of management practices, even though considerable efforts have been exerted by some to build the groundwork for the present scientific base of forest management (Wellner 1978).

The situation changed rather dramatically during the post-World War II era and especially in the 1970's (Waters and Stark 1980). On public lands a dominant use, timber management, has been changed to multiple use. Prompted by declining timber supplies, market forces, and public pressure, the former timber extraction emphasis on both public and industrial lands has changed to an emphasis on management for fiber and timber that is constrained by multiple-use considerations.

Spurred by Carson's *Silent Spring* in the early 1960's, the environmental movement was started, and with it ongoing public and legislative pressure on natural resources management and sciences. The practice of forest protection was affected by legislative and regulatory restrictions, especially with regard to the use of pesticides and herbicides. The practice of forestry had to be modified to accommodate public concerns over clean air and water, rare and endangered plants and animals, and wildlife and esthetic values. All this increased the scope of forest protection.

Advances in the fields of animal and plant biology and ecology and other basic and applied natural sciences were integrated into a new concept of viewing and dealing with pest disturbances—Integrated Pest Management (IPM). IPM, formally recognized in the National Forest Management Act of 1976 in the United States (Stark 1979), is based on understanding of the problem factors' ontogeny, causal relationships, developmental dynamics, effects on the resources, and on information pertaining to the applicability of alternative or complementary control and prevention measures, and environmental impact assessments (Stark 1977, 1987). The hallmark of the previous era—pest control through use of persistent, broad-spectrum chemicals—has been deemphasized or phased out under IPM (Ciesla 1982).

Recently, as reviewed by Waring and Schlesinger (1985), we have begun to realize that disturbances, particularly biotic disturbances, develop in response to stress-related changes in the forest and that, in an ecological sense, the occurrence of a disturbance tends to alleviate the stress conditions that would have prompted an insect or disease outbreak.

Research has shown that disturbance-prone situations are identifiable and can be modified through silviculture; thus, forest protection concerns can be integrated into silvicultural decisions. Protection, once a specialty field second only to logging engineering, has lost this "distinction" and is gaining in its effectiveness through integration with silviculture (see Baumgartner and Mitchell 1984; Carlson and others 1985; Fellin and others 1984; Stoszek and Mika 1978).

PROTECTION CONCERNS, CURRENT ACCOMPLISHMENTS, AND WARNINGS

Mature and Overmature Stands

Protection concerns and associated research and development (R&D) efforts to date have largely focused on bark beetles, defoliator outbreaks, root rots and stem decays, mistletoes, and fire control in mature and overmature stands. Advances in other forest sciences, especially forest ecology, have led to the recognition of the role of biotic and abiotic disturbances in developmental dynamics of the forest. In particular, the detrimental effects of fire exclusion and indiscriminate use of insecticides on forest structure and development, nutrient stress, and disturbance risk have been identified (see Arno 1983; Bart and Hunter 1982; Schmidt 1985; Stoszek 1986). Progress made in the last decade in fire ecology, fire prevention, and management has contributed, by example, to the overall integration of other protection specialty fields and helped the merging of forest protection into silviculture.

Through current R&D efforts by Canadian and United States scientists, knowledge pertinent to IPM has been vastly improved (Stark 1979). Successful bark beetle attacks are now commonly viewed as symptoms of trees under physiological stress brought about by a combination of site- and stand-related factors, climatic extremes, effects of pathogenic organisms, and management-related changes in the forest ecosystem (such as fire exclusion, logging injuries, disruptions in drainage patterns) or industrial atmospheric depositions (see Berryman and Wright 1978; Kimmins 1987; Ryker and Rudinsky 1979; Stevens and Hawksworth 1984; Waring and Schlesinger 1985). Silvicultural and other management interventions capable of preventing development of physiologically weakened or maladapted tree-stand conditions are now viewed as bark beetle outbreak prevention (see Amman and others 1981; McGregor and Cole 1985; Raffa and Berryman 1986; Safranyik and others 1974; Schenk and others 1980). Various site and tree stand hazard rating models have been developed to help the manager in identifying and prioritizing risk stands to sanitation thinnings or harvest (for example Mitchell and others 1983; Moore and others 1978; Schmid and Frye 1976; Waring and Pittman 1980; Waters 1985).

Development of outbreaks by the major western defoliators, Douglas-fir tussock moth and western spruce budworm, is viewed in a similar manner to the bark beetle problem, although with less unanimity. Population increases of both insects appear associated with site and stand conditions prone to development of nutrient deficiencies or imbalances in host trees (Stoszek and Mika 1985b; Stoszek and others 1981). Moisture and nutrient stress-related changes in the synthesis of chemical defenses of the host foliage are considered of key importance to defoliator population increases (Cates 1985; Stoszek 1986). However, lack of experimental support on the nutrient stress predisposition hypothesis hampers adequate understanding of defoliator-host tree relationships.

Substantial advance has been achieved in forest pest outbreak detection and outbreak forecasting techniques (see Beveridge and Thier 1982; Dewey and Campbell 1978; McDonald and others 1981; Rudinsky 1979; Sheehan and others 1987; Stage 1978).

Site and stand hazard models of various predictive capacity have been developed to aid the manager in identifying defoliator-prone configurations (Hedden and others 1981; Heller and Sader 1980; Kessler and Ulliman 1985; Stoszek and Mika 1985a; Stoszek and others 1981) and in designing silvicultural preventions and direct control efforts (Fellin and others 1983, 1984; Stoszek 1985; Stoszek and Mika 1978, 1984). However, the risk rating utility of models based on multivariate regression equations is limited to the realms of conditions under which they were developed (Stoszek and Mika 1985b). Preliminary models conceptualizing the insights gained through risk rating and host-defoliator relationships research are available for the western spruce budworm (Carlson and others 1985). A rather sophisticated simulation-based evaluation of defoliator control strategies can now be attempted through linkage of defoliator impact models with site-stand hazard models, stand prognostication techniques, and economic models (May and others 1984).

Scientific inquiries into host colonization and mating behavior of some of the major forest insect pests led to the discovery of "sex" attractants (pheromones) and antiaggregation compounds elicited by the insects (Wood 1982). Some of these semiochemicals have been synthetically produced and operationally tested to lure (pheromones) or repulse (antiaggregants) insects associated with a given compound. Pheromone analogs have been recently made operationally applicable in both survey and pest population reduction efforts for the mountain pine beetle (Borden and others 1983), the Douglas-fir tussock moth (Daterman and others 1979), the western pine shoot borer (Sower and others 1982), and ambrosia beetles (Borden and McLean 1981). The synthetic analog of an antiaggregant produced by the Douglas-fir beetle, methylcyclohexenone (MCH), has proven successful in warding off Douglas-fir beetle infestations in downed trees (Furniss and others 1981) thereby preventing population buildups of this pest.

Substantial contributions were made in the area of root rot and stem decay ontogeny, interactions with other factors weakening tree health, and impact assessment (Hadfield 1984; Hertert and others 1975). Particularly comprehensive are the R&D accomplishments in dwarf mistletoe impact assessment techniques and silvicultural controls (Hawksworth 1980; Stevens and Hawksworth 1984; Wicker 1984).

Following the accidental and devastating introduction of white pine blister rust in the 1930's, a blister rust resistance R&D program was initiated to develop the knowledge base needed to retain western white pine as a commercially viable component of forests within its original distribution range. The tools to assess tree and stand risk to blister rust-caused pine mortality and guidelines for design of stand improvement treatments incorporating techniques to reduce blister rust impacts were developed (Bingham 1983).

Immature Stands

A substantial body of knowledge has been developed during the past decade on disturbance factors affecting regeneration and growth of juvenile forests (Baumgartner and Boyd 1977; Cleary and others 1978). Pesticidal means for protecting seed from insect and rodent depredation were developed. However, cost and environmental concerns (Bart and Hunter 1982) limit the large scale applicability of chemicals, while lack of knowledge on factors affecting cone resistance to insect and disease attacks hampers development of specific silvicultural practices for reducing cone and seed losses.

It is now commonly accepted that matching tree species and seed source with elevation and habitat type is essential to the reduction of impacts by frost, heat, or drought. But more attention should be given to better correlation among genetic traits of major tree species and their currently delineated seed zones (Rehfeldt 1984; Silen 1982). Also, there is clearly a need for a stronger recognition that genetic attributes other than superb tree growth must be considered in tree improvement programs. Acid tolerance, drought and frost hardiness, and insect and disease resistance are examples of traits that would enhance success of intensive timber culture in the Mountain West.

Improvement is needed in application of available know-how to quality seedling production, seedling storage, and handling and planting techniques; the pay-off is bound to extend beyond stand establishment in reduced damage severity by climatic and biotic factors. It can be safely predicted that root rot will be the single most difficult problem in sapling to pole-sized plantations throughout the Interior West region. The primary predisposition will be, I think, root-binding that has resulted from cumulative effects of both poorly designed and implemented planting techniques and ill-formed root systems of bare-root and container-grown planting stock (Stoszek 1978). The planting bar and dibble planter will gain the dubious distinction as tools creating "self-destructive" forests!

Both vertebrate and invertebrate animals have been recognized in many parts of the Mountain West as factors limiting successful plantation-based forestry (Baumgartner and others 1987). Intolerable animal damage levels are usually the consequence of habitat conditions created by inappropriate methods of harvest-regeneration, site preparation, and shrub control. As with other major disturbances, animal damage levels can often be predicted on the basis of changes (usually management induced) in structure and plant species composition of the forest, particularly its subordinate vegetation. To assure cost-efficient and sustainable stand cultures, risk assessment and abatement costs for animal damage must become an integral part of decisions on silvicultural systems, harvest-regeneration methods, and management intensity.

Research and experience on plantation damage from livestock-caused trampling, browsing, rubbing, and soil compaction confirm the notion that capital-intensive investments in forest culture don't coexist well with livestock grazing practices. This resource-use conflict can be resolved through land-use allocation policies and coordination/integration of timber management with forest range management efforts (Kingery and others 1987). In certain situations, site-appropriate grazing may enhance attainment of timber production goals through reduced vegetative competition, reduced rodent damage, and ground fire hazard. This exemplifies the value of integrated coordination efforts. However, even this may prove ultimately counterproductive because of the potentially adverse effects of grazing on physical and chemical condition of soils.

Soil Productivity Protection

While developing efficient slash disposal and site preparation techniques, we came to recognize that other effects were involved than reduced fire hazard, increased planting efficiency, or numbers of plantable spots per acre. Reduced seedling survival from frost heaving, frost burn, desiccation, or heat injury, low growth rate resulting in prolonged exposure to animal damage or increased susceptibility to insects and diseases—these became all too familiar problems. Many are associated with excessive or heavy-handed application of various site preparation techniques and unwise, indiscriminate use of logging equipment or poorly chosen planting tools—such as the dibble and planting bar.

Despite a wealth of published knowledge on soil forming processes, nutrient cycling, nutrient uptake, and tree nutrition, we are still in a rather primitive stage in incorporating knowledge of these processes into resource management and silvicultural decisions. We must recognize that the production potential of forest lands, the composition and developmental dynamics of forests, and their resistance to and recovery from disturbances are totally dependent on soil-plant interaction processes.

Recently Ulrich (1986) stated that a forest ecosystem is in a steady state when the rate of protons released through mineralization of organic matter is matched by the rate of protons consumed by plants and weathering processes. One would perhaps shrug this assertion off as "theoretical science stuff" were it not for the fact that a prolonged imbalance of the ion cycle equation leads to soil acidification and related changes in organismic composition and health of the forest. Notable consequences are plant nutrient stress, predisposition of forests to frost injuries, insect and disease epidemics, and prolonged ecological changes through elimination of acid-intolerant plant species and decomposer organisms (see also Kimmins 1987).

According to Ulrich (1986) the ion cycle may be disrupted through the following:

1. Tie-up of nutrients and bases in undecomposed organic matter and consequent depletion of bases from the soil solution.
2. Increased variation in soil temperature or humidity which results in large amplitudes of mineralization/acidification and deacidification processes.
3. Decrease of organic-bound nitrogen storage in the soil through acidification and nitrate leaching.
4. Spatial separation of nitrification and nitrogen uptake processes in the soil.

Processes under item 1 above tend to occur in forests on droughty or cool sites characterized by low rates of organic matter decomposition; stands near the biological rotation age appear particularly vulnerable. In our region the problem probably has been magnified by the widespread exclusion of wildfires. On droughty sites with a history of recurring ground fires, exclusion has encouraged overdense understories of shade-tolerant tree species. Lack of catastrophic fires in cool environments of the mountain forest has resulted in large expanses of overdense stands characterized by high levels of undecomposed woody residue.

Tie-up of nutrients in undecomposed phytomass leads to disruption of the ion cycle. The resulting nutrient deficiency is suspected to cause an upset in synthesis of tree defense chemicals against insect feeding and predisposes the trees and forest stands to defoliator outbreaks (Stoszek 1986). Thus, it is not surprising that increasing site occupancy (ratio of basal area to site index) has been correlated with increasing tussock moth defoliations, and that on cool sites of the subalpine fir vegetation series a positive relationship exists between western spruce budworm defoliation levels and both basal area and the amount of undecomposed woody residue in host stands (Stoszek and Mika 1985a; Stoszek and others 1981).

Disruptions in the ion cycle associated with Ulrich's (1986) second point are a function of climatic extremes—drought or high solar radiation loads. Open-grown stands, and particularly heavily thinned stands on warm-moist sites, are prone to drastic alterations in soil temperature and associated mineralization-acidification processes that extend deep into the tree rooting zone. Nutrient stress resulting from such processes is suspected to predispose pole-sized grand fir stands to western spruce budworm defoliation. Open-grown, pole-sized host stands on warm-moist sites of the western hemlock vegetation series in northern Idaho were associated with highest budworm defoliation levels (Kessler and Ulliman 1985; Stoszek and Mika 1985a). These stands were also characteristically low in undecomposed organic matter levels.

The decrease of organic bound nitrogen in the soil through acidification and nitrate leaching (item 3) is triggered by warm climate and high solar radiation levels at the soil surface, which favor mineralization of organic bound nitrogen deep into the rooting zone. The process occurs more frequently on poor sandy soils where the protons released through nitrification are not balanced with those used by plant uptake and weathering. Intensive stand-replacement fires, clearcutting, heavy-handed slash disposal practices, excessive grazing, and herbicide applications—all augment the process and probably predispose stands to higher incidence and severity of rootlet mortality and higher, more virulent rates of root pathogen infections.

I also suspect that the consequences of reduced cation exchange capacity of the soil through well-intended but poorly thought through silvicultural measures during the stand establishment phase will become evident during the pole-size phase of stand development when the high demands for balanced nutrition won't be satisfied by the rate of nutrient supply. The resulting nutrient stress and reduced synthesis of host defense chemistry are apt to predispose the trees to insect feeding and pathogen infections. This presumably took place in heavily budworm defoliated, even-aged, pole-sized host stands on warm-dry sites of the Douglas-fir vegetation series and in relatively moist host stands on grand fir habitat types. There the highest budworm risk situations were associated with open-grown stands characterized by low organic matter levels on the ground (Stoszek and Mika 1985a). Increased infestation rates by the western pine shoot borer in ponderosa pine terminals occur in plantations established on sites where occurrence of processes associated with points 2 and 3 above is also highly likely (Robertson 1982; Stoszek 1986).

The spatial separation of mineralization and nutrient uptake processes in item 4 above are associated with, or lead to, soil podzolization. Naturally acidic sites are prone to this problem. Such sites tend to be occupied by acid-tolerant woody species (such as pines or spruce) that produce leaf litter high in soluble phenols and low in nitrogen content. Such litter is hard to decompose. In such systems a raw litter layer develops with suppressed nitrification. Since acid production associated with ammonium nitrate (NH_4) uptake is limited to the A horizon, acid loading within this 4- to 8-inch stratum is large. The horizon acidifies down to the iron buffer range, according to Ulrich (1986). The organic acids accumulate deeper in the soil, and this may lead to formation of a podzol with a hardpan.

On soils with severe podzolization, either natural regeneration fails or shallow-rooted seedlings develop. In fact, if unchecked, the podzolization process may ultimately lead to an acid grassland. Planting is the only alternative if the subsoil shows higher base saturation. However, the resulting plantations usually cannot develop into productive forests. The relatively shallow rooting zone does not contain sufficient nutrients, and nutrient deficiencies develop; root rots, frost problems, and insect infestations may become rampant, as in Europe.

The acidification process, including podzolization, is reversible as long as the soil contains weatherable silicates, the system is amenable to an increase in base saturation, and acid loading of the mineral soil stops (this includes acid loading associated with atmospheric depositions). The soil-degrading development can also be avoided by multispecies forests and maintenance of tolerable levels of shrub cover to ensure improved litter decomposition and nutrient cycling. Chemical and biological soil amendments (such as site- and stand condition-specific fertilizer implementation) have a high potential in helping to prevent or correct such a problem. One can't help but agree with Ulrich and others that management of soil fertility is clearly among the top challenges to forestry.

CONCLUSIONS AND RECOMMENDATIONS

In this cursory review of accomplishments, concerns, and voids in the practices of silviculture and integrated forest protection, I have tried to express some of my concerns pertaining to disturbances and their effects in young forests of the Mountain West. I hope that the concerns expressed will assist you in your deliberations. In summary:

1. Forest cultures in the Mountain West region are highly diverse in developmental dynamics, tree species composition, and structure. This is due to diverse growing conditions (elevation, soil, and site climate) and differences in management systems and practices. As a consequence, the variation in product (and function) value yield potential of forest cultures will be high.

2. A variety of disturbance factors affect forest cultures. The occurrence, frequency, and damage severity of disturbances are associated with site- and stand-specific conditions, both natural and human-modified. In this sense, the potential damage levels of key disturbance agents are identifiable, both spatially (where) and temporally (when).

3. Stress physiology processes are generally involved in predisposition of a given site-stand configuration to biotic disturbance agents; physiological stress (including nutrient deficiency) also renders a tree susceptible to injuries by frost, heat, desiccation, and atmospheric pollutants. Many stress-generating processes are identifiable and can be inductively diagnosed from descriptive site-tree-stand characteristics; however, further experimental research is needed.

4. Structural attributes of sites (terrain and soils), trees, and stands are involved in predisposition to snow and wind damage. The potential occurrence frequency and damage severity need to be locally assessed.

5. Design of disturbance-preventive management strategies is predicated on identification of processes predisposing trees and stands to disturbance agents. It is implicit that disturbance-preventive treatments must be site- and stand condition-specific. In short, disturbance problems in forest cultures are manageable.

The problem we are facing rests in the fact that scientific understanding of how the forest ecosystem functions is still incomplete, and this knowledge gap is substantially larger on the managers' level. All this is further augmented by a piecemeal approach to problem solving and the still pervading quick-fix mentality. There is an urgent need to bridge the existing knowledge gap through continuing education programs; and there is need for higher levels of financial support of research on ecosystem processes. Above all, forest resource management planning must be based primarily on ecosystem considerations, with socioeconomic considerations exerting a secondary function.

Despite the gaps, much of the basic knowledge and tools needed to implement such an approach are available. With Geographic Information System (GIS) the manager gains access to an inventory of ecological site conditions, ecological and mensurational stand characteristics and land use, and operability and access configurations (Pence and others 1983). The GIS permits grouping of forest land strata according to land use, site and stand characteristics, and access/operability parameters. Each category can be evaluated in terms of ecological potential and productivity concerns associated with physical and biotic disturbance factors and socioeconomic considerations. This evaluation will then guide simulation-based evaluation of silvicultural goals. Silvicultural systems, harvest-regeneration methods, and site improvement practices best suited to attain the generically selected silvicultural goals in a sustainable, low-disturbance risk and economically feasible manner will then be chosen. Management planning units scheduled to receive similar silvicultural treatments and management intensity may then be grouped into operational similarity categories and integrated into the regulatory management planning process using FORPLAN or other suitable tools.

The approach I suggest avoids using the stand as the basic management planning unit. Instead, the basic management planning units are permanently identifiable site configurations with relatively uniform production potential and operability characteristics. Under this approach the stand is inseparable from the site and land type condition. This is sensible if we are to integrate forest protection concerns into silvicultural and technical-operability considerations. It makes sense in terms of efficient use of currently available (and future) modeling and simulation technology programs. It enables development of site-, stand-, and goal-specific generic silviculture prescriptions. It makes proven sense in terms of integration of silviculture decisions and priorities (including protection concerns) into the overall regulatory management planning processes.

FINAL COMMENT

Finally, a review such as this would be grossly incomplete without a few comments on the role of computers and the emerging biotechnology. While the environmental movement provided the impetus for development of IPM, the computer has been instrumental in the application of IPM. The computer enabled prognostication of pest population and forest development trends, assessment of pest impacts, site-stand ratings of susceptibility to disturbances, and evaluation of damage-prevention measures. Without computers it would be extremely difficult to integrate forest protection into the management decision process. Additional prospects for computer-based technology in improving the efficiency of the management decision process are promising. Consider, for example, Geographic Information Systems or the possibilities offered by the newly emerging Expert Systems (Colson and others 1987).

Some forest scientists extol the great potential of biotechnology. Opinions differ, however, as to whether a genie is apt to be released, another unsuccessful quick fix situation created, or whether products of biotechnology might prove to be a genuine breakthrough.

We need to recognize that whatever new plant strains or organisms are produced must not only survive in the managed ecosystem, but must not cause undesirable changes in the system. Thorough tests will have to be conducted; their evaluation is predicated on thorough understanding of forest ecosystems. Our present level of understanding of forest ecosystems appears far from that called for by this technology.

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USING STAND CULTURE TECHNIQUES AGAINST DEFOLIATING INSECTS

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ABSTRACT

Defoliating insects are a serious problem in young Douglas-fir and true fir stands of the Mountain West. Western spruce budworm and Douglas-fir tussock moth infest these stands and cause growth loss, mortality, visual impact, and other damage. Changes in the character of forests and stands since the early 1900's appear to have predisposed them to heavy feeding by defoliators. Extensive harvesting of mature seral conifers, dramatic reduction in forest fire frequency, and inadequate site preparation have substantially increased the proportion of shade-tolerant conifers in most stands. The increased amount of host is partly responsible for the large and destructive infestations periodically observed. Stand culture techniques that favor shade-intolerant conifer species, rapid stand growth, and genetically superior trees will discourage the defoliating insects.

INTRODUCTION

Defoliating insects may be the primary benefactors of many of our future forests in the Mountain West unless forest managers decide to aggressively use silvicultural practices to create stand conditions unsuitable for high insect populations. Two pests particularly damaging to many of our current forests are featured in this paper: western spruce budworm (*Choristoneura occidentalis* [Freeman]) and Douglas-fir tussock moth (*Orgyia pseudotsugata* [McD.]). These two defoliators are well known for the extensive damage they cause to immature forests over much of the Northern Rocky Mountains. Forest management since the late 1800's set the stage for our current insect problems. We now recognize the mistakes and know how to correct them, but we are far behind in implementing corrective actions. This paper outlines current knowledge relating these two important defoliators with stand conditions and suggests remedial actions. Two less important insects, larch casebearer (*Coleophora laricella* [Hubner]) and a small needle weevil (*Magdalis gentilis* LeC.) also are considered.

THE FOREST, BUDWORM, AND TUSSOCK MOTH

Budworm and tussock moth are native North American insects and have similar habitat requirements; these conditions have been reviewed in detail elsewhere (Beckwith 1978; Carlson and others 1985; Wellner 1978; Wickman and Beckwith 1978; Wulf and Cates 1985). Both have about the same geographical range, although tussock moth is not abundant east of the Continental Divide, and both are infrequent west of the Cascades. Primary hosts are Douglas-fir (*Pseudotsuga menziesii* ssp. *glauca* [Beissn.] Franco), grand fir (*Abies grandis* [Dougl.] Forbes), white fir (*Abies concolor* [Gord. & Glend.] Lindl.), and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.). Larval stages of both insects are favored by warm, dry spring weather and warm habitats. Much dispersal occurs during the larval stages, and survival of dispersing larvae is best in storied tree canopies. Vigorous trees appear to be less nutritious for the insects; stressed trees may have the opposite effect.

Budworm and tussock moth are serious pests of Rocky Mountain coniferous forests. Growth losses due to budworm approached 44 percent in Canada (Alfaro and others 1985) and tussock moth caused 72 percent mortality of infested trees in forests of Oregon and Washington (Wickman 1978). Both insects destroy host foliage and create unsightly conditions that detract from recreational use. Other resource values also may be adversely affected.

Forestry practices since the late 1800's have created ideal conditions for budworm and tussock moth. Early logging removed high-value seral conifers—such as western larch (*Larix occidentalis* Nutt.), ponderosa pine (*Pinus ponderosa* Dougl.), and seral Douglas-fir which are essentially nonhost species for the insects. Douglas-fir is only slightly susceptible when seral but highly so when climax. After this early logging, sites seldom were properly prepared for regeneration of the seral species—mineral soil bared by burning or mechanical means and large canopy openings are necessary. Shade-tolerant host conifers established prior to the selective logging became dominant following release from the seral overstory. Unlike seral stands, which tend to be even-aged and single-tiered, these shade-tolerant stands usually have several tiers or stories, are uneven-aged, and are usually overstocked. Furthermore, since about 1910, the frequency of wildfire has been reduced substantially. Effective fire suppression, extensive cattle grazing (which reduced the fine-fuel loading), and reduced ignition of wildfires by humans have contributed to the current low incidence of fire (Arno 1980). These historic fires favored the seral species and prevented extensive establishment of climax species. The combined effect of reduced fire and selective logging has been a tremendous increase in the amount of host substrate available and stand structures ideal for the insects. Budworm outbreaks are now more severe and last longer than before the turn of the century (Anderson and others in press).

SILVICULTURE AND INSECTS

Populations of and damage caused by forest insects can be reduced by silvicultural treatment. Methods appropriate for budworm, tussock moth, and other insects are discussed here.

Budworm and Tussock Moth

We know how to deal with budworm (Carlson and others 1985; Carlson and Wulf in press) and tussock moth over the long haul. All we need to do is control stand composition and structure—more easily said than done! Even-aged silviculture, featuring seral species, can be very effective. Clearcut, seedtree, and shelterwood methods immediately reduce stand susceptibility at the time they are done, but they must be properly done. The seed and shelterwood trees should be predominantly nonhost. The site should be prepared, preferably by burning or scarifying. Planting may be necessary to assure that the new stand is at least 70 percent nonhost species. If these guides are not followed, chances are that the new stand will be shade-tolerant and susceptible to the insects.

Susceptibility of existing immature host species stands can be greatly reduced by thinning from below, leaving the best, most vigorous trees as growing stock (Carlson and others 1985). Even though leave trees may be defoliated during heavy outbreaks, they tend to recover faster than defoliated trees in unthinned stands (Schmidt 1978).

Silvicultural treatment of relatively large forested areas over time will reduce forest susceptibility. Summarized below are actions that will reduce stand and forest susceptibility (from Carlson and Wulf in press):

1. Strive for species diversity by favoring seral trees and removing the majority of the most shade-tolerant host species.
2. Regulate stand density and vertical structure through appropriate release cuttings and thinning to improve and maintain tree vigor and stand growth.
3. Create and maintain even-aged stand structures by using even-aged regeneration systems, followed by periodic low and crown thinnings.
4. Promptly remove all overwood trees once regeneration is established in seed-tree and shelterwood cuttings.
5. Improve stand vigor by removing diseased, heavily infested, or otherwise unhealthy trees in all cuttings.
6. Capitalize on phenotypic and genetic resistance by selecting the most heavily defoliated trees for removal. Retain the lightly or nondefoliated trees for seed trees; direct cone-collection programs to those phenotypes.
7. Regenerate host stands with less susceptible species at or before biological maturity.
8. Diversify the host forest by creating seral stands in homogeneous areas of late successional or climax host stands.

Other Defoliators

Two other forest defoliators are worth mentioning here. *Magdalis gentilis* LeC. is a tiny defoliating weevil found on lodgepole pine (*Pinus contorta* ssp. *latifolia* Engelm.). Early spring thinning of young lodgepole stands apparently attracted weevils to the residual trees (Fellin 1973). The weevils fed on current year needles and persisted for only 1 year; thus, damage was not serious. Stands thinned in late summer or fall were only lightly infested. Even though this insect is not particularly damaging, it would be prudent to not schedule thinning of lodgepole in spring.

Larch casebearer populations increased on residual crop trees after thinning, but populations did not reach damaging levels (Schmidt 1978). However, levels decreased substantially in the thinned stands following a wet, cold spring whereas insect numbers in the unthinned stand did not change. Apparently the casebearer was more vulnerable to adverse weather in the more open environment of the thinned stands. Therefore, for these two insects, as well as budworm and tussock moth, we feel that stand density control ultimately will benefit the trees and discourage the insects.

THE REAL PROBLEM

Knowing what to do about budworm, tussock moth, and other insects is relatively easy—getting it done is much more difficult. Nearly 430,000 acres of second-growth host type now exist just on National Forest lands in the Northern Region (Chew personal communication). (Second-growth host type is the acreage of stands 30 to 70 years old with at least 40 percent basal area in any combination of Douglas-fir, grand fir, or subalpine fir.) A lot more is present on State and private lands. Conversion of these stands to seral species is a worthy goal but may not be practical now because they represent an investment of nearly half a rotation and the Forest Service is obligated to bring current stands through to a merchantable crop. Chainsaw thinning would decrease susceptibility in many of these stands, but in most cases there would be no revenue because of small stem size. Declining budgets, reduced numbers of personnel, high cost of precommercial thinning, and difficulty in reconciling resource use (for example, wildlife hiding cover) decrease the likelihood that these cultural activities will be used extensively to combat budworm. Nevertheless, these stands are an important investment. They will be an important resource 50 years from now and will provide substantial public benefit. Silvicultural treatments applied now will be strong factors in realizing these future benefits.

Even though foresters know the factors involved in budworm dynamics, we continue to augment the problem. This is perplexing. In some current sales on public lands, helicopters are being used to move logs (mature ponderosa pine and other seral species) to the landing. Little or no site preparation is planned. There is a false hope that existing advance regeneration will form the future forest. This advance regeneration is mostly Douglas-fir, grand fir, and subalpine fir—budworm host species. Driven by current economic conditions, sales on many private lands are removing the last of the old-growth pine and larch, leaving the immature second-growth budworm host species. These residual stands are protected from fire, much as we have done for the past 60 to 70 years. Short-term economics, and at times a lack of biological understanding, are driving current forestry whereas quite the opposite should be happening: we should be making long-term, biologically sound investments in our future forests.

During the 1960's and 1970's, much forested land was managed using even-aged methods. Clearcuts and seedtree cuts significantly reduced the amount of habitat available for budworm and tussock moth. Our studies between 1980 and 1984 (manuscripts in preparation) showed very well that young, even-aged stands of mixed species were only slightly damaged by budworm, even though adjacent stands were heavily defoliated by the insect. These studies were conducted in stands created through even-aged regeneration methods in the 1960's and 1970's. The studies also showed that uneven-aged methods (selection, highgrading) caused serious insect problems. So, we know that even-aged methods work—we just need to continue to apply them properly.

What legacy do we want to leave for foresters 100 years hence? We have the opportunity through ecologically sound forestry practices to bequeath vigorous forests, resistant to insects and disease. We have the opportunity to establish productive lands with seral, fire-adapted species. We have the opportunity to significantly reduce conditions conducive to insect outbreaks. In short, we can leave them with highly productive forests suitable for intensive multiple resource management. We believe these are desirable goals. They can be attained by proper long-range, multidisciplinary planning and execution of timber sales. They cannot be attained through short-sighted activities that ignore biological reality. The choice is ours—we need to emphasize strong, ecologically sound forestry. If we do not, we will leave a legacy of decadent forests of poor value, seriously damaged by insects and diseases. Foresters 100 years hence will wonder why we didn't use the available knowledge and practice silviculturally and biologically sound forestry.

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STAND CULTURE/BARK BEETLE RELATIONSHIPS OF IMMATURE TREE STANDS IN THE INLAND MOUNTAIN WEST

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ABSTRACT

Bark beetles cause serious damage in many of the coniferous forests of the Inland Mountain West, where, historically, major beetle epidemics periodically occur. Although bark beetles predominantly affect mature and overmature stands in this region, several species of bark beetles cause losses in immature stands. This paper summarizes ecological relationships associated with outbreaks of the major bark beetles of the Inland West and discusses the management implications of specific cultural practices that may delay or hasten the likelihood of outbreaks. Bark beetles generally behave as natural "thinning" agents. They normally kill trees weakened by age, competition, diseases and insects, or physical damage, but in some cases periodically kill much larger proportions of trees normally not attacked. Because of the latter behavior, appropriate silvicultural practices provide the most feasible strategy for preventing or reducing losses especially in immature stands. When practices are properly selected and executed, immature stand culture promises to reduce or avoid bark beetle hazards while improving the growth, yield, and general resource productivities of Inland West forests.

INTRODUCTION

Bark beetles have historically killed vast numbers of trees in mature and overmature forests of the Inland Mountain West—here defined as the region west of the Great Plains and east of the Sierra Nevada and Cascade Mountains—but sometimes immature trees and stands have been involved. In this geographical area, major bark beetle problems, and opportunities for reducing the problems, largely occur with shade-intolerant pines—species that often grow in pure, even-aged stands where serious overstocking is common. Much less frequently, serious bark beetle problems occur with more shade-tolerant conifers, but these problems usually occur in mature or overmature stands.

In many cases bark beetle impacts on immature stands result from large beetle populations that develop in mature and overmature stands having larger trees. After decimating the older stands, epidemic populations often move into normally nonsusceptible unmanaged immature stands—killing appreciable numbers of trees before populations and damage levels recede. In this situation the largest and healthiest host trees of the immature stands are usually killed and, realistically, only stand culture could have prevented these losses.

In other cases, immature stands sometimes incur significant damage from normally innocuous bark beetles that respond opportunistically to changed stand conditions resulting from natural and human causes. Natural causes include competition, drought-induced stress, debilitating effects of other insects and diseases, and physical damage to trees from fire, wind, snow, ice, and animals.

Reducing future losses from bark beetles in mature or immature stands is best accomplished with silvicultural practices designed to enhance stand conditions. Young stands offer the most promise, but until recently, relatively few young stands have been treated silviculturally to reduce future bark beetle losses. Good management considers the influence of silvicultural practices on specific bark beetle problems and recognizes that cultural practices carried out for other management objectives—such as improving the composition, or growth and yield characteristics of the stand—can also increase or decrease the potential for problems from certain bark beetles, depending on how and when the practices are carried out.

In this summary of stand culture/bark beetle relationships, the emphasis is placed on those bark beetles likely to cause high levels of mortality in immature stands and whose impacts in both younger and older stands can be influenced by stand culture. Several bark beetle species, important in old-growth forests, are treated collectively because they are considered to be of little consequence in immature stands and because harvest and young stand culture promise to greatly reduce their future impacts in old-growth stands. Minor—sometimes called secondary—bark beetles are important in the ecology of all of the bark beetle/host relationships discussed; however, elaboration on them is beyond the scope of this paper.

Silvicultural practices discussed do not include those using nonnutrient chemicals. It is recognized that cultural practices involving chemicals are being effectively used in Canada to accomplish both thinning and abatement of bark beetle hazard. However, the status of many herbicides, pesticides, and even synthetic insect compounds in the United States is uncertain because of registration requirements of the U.S. Environmental Protection Agency; therefore, we do not discuss practices involving chemical applications.

For detail on the life history and habits of the bark beetles discussed, readers are referred to forestry and entomology literature under the general classification Coleoptera:Scolytidae.

MOUNTAIN PINE BEETLE

The mountain pine beetle (MPB)(*Dendroctonus ponderosae* Hopk.) is the most damaging of the bark beetles of the Inland Mountain West (Klein 1978). Its primary targets in this geographical region are lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and ponderosa pine (*P. ponderosa* Dougl. ex Laws.) (McGregor 1982; Van Sickle 1982). Less-affected hosts are western white pine (*P. monticola* Dougl. ex D. Don) and whitebark pine (*P. albicaulis* Engelm.). The MPB prefers the larger, generally older, trees of all of its host species, although immature pine stands also support outbreaks if too dense (Johnson and Schmitz 1965).

Preventing, or reducing the magnitude of, MPB outbreaks is largely a matter of managing stand composition, controlling stand density to maintain growth and vigor, and harvesting stands before they become overmature or lose vigor. Several cultural practices for immature stands are useful for promoting good stand vigor and health while some otherwise good practices must be carefully considered because of possible undesirable side-effects.

Thinning

Thinning appears to be the most valuable cultural practice for reducing future losses from the MPB. Even whitebark pine stands, often not scheduled for timber harvest because of the environmentally sensitive sites they occupy, can be protected from MPB attack by thinnings in lodgepole pine where outbreak populations usually develop and spread into the whitebark pine (McGregor and Cole 1985). Nevertheless, tree diseases such as dwarf mistletoes, root rots, and rusts, can limit the opportunities for thinning. Because of devastation by the blister rust (*Cronartium ribicola* Fisch.), opportunities for thinning young western white pine, in particular, have been limited. With the development of blister rust-resistant white pine genotypes and increasing natural resistance in young trees, more and more acreage of young white pine stands will be featured in management (Graham and others 1983). Western white pine in these stands will benefit from thinnings designed for growth promotion and will likely remain at lower risk to MPB attack for many more years than if left unthinned (Johnson and Schmitz 1965).

Low thinning is the indicated thinning method for immature stands of the major host species of the MPB. But just what timings and spacings are optimum for providing long-term protection and good timber yields is not yet clear. Several studies are under way in lodgepole pine and ponderosa pine to help answer this question (Cole 1983, 1985; Mitchell and others 1983; Pitman and others 1982; Sartwell 1971; Sartwell and Stevens 1975). Early results indicate that the thinned stands are markedly less susceptible to outbreak MPB populations, but for how long can only be determined by observing these studies for a considerable number of years yet. In immature stands older than 50 years of age, there is some indication that low thinnings should reduce ponderosa pine basal areas below 120 ft^2 on the high sites of the Sierras and Pacific Northwest (Pitman and others 1982; Sartwell and Stevens 1975) and below 80 ft^2 on poorer sites eastward and southward (McCambridge and others 1982). Because lodgepole pine is less able than ponderosa pine to maintain tree vigor at high basal areas, it appears that residual basal areas following thinning should be lower for lodgepole pine—perhaps no more than 80 ft^2 (Mitchell and others 1983) for the thinnings to be effective in withstanding outbreak MPB populations. Of course, if stands are greatly overstocked and unmanaged to this point, more than one thinning over a number of years would sometimes be necessary to reach these basal area levels without incurring serious windfall problems. In the meantime, thinning prescriptions keyed to growth and yield objectives of timber management are a good starting point for reducing future losses, especially in younger immature stands (Cole 1978; Sartwell and Stevens 1975).

Recent experience with low thinnings in immature lodgepole pine suggests that, in addition to increased tree vigor, changes in microenvironment are involved in the reduced susceptibility of the thinned stands to outbreak MPB populations in adjacent stands (Amman 1986). Some mortality can be expected among crop trees of thinned lodgepole pine stands in outbreak MPB situations, but the rate is often much less than for similar tree classes in adjacent unthinned stands. Evidence that changes in microenvironment are involved with the reduced susceptibility is seen particularly in habitat types characterized by tall shrub understories and mixed-tree species, where the pattern of the mortality that does occur appears to be associated with shading of lower boles. Conversely, surviving crop trees in these situations seem to have benefited from microenvironments resulting from less shading of the lower boles. Whether the important (to the beetle) effects of shading are reduced light levels, reduced temperatures, higher moisture levels, or a combination of these, is not known; but thinning can obviously influence these factors. How, when, and where growth-directed thinning prescriptions for immature pine stands should be modified to create microenvironments that discourage MPB attack, await specific studies. But until knowledge is obtained for fine-tuning of thinning prescriptions, thinning should proceed—with a reasonable expectation that procedures and reserve densities appropriate to present bark beetle wisdom, the silvics of the species, and growth objectives of management will result in significantly lower risk stands.

Improvement and Sanitation Cuts

Improvement and sanitation cuts can reduce the risk of losses to the MPB, depending on the proportion of host species in the stand, condition of the stand, and the presence of nonhost species favorable to management. In pure lodgepole and ponderosa pine stands, improvement and sanitation cuts can be used to remove low-vigor, damaged, or diseased trees that sustain secondary bark beetles and endemic MPB (Lessard and others 1985; Schmitz 1984; Tkacz and Schmitz 1986). The earlier this is done in the immature stand, the greater benefit will be gained in long-term avoidance of MPB attacks. Stands having mixed species in the overstory provide even more opportunities for improvement and sanitation cuts than pure stands, for here the silviculturist often has the option of discriminating against beetle-susceptible species while still maintaining a desirable overstory for management.

Clearcutting

Some stands are in such poor condition due to extreme effects from such factors as competition, insects, disease, and physical damage that they cannot respond adequately to thinning or to improvement or sanitation cuts. Yet, if left untreated, such stands can eventually contribute to the MPB problem. Clearcutting to regenerate a manageable stand not only allows a wide range of future silvicultural options, but also can contribute to the creation of age-class mosaics that provide extremely valuable preventative strategies for reducing future losses to the MPB (Roe and Amman 1970).

Pruning

Pruning has the potential for both negative and positive effects on the MPB problem, depending on the species involved and the timing and extent of the pruning. Indications from unmanaged ponderosa pine are that if trees attain 8 inches d.b.h. and crown lengths fall below 33 percent, growth rates will slow to less than 0.05 inch per year and susceptibility to MPB attack will be greatly increased (Sartwell 1971). These facts cast serious doubt on the wisdom of pruning ponderosa pine when trees are much beyond 8 inches d.b.h. unless crown lengths and growth rates have been maintained considerably above these levels by thinning. Regardless, pruning thinned ponderosa pine to crown lengths of less than 33 percent of total height would appear to be counterproductive in terms of growth and quite risky in terms of the MPB.

Thinned lodgepole pine, on the other hand, might benefit from modest pruning to alter the shading of lower boles. Increased vulnerability because of shaded lower boles is suspected to be involved with those scattered trees in thinned areas and clearings that are killed by the MPB. Although the thinner barked lodgepole pine of 6 to 10 inches d.b.h. are less susceptible to MPB attack than similar size ponderosa pine, growth considerations would also argue against reducing crowns much below 33 percent in prunings of lodgepole pine.

Pruning is a likely cultural practice in thinned stands and plantations of western white pine. Because MPB problems in white pine have been associated predominantly with mature and overmature trees, pruning of immature western white pine should not increase its susceptibility to the MPB, but will markedly increase the lumber quality of this naturally poor pruner.

Fertilizer Treatment

Although empirical studies have yet to confirm its efficacy as a practice for preventing MPB attacks, fertilizer, applied in conjunction with thinning, would likely help reduce susceptibility of pine stands to MPB attack because of its ability to increase tree vigor. In most cases fertilizer treatments are not economically justifiable in relation to thinning alone, but with the benefit of a measure of additional protection against the MPB, this practice might find wider justification.

Prescribed Fire

Discouragement of MPB populations through periodic prescribed burning has been suggested as a possible supplemental practice for thinned pine stands (Mitchell and Martin 1980). The idea is to further enhance the vigor attained by thinning, with periodic ground fires to reduce competition from understory vegetation. Aside from the general hazards of escaped fire, this practice has other risky aspects. Of the pines susceptible to the MPB, only ponderosa pine has considerable resistance to fire, and even it can be damaged in the first of the periodic burns when fuel amounts are greatest. Scorched pines are particularly vulnerable to attack by pine engravers (*Ips* spp.), the red turpentine beetle (*Dendroctonus valens*), and other minor bark beetles. Scorched trees are typically attacked at their bases by the turpentine beetle and lesser bark beetles, followed by attacks by *Ips* in the tops and midboles. Damage can also occur to roots in such prescribed burns, and this damage can be quite insidious. Roots near larger fuel such as downed and buried logs often become burned or scorched, and these injury sites often become infection courts for soilborne root diseases (Gara and others 1985). Over the years root diseases weaken trees and make them increasingly susceptible to bark beetle attack (Lessard and others 1985; Tkacz and Schmitz 1986). Because risks are high compared to the benefits of reduced understory competition, prescribed burning appears to have limited value in reducing MPB hazard in immature stands.

PINE ENGRAVER BEETLES

Pine engraver beetles (*Ips* spp.) periodically cause serious losses in immature ponderosa pine stands. Outbreaks also occur in immature lodgepole pine stands (Amman and Safranyik 1985), but far less frequently than in ponderosa pine. Very infrequently, several other pine species are attacked (Hopping 1964). Two species of *Ips* cause the bulk of the problems in the Inland Mountain West. From Utah and Colorado northward into Canada, and from eastern Oregon eastward to the Black Hills, the pine engraver (*Ips pini* Say) causes significant losses in immature ponderosa and lodgepole pine stands. Southward, the Arizona five-spined ips (*Ips lecontei* Swaine) causes similar damage in immature ponderosa pine stands of Arizona and New Mexico. Because of generally similar behavior and effects, both species will be treated together in discussing their relationship to cultural practices.

Endemic populations of pine engravers are sustained in scattered trees weakened by competition, disease, other insects, or damage such as wind and snow breakage. Population increases are associated with increases in pine slash or trees weakened or damaged by stand disturbances because overwintering adults actively seek out green slash or damaged trees for colonization in the spring.

Several factors have been correlated with outbreaks of pine engravers, among them other insects (Dewey and others 1974; Wright and Berryman 1978), drought conditions in spring and early summer, physical damage to trees, and creation of slash from management activities (Dolph 1971; McGregor and others 1977; Parker 1979). Because *Ips* populations are present in most pine forests (Hopping 1964), the potential for outbreaks and tree killing is present and able to be expressed when the aforementioned factors occur together. The threat of *Ips* outbreaks should be considered, then, in planning and executing thinnings and other management practices involving stand disturbances in immature ponderosa and lodgepole pine stands.

Thinning

Ponderosa pine stands that have been thinned can be seriously damaged by *Ips* outbreaks; sometimes this occurs with lodgepole pine (Amman and Safranyik 1985). However, if several factors are considered in the planning and execution of thinning programs, the risk of losing residual trees in thinned stands can be reduced to a relatively insignificant level.

Although *Ips* actively seek green slash and weakened and damaged trees, they apparently do not travel more than one-half mile in their search (Livingston 1979). This trait can be exploited to accomplish thinning while still keeping *Ips* populations innocuous. If *Ips* populations are low in an area before a thinning program is begun, thinnings in consecutive years should be kept a mile or so apart. Because overwintering adults seldom attack healthy green trees (Dolph 1971), the population increase in the slash of a given thinning would recede the following year in the absence of nearby fresh slash. However, all thinnings in immature ponderosa pine should be approached with caution if either of the following events have occurred within the past year in pine stands in the vicinity of the contemplated thinning:

1. Appreciable stand disturbance from wind or snow damage, fire, logging, road clearing, or thinning.
2. Drought in spring and summer.

If either of these things has occurred, thinning should be delayed until the area is examined by an entomologist and determined to be low enough in *Ips* population to allow thinning. These precautions will allow the execution of low thinnings in ponderosa pine that succeed, at low risk of *Ips* outbreak, in increasing the vigor and eventual productivity of overstocked stands while reducing future susceptibility to *Ips* and other bark beetles.

Another strategy, popular with managers of large acreages where thinnings are programmed every year, is to thin every year and provide enough slash to absorb the attacking beetles (Dolph 1971). In following this approach a continuous supply of fresh slash is necessary during the flight periods of each generation of that season; yet thinnings must be concluded early enough in the summer season that slash can dry enough before winter to make it poor habitat for brood development (Livingston 1979; Parker 1979). If thinning is done during the months of January to June under dry conditions, special measures such as chipping or trampling will be necessary to dry the slash enough to make it poor breeding material for overwintering adults. Failure to reduce slash moisture in the spring and summer provides good breeding material for overwintering adults and results in a large population of the aggresive first generation of the year. First-generation adults are responsible for almost all tree killing associated with *Ips*. In very wet springs no slash treatment is necessary because these conditions are unfavorable for survival of overwintering adults. Although commonly used, thinning every year to provide fresh slash for the progeny of last year's slash carries higher risks of losing residual trees than the strategy of separating thinnings to cause the engraver population to recede. An aspect of the "continuous slash" strategy that is often overlooked is what to do when thinnings finally cease. The elevated *Ips* population resulting from the most recent thinning will be a threat to thinned stands in the area, unless special slash-handling measures are taken to diminish populations. In this situation, slash should be piled and burned, or piles covered with plastic, which results in high temperatures and mortality of *Ips* broods.

Other Practices

Improvement and sanitation cuts in pine stands can benefit the composition, vigor, and condition of stands, reducing their susceptibility to bark beetles, including *Ips*. However, caution must be exercised in older immature stands where large trees are removed, to avoid damaging the residual trees and making them attractive to *Ips* beetles. Fertilizer applied just before thinning in ponderosa pine stands might reduce the susceptibility of the stand to *Ips* attacks, but to our knowledge this possibility has not been tested with controlled experiments.

AVOIDING FUTURE PROBLEMS FROM BARK BEETLES IN OLDER STANDS

As is the case with lodgepole pine and the mountain pine beetle, large acreages of mature and overmature stands of other species have historically been decimated by several other bark beetles. Notable among these are the western pine beetle (*Dendroctonus brevicomis* Lec.), the spruce beetle (*Dendroctonus rufipennis* Kir.), the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopk.), and the fir engravers (*Scolytus* spp.) Unlike the mountain pine beetle, however, these pests of old-growth forests have had little effect in immature stands. Still, it would be worthwhile to briefly review host/pest relations of these bark beetles, to note specific conditions associated with outbreaks and stand culture opportunities for forestalling their occurrence.

The consensus among forest entomologists is that conditions favorable to western pine beetle outbreaks in ponderosa pine can largely be avoided by managing stands throughout their immature and mature stages to maintain good health and vigor and by renewing them with regeneration harvests before they become susceptible to the beetle. Thinning in the immature stage and attention to health of stands are of prime importance. This is well-illustrated by an outbreak of western pine beetle in the Boise National Forest in the period 1972-76 (Valcarce and others 1977). Severe winter storms in 1971 caused extensive top breakage over several hundred acres of heavily stocked immature ponderosa pine (age 73) containing scattered old-growth trees (age 200). Western pine beetles were observed attacking broken boles the following summer. The pine beetle continued to build its population in pockets around the initially damaged trees and in 1975 developed to outbreak status throughout the stand, killing mature and immature trees in the denser portions of the stand where basal areas averaged 276 ft^2/acre. The outbreak intensified further in 1976 until a salvage logging and thinning was conducted throughout the outbreak area, reducing the stand basal area to about 90 ft^2/acre. Following the thinning, tree killing ceased and the western pine beetle population returned to endemic levels. The residual stand was greatly improved in vigor, health, and potential for future growth and should be secure from any bark beetle problems for years—particularly if thinning is carried out again when the stand basal area grows past 120-150 ft^2.

The effects of spruce beetle and Douglas-fir beetle are similar to those of the western pine beetle in that outbreaks are restricted largely to mature and overmature stands and thus are not a threat to immature trees and stands (Furniss and others 1979; Schmid and Frey 1977). Engelmann spruce (*Picea engelmannii* Parry) and white spruce (*Picea glauca* [Moench] Voss.) are the primary hosts of the spruce beetle in the Inland Mountain West, while Douglas-fir is the only host of consequence for the Douglas-fir beetle. Spruce beetle and Douglas-fir beetle outbreaks usually begin in conjunction with extensive windthrow, fire, logging, or land clearing in mature and overmature stands (Alexander 1974; McMullen 1984). Live trees weakened by drought, flooding, defoliation, root disease, root compaction, or advanced age are also susceptible to attack (Hard and Holsten 1985; McGregor and others 1984). Some of these factors are typically worse in mature and overmature stands than in immature stands. Stand culture in the immature stage can lessen some of these effects in the future stand. In immature spruce, spruce-fir, or Douglas-fir stands, in which the host species are a major part of the overstory, carefully executed cultural practices—such as thinnings and sanitation or improvement cuts that improve the growth, vigor, and health of the stand—can only improve the chances of these stands escaping beetle outbreaks until planned harvest.

Fir engravers (*Scolytus* spp.) attack several true firs of the Inland Mountain West (Ashraf and Berryman 1969; Ronco and others 1983), but cause major losses only with mature and overmature grand fir (*Abies grandis* [Dougl.] Lindl.). Grand fir is shade tolerant and seldom occurs in pure stands (Foiles 1959). The fir engraver (*Scolytus ventralis* LeConte) is almost always the insect directly involved in the grand fir mortality associated with engraver outbreaks, but several other stand factors, alone or in combination, appear to predispose stands to fir engraver outbreaks. These factors include species composition, overstocking (Schenck and others 1977), drought (Ashraf and Berryman 1969), defoliation—primarily by the Douglas-fir tussock moth (*Orgyia pseudotsugata*) and the western spruce budworm (*Choristoneura occidentalis* Free.) (Wright and Berryman 1978), and root diseases (Hertert and others 1975; Partridge and Miller 1972). Silvicultural methods, particularly in the immature stage of stand development, probably offer the greatest opportunity for modifying these factors and minimizing losses (Schenk and others 1976). Specifically, thinning and improvement and sanitation cuts can be used to regulate the composition, density, and condition (health) of immature grand fir stands and reduce susceptibility to the fir engraver. Although root diseases can be discouraged by immature-stand culture, it should be recognized that they also can be worsened by stand disturbances because grand fir is particularly susceptible to early invasion of root diseases (Foiles 1959). Immature stands containing grand fir should be examined carefully for root diseases before stand culture proceeds. If high incidence of root disease is found, the manager should seriously consider discriminating against grand fir with improvement cuts. Because grand fir so commonly occurs with other desirable timber species, this option is often quite relevant and will usually reduce the risk of defect and mortality from both root disease and the fir engraver.

SUMMARY

Intensive management, particularly in immature stands, holds great promise for significantly reducing the level of losses from bark beetles in the Inland Mountain West. Properly selected, timed, and executed stand culture improves the growth and vigor of trees and hence their ability to resist bark beetle attacks. The improved growth and vigor resulting from stand culture in the immature stages of stand development can last for many decades, extending its influence well into the period of stand maturity and providing effective protection for most conifer species of the Inland Mountain West. Stand culture can also change the stand environment to make the site less attractive for beetles.

The single factor most likely to prevent silvicultural practices from reducing major bark beetles to minor problem status is the inability of forest managers to manage the whole forest area in which bark beetle problems occur. In parks and wilderness areas bark beetles are considered a natural part of the ecosystem, and their effects are seen as a natural part of forest cycles. Effects described as losses in other forest lands are not losses in wilderness areas because no utilization of the trees was intended. Nonetheless bark beetle outbreaks in forests excluded from timber management or prevented from renewal by natural fire will continue to pose serious problems for timberlands near them. Realistically, the best forest managers can expect to do in the future is to work toward a diverse managed forest of varying composition and age classes and to maintain the growth and vigor of individual stands with appropriate stand culture throughout their planned rotation.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Bill Coburn)—In the Black Hills the suggested basal area (BA) stocking for immature ponderosa pine has been set at between 60 BA to 80 BA. Is this stocking target too low, or does the recommended residual stocking depend on the site index?

A.—The stocking recommendation for the Black Hills is probably realistic considering the much lower quality sites there compared to central and eastern Washington where the higher residual basal area recommendations I cited were developed. I agree that the site index differences between these areas likely account for most of the difference in the recommended residual stocking levels for these regions. It is commonly understood that tree vigor can be maintained at higher basal areas on good sites than on poor sites.

Q. (from G. H. Eichel)—Why should thinning decrease the susceptibility of lodgepole pine for MPB, when experience in British Columbia had the first infestation in the open and mixed types where pine had been the pioneer component?

A.—It's hard to say, without seeing the British Columbia stands, how they offer evidence contradicting the potential value of thinning in reducing stand susceptibility to MPB. Perhaps the British Columbia infestations keyed on trees that, although large and once vigorous, had suffered a decline in vigor. Might other vigor-influencing factors, such as age and climate (drought), have been involved? It is often observed in the intermountain area that outbreaks begin in the lower parts of drainages in larger trees on the edges of openings—trees normally thought to be the most vigorous in the stand. If they can be successfully attacked, these large trees produce large increases in the MPB population. With their larger crowns they can suffer greater moisture deficits in drought periods than trees with smaller crowns within the stand. Some feel this temporary loss of vigor is all the MPB needs to successfully attack otherwise resistant trees. Others feel that such trees become targets because of their size and thick phloem after the MPB population has already reached levels able to kill any tree regardless of its vigor. When these differing theories are resolved we'll be able to design cultural treatments specifically to discourage the fundamental biology of the beetle. In the meantime we'll have to accept the fairly extensive empirical evidence that thinning generally reduces the susceptibility of stands to the MPB—regardless of whether the benefit comes from increased tree vigor, or modified microenvironment, or a combination of the two.

STRATEGIES FOR REDUCING IMPACTS OF TERMINAL SHOOT INSECTS

Imre E. Bella
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ABSTRACT

A diverse group of insects adversely affect height, form, and volume growth of young forests in the Mountain West. The species with potentially major impacts are identified and their host-habitat relationships and damage are reviewed. Although their impact is rather inconspicuous at low levels, under certain conditions they can cause dramatic impacts. Insecticidal controls for these insects are generally ineffective, costly, or environmentally unacceptable. Damage prevention or pest hazard reduction through silvicultural and resource management measures are outlined; these have to be integrated in the planning process. Such strategy is based on the identification of pest-prone habitats. Research needs are indicated.

INTRODUCTION

In this paper we provide management strategies for reducing damage impacts of a diverse group of insects that affect tree height, form, quality, and volume yield in intensively managed forest stands of the Mountain West. We review information on biology, host-site relationships, damage impacts, and management control measures of the potentially important insects infesting shoots and buds of major coniferous timber species in the region (table 1).

Although the damage caused by these insects is not as apparent, for example, as bark beetle-caused mortality or a defoliator epidemic, their actual impact on growth and merchantable volume yield is often substantial, and of concern to forest managers. We share this concern. Through synthesis of relevant literature, discussions with others in the field, and personal research and experience, we derived and present silvicultural guidelines to reduce damage by these insects.

WEEVILS

Two species of weevils (*Pissodes* spp.) cause significant terminal damage to young pines and spruces in the region (table 2): the lodgepole pine terminal weevil (*P. terminalis* Hopping) associated with lodgepole pine (*Pinus contorta* Dougl.), and the white pine weevil (*P. strobi* [Peck]) which attacks lodgepole pine, white spruce (*Picea glauca* [Moench] Voss), and Engelmann spruce (*P. engelmannii* Parry). Attacks by either species reduce tree height and cause formation of multiple leaders and crooked stems. Trees subjected to repeated attacks are bushy and of low timber value (Ives 1983). Open-grown stands have a higher incidence of severely deformed trees than dense stands (Maher 1982).

The lodgepole pine terminal weevil kills the current year's terminals through larval mining in the phloem, sapwood, and pith (fig. 1) (Drouin and others 1963; Stark and Wood 1964); occasionally, lateral shoots are infested. Height growth loss of lodgepole pine in the year after *P. terminalis* attack amounts to about 40 percent of the potential annual increment. However, the following year, the leader resulting from the lateral-turned-terminal is 30 percent shorter, and in the third season the reduction in height growth amounts to 10 to 15 percent of potential growth (Bella in preparation). Thus, a single weevil attack on lodgepole pine reduces tree height growth by nearly 30 percent for three seasons. Stevenson and Petty (1968) also suggested that barring further attacks, the tree resumes normal height growth within 2 to 3 years. Although regionally *P. terminalis* infests less than 10 percent of potential crop trees, the infestation rate in some stands exceeds 50 percent (Bella and Ives in preparation). In west-central Alberta, over 80 percent leader mortality was noted in open-grown and thinned stands (Drouin and Wong 1986); in central British Columbia, two surveyed stands showed 40 and 50 percent top kill (Johnson and others 1971); and in two weevil-affected stands in Idaho, 50 percent (Stevens and Knopf 1974) and 80 percent (Klein and Tegethoff 1970) of the trees were found infested.

The white pine weevil infests the 1-year-old stem internode, killing both the preceding and current year's growth (fig. 2). With leader dieback, the lateral shoots or branches of the terminal whorl assume dominance; this reduces the actual loss in height growth.

Quantitative information on *P. strobi* attack in the Mountain West is rather limited. In the Prince George area of British Columbia, between 6 and 7 percent of young white spruce trees under hardwood suppression were attacked (Cozens 1984); however, once these plantations outgrow the hardwoods, a much higher infestation incidence (approximately 20 percent) is expected (Cozens 1986).

Little is known of the relationship between site characteristics and the incidence of weevil attacks. Analysis of 5 years of data from permanent study plots in west-central Alberta showed no consistent relationship between incidence of lodgepole terminal weevil attacks and soil series (mainly glacial tills), aspect, or elevation (Bella and Ives in preparation); similar lack of elevation effect was found in interior British Columbia (Maher 1982).

There is an association between attack incidence of both weevils and tree age, size, and growth rate. Attacks are most common in 10- to 25-year-old stands that range between 1.5 to 6 m in height (Drouin and others 1963; Stevenson and Petty 1968), and leaders of fast growing

Table 1—Risk rating of insects affecting height growth of the major timber species in the Mountain West

Tree species	Weevils			Moths						Aphids			Midges	
	Pissodes strobi	*P. terminalis*	*Cylindro-coptura furnissi*	*Eucosma sonomana*	*Petrova* spp.	*Rhya-cionia*	*R. buoliana*	*Choristo-neura occidentalis*	*Zelleria haimbachi*	*Adelges cooleyi*	*A. picea*	*Cinara* spp.	*Rhabdo-phaga swainei*	*Cecidomyia*
Abies lasiocarpa											#[1]	#		
A. grandis											#	#		
A. amabilis											#	#		
Larix occidentalis								#						
Picea glauca	*[2]									#		0	0[3]	
P. engelmannii	*											#	#	
Pinus contorta	#	*		#	*		#		#			#		#
P. ponderosa				*	#	#	*		#			#		0
P. jeffreyi		0		0										
Pseudotsuga menziesii			#							#				
Tsuga spp.												#		

[1]#-Generally minor threat.
[2]*-Potentially serious threat.
[3]0-Occasional problem.

Table 2—Host injuries, predisposition factors, and impact of insects affecting height growth

Insect pest			Host tree			Predisposing or controlling factors				Damage	
	Injurous stage										
Species	Mature	Immature	Species	Susceptible age/size	Affected parts	Genetic	Weather[1]	Habitat[2]	Soil[3]	Nature[4]	Impact potential
Weevils:											
Pissodes strobi		x	wS, eS, lP	saplings, poles	terminals	x	—	W-M	P	HG, F	serious
P. terminalis		x	lP	saplings	terminals		—	—	—	HG, F	serious
Cylindrocopturus furnissi	x	x	DF	seedling-sapling	twigs-stems		W-D	W-D	P	HG, F, Mort.	moderate
Moths:											
Eucosma sonomana		x	pP, lP, (eS)	sapling-pole	term. + lat.	x	—	W-D	P	HG, F, V	serious
Petrova spp.		x	lP, pP	sapling-pole	stem-whorl					breakage	moderate
Rhyacionia spp.		x	pP, lP	seedling-sapling	shoots, buds			W-D	P	HG, F	serious
Choristoneura occidentallis		x	wL	sapling-pole	shoots		W-D (C)	all	P	HG, F	serious
Zelleria haimbachi		x	pP, lP	seedling-pole	new shoots		—	—	—	HG	low to mod
Aphids:											
Adelges cooleyi	x	x	DF, eS, wS	seedling-mature	foliage, shoots, cones	x	—	M	G	growth loss	serious
A. picea	x	x	true firs	sapling-mature	bole, branches twigs	x	(C)[5]	M	G	mort., growth loss	serious
Other A. spp.	x	x	all timber except DF	seedling-mature	foliage, shoots, cones	—	—	—	—	—	—
Cinara spp.	x	x	all timber exc. DF, wrC	seedling-mature	twig, branches, bole, roots	—	—	M	G	growth loss	low to mod
Midges:											
Rhabdophaga swainei		x	wS, eS	seedling-pole	buds		—	—	P	HG	low to mod
Cedicomyia spp.		x	pP, lP	sapling-mature	shoots	x	H	W-D	P	HG, F	moderate

[1] No information — ; Hot H; Cool C; Warm-dry W-D

[2] Warm-dry W-D; Moderate M; Cold C

[3] Good G; Poor P

[4] Height growth HG; Form F; Volume V

[5] ( ) suggests control; underline documented

Figure 1—*Pissodes terminalis* damage on lodgepole pine.

Figure 2—White spruce showing current year *Pissodes strobi* attack. (Photo by R. Cozens, British Columbia Ministry of Forests.)

trees are preferred (Bella 1985b; Connola and Beinkafner 1976; Maher 1982; VanderSar and Borden 1977). Open-grown, thinned stands, and plantations may show a higher relative incidence of attacks, as such stands tend to have a greater proportion of fast-growing trees (Bella 1985a). Conversely, at higher stand densities, the percentage of trees attacked is generally lower, but the number of potential crop trees attacked per unit area is similar to that of the open or thinned stand condition (Bella 1985a, 1985b).

Direct controls with contact insecticides proved ineffective in controlling weevil damage. Application of systemic insecticides provided a measure of success (DeBoo and Campbell 1972); however, the environmental hazards posed by such compounds render them operationally unsuitable. Clipping and burning of infested terminals provide some weevil population control in stands with low infestation levels; such treatments are planned on an operational scale in spruce plantations in British Columbia (DeBoo and Cozens 1986).

Identification and delineation of weevil-prone stands/sites is a major task toward reducing weevil damage to tolerable levels. Establishment of multispecies forests, with species adapted to particular site conditions, is likely to reduce not only the weevil hazard but also the risk of other disturbances. As weevil risk appears higher in open-grown host stands with warm, southern exposures, it has been suggested that spruce should be grown under semishaded conditions with competing hardwoods and lodgepole pine in initially dense stands to provide a degree of protection from weevil damage during the sapling stage (Cozens 1984; Stiell 1979). For the same reasons, precommercial thinning in young spruce or lodgepole pine stands on weevil-prone sites should be delayed until the stand passes the weevil-prone age. A surplus of trees should be retained, however, to allow for removal of weevil-damaged trees later in a commercial thinning entry.

Instead of clearcutting, stripcutting that facilitates side shading is another means for reducing the weevil problem on high hazard sites. Berry and Stiell (1976) suggested that the width of strip cuts should not be larger than the average tree height of the current stand multiplied by 1.5 or 2. They reported reduced weevil infestation in young eastern white pine stands established in strip cuts where insolation levels were 25 percent lower than from potential levels; however, uninfested tree height growth was also substantially reduced.

Encouragement of natural predators and parasites, quite numerous for *P. strobi* (VanderSar 1978) but unknown for *P. terminalis*, offers another indirect means for weevil population and damage reduction. Because resinosis is a major host defense to weevil infestation (Silver 1968), breeding highly resinous strains of white spruce or lodgepole pine may provide additional opportunities for damage prevention should weevil problems become serious.

Figure 3—*Eucosma sonomana* damage, exit hole.

The Douglas-fir twig weevil (*Cylindrocopturus furnissi* Buchanan) attacks seedling and sapling-sized Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco); it may kill the seedlings and on older trees cause dieback of terminals and twigs. Planted trees are especially susceptible to the damage (Furniss and Carolin 1977). The weevil occurs in Oregon, Washington, and the British Columbia interior. Damage is usually confined to dry sites and is higher during drought years. Heavy attacks retard tree growth and deform trees.

The adults emerge in midsummer, feed on tender twigs, and deposit eggs on stems and branches. The larvae feed in the cambial region, creating distinct galleries. Prior to pupation they frequently bore through the wood into the pith causing twig or stem breakage.

In areas with a history of twig weevil damage, weevil-prone sites should be identified. On such sites, special efforts should be made to protect soil fertility and moisture-holding capacity during harvest regeneration operations. On high-risk sites, planting of ponderosa pine or other suitable nonhost species should be considered. As moisture stress seems to increase host susceptibility to twig weevil attacks, timely application of stocking controls in young Douglas-fir stands should alleviate moisture deficit and reduce the weevil risk.

MOTHS

Western Pine Shoot Borer

The western pine shoot borer (WPSB)(*Eucosma sonomana* Kearfoot) infests ponderosa pine (*Pinus ponderosa* Laws.), lodgepole pine, and Jeffrey pine (*P. jeffreyi* Grev. and Balf.) in the Western United States and Canada. Eggs are laid in the early spring, and the larvae mine into the pith tissues of elongating shoots, particularly shoots on the terminal whorls. Before the shoots' woody tissues harden, the fully grown larvae exit through the side of the shoots, drop to the ground, pupate, and overwinter in the duff (fig. 3). For a given even-aged stand, the infestation rates appear relatively stable from year to year (Stoszek 1973).

Larval mining stunts elongation of infested shoots and results in reduced shoot length the following season. Dieback of infested shoots is rare. Deformed, bushy, and limby crowns, and reduced height increment and volume yields are the main shoot-borer impacts (Sower and Shorb 1984; Stevens and Jennings 1977; Stoszek 1973). In young ponderosa pine plantations on ponderosa pine (climax) sites in eastern Oregon the WPSB was found to infest between 50 to 70 percent of leaders yearly; this was estimated to reduce volume yield by up to 22 percent (Stoszek 1973). Impacts of similar magnitude were found for highly infested ponderosa pine plantations in central Idaho (Stoszek and others 1981b).

Once the potential impact of this insect was assessed, attention was directed toward development of controls. While conventional insecticides (contact and systemic) failed to protect trees from this pest, a pheromone-based male-confusion technique provided an operationally successful measure of WPSB control (Overhulzer and others 1981).

Operational application of pest controls needs to be subjected to cost benefit analysis like any other management measure. Recently completed models that predict the percentage of ponderosa pine leaders infested by the WPSB in sapling-sized ponderosa pine plantations in north-central Idaho, combined with models assessing WPSB losses in cumulative height and volume growth (Robertson 1982; Stoszek and others 1981b) provide the basis for such analysis. Shoot borer infestation rates were found positively correlated to stand basal area, average annual height or basal area increment, and negatively correlated with elevation. Stands established on metasediments/volcanics and granitic parent materials were found to be under highest risk from the shoot borer (infestation rate >60 percent); stands established on volcanic ash/loess and basaltic parent materials were of lower risk (infestation rate <44 percent).

Infestation incidence predicting (or hazard rating) models serve to identify WPSB hazard from site-stand information (useful only in the area for which the risk predictive equations were developed) and provide a basis for the interpretation of insect-host tree-stand-site relationships. When in agreement with established ecological concepts, such hypothetical interpretations may serve as the tentative basis for design of silvicultural or other management measures to reduce pest damage, and as a basis for experimental research.

The WPSB model and Douglas-fir tussock moth and western budworm hazard rating models were interpreted for such a purpose (Stoszek 1986; Stoszek and Mika 1984; Stoszek and others 1981a, b). With respect to the WPSB, a tentative conclusion derived from these interpretations is that persistently high shoot borer infestations are a reflection of the host trees' mineral nutrient stress. It is assumed that the mineral nutrient deficiency (imbalance) of the host results in an inadequate synthesis of tree defense compounds against the shoot borer attack.

Silvicultural and management strategies to reduce WPSB attacks include the following: (1) use of hazard rating models and growth loss estimating models for identification and delineation of shoot borer hazard-prone sites and stands, and for evaluation of cost-effectiveness of available controls or other preventative strategies against WPSB; (2) application of harvest-regeneration practices that protect soil fertility and soil moisture holding capacity and enhance organic matter decomposition and nutrient cycling rates; (3) refraining tentatively from application of N-fertilizers as there is evidence that this could magnify nutrient imbalances (Moore this proceedings) in hosts and possibly increase tree predisposition to the pest.

Figure 4—*Petrova albicapitana* damage on lodgepole pine.

Pitch Nodule Moth

Two species of pitch nodule moths—*Petrova albicapitana* (Busck) and the more abundant *P. metallica* (Busck)—cause serious injuries to the twigs and terminal shoots of young lodgepole pine in Alberta (fig. 4) (Hopping 1961; Wong and others 1985), although Furniss and Carolin (1977) consider them of minor importance. Both species occur throughout the Mountain West.

The moths lay their eggs on needles or at the base of needle sheaths on pine twigs and terminals from early June to mid-July (Hopping 1961; Turnock 1953). The larvae of *P. metallica* feed in the xylem and pith, tunneling downward beyond the internode and causing slight swelling of the shoot. The larvae of *P. albicapitana* feed in the bark and cambium and enter the xylem and partly girdle the shoot (Wong and others 1985). The larvae overwinter in the nodules formed from pitch at the feeding site. In spring the larvae move to the junction of a branch and main stem or the junction of two branches, resume feeding, and form new nodules where they spend the second winter. Adults emerge in the following summer.

Attacks by either species reduce height growth and cause leader breakage, crooked stems, and development of multiple leaders. A study in Alberta showed that faster growing trees are attacked more frequently than slower growing trees (Bella 1985a).

Information on site characteristics and *Petrova* spp. attack incidence relationships is scanty. In a survey over a 5-year period, Bella and Ives (in preparation) found much higher levels of infestations on the warmer southerly and wind-sheltered easterly slopes than on northerly aspects. Stands with higher infestation rates also showed greater variation in infestation, which declined within 5 years from initially high levels to near zero. This study also found the highest frequency of attacks at elevations below 1,300 m. Considering the altitudinal distribution of the host, which ranges from 800 to 1,800 m, *Petrova* attacks seem to be confined to warmer and drier sites for lodgepole pine. The above information on *Petrova* spp. is similar to that of the stand hazard rating model developed for the western pine shoot borer by Stoszek and others (1981b) in central Idaho.

Based on the above information it appears that application of stocking controls in young lodgepole pine stands on *Petrova*-risk sites (those with lower elevations and southerly and easterly aspects) should help in reducing *Petrova*-caused damage impacts. The widely spaced saplings will develop a greater stem taper, which should reduce the chances of snow breakage at *Petrova*-caused feeding injury points.

European Pine Shoot Moth

European pine shoot moth (*Rhyacionia buoliana* [Schiff.]) poses a potentially serious threat to young ponderosa pine and lodgepole pine stands in some areas of the Mountain West (Evans 1982; Flora 1965; Miller and others 1970). This highly destructive pest is gradually spreading on ornamental pines throughout Oregon, Washington, and British Columbia (Furniss and Carolin 1977; Harris and Ross 1973). To date, infestations of native pine plantations and natural regenerations have not been reported even though naturally growing lodgepole and ponderosa pines have been shown to be susceptible to the insect. Low winter temperatures (below -20 °C) and light snow cover hinder the establishment and survival of the shoot moth; pine stands in southern Oregon and northern California are considered highly susceptible (Daterman and Carolin 1973).

The moths fly in midsummer and lay eggs on twigs, buds, and needles; there is one generation annually. The web-spinning larvae mine the needle bases and later the buds, causing pitch formation. They overwinter either in the mined bud or under the pitch and resume feeding in the spring by mining other buds and then the bases of elongating shoots. Pupae form in the hollowed-out shoots.

In the Lake States, where *R. buoliana* is well-established, heavy attacks on planted red pine retard and deform tree growth to a point that may render the tree commercially useless (Evans 1982; Miller and others 1978; Syme 1976). Plantations on poor sites are highly susceptible (Heikkenen and Miller 1960). Vigorous shoot growth and copious resin flow of pines on productive sites have been associated with reduced damage. Also, numerous natural parasites, mainly wasps, were found important in reducing shoot moth populations.

Silvicultural strategies to reduce shoot moth damage in the Lake States consist of planting red pine on productive sites and encouraging certain flowering plants of the subordinate vegetation that are an important food source for the parasitic wasps (Syme 1976). Pruning of lower branches on pines to prevent snow-cover-related winter survival of larvae has been suggested as another measure to reduce pest damage. Contact insecticidal controls proved ineffective due to the insect's feeding habits (Syme 1976). The application of synthetic pheromone was also unsuccessful.

Whether such preventative strategies could be feasible under Intermountain West conditions is a matter of opinion. At present, the European pine shoot moth is one among many potential hazards for western pines on poor sites.

Unidentified Shoot Moth

Seedling and sapling-sized ponderosa pines on the Northern Cheyenne Reservation and Custer National Forest in southeastern Montana were found by one of the authors to have chronically high infestations of a native, as yet taxonomically unidentified, shoot moth species. Trees grown in semishaded conditions were severely stunted with virtually all buds destroyed by larval feeding. Open-grown saplings were subject to relatively lower infestations, nevertheless exhibiting a high incidence of stem forks. The infestation rates appeared higher on poorer sites, but virtually all sites were impacted by this pest. Prompt overstory removal or reduction of side shading is a must for viable growth and development of ponderosa pine regeneration in this area.

Western Spruce Budworm

Western spruce budworm (*Choristoneura occidentalis* Free.) has been discussed by others in this symposium. We are interested in the budworm because it also feeds on terminal shoots of western larch (*Larix occidentalis* Nutt.) reducing its height growth, form, and stem volume (Fellin and Schmidt 1973). Frequent infestations will lower the competitive advantage of juvenile larch with regard to its associates and render this extremely shade intolerant species vulnerable to suppression by other stand components; the budworm may thus indirectly cause larch mortality.

Young larch stands in some localities are subject to frequent and heavy budworm infestations, while at other locations they are free of damage. Operational risk rating systems to account for this have already been developed for budworm infestations in Douglas-fir, grand fir, and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) stands (Stoszek and Mika 1984). Similar systems are needed for western larch cultures as a basis for integrating budworm impact concerns into silvicultural planning.

Pine Needle Sheathminer

The pine needle sheathminer (*Zelleria haimbachi* Busck.) is a widely distributed moth infesting two- and three-needle pines. The moths lay eggs in summer on current-year needles. The larvae mine into the needles to overwinter. In the spring they move to the base of newly grown needles and feed within the needle sheath (Furniss and Carolin 1977). Partially grown, dead needles on current year's shoots are symptoms of sheathminer infestation. Repeated defoliation may result in substantial reduction of height and diameter growth.

Our knowledge about the insect's habits, site, host tree-stand condition relationships, and impacts is too scarce to design pest-specific damage prevention measures. The substantial variation in occurrence and severity of defoliation between stands established on ecologically different sites suggests that site factors may be important in host susceptibility to sheathminer infestations. Appropriate site risk rating schemes and results on impact are needed as a basis for design of silvicultural preventions.

APHIDS

Gall aphids and bark aphids, known as *Adelges* [*Chermes*] and *Pineus*, attack only conifers. They have a complex life cycle. The sexual form, if present, always develops on spruce, the primary host. The asexual forms feed on *Abies, Larix, Pinus, Pseudotsuga*, and *Tsuga* spp., which are secondary hosts. This group includes the introduced balsam woolly aphid (*Adelges piceae* [Ratze.]), which is a serious pest of true firs; and native spruce gall aphid (*A. cooleyi* [Gillette]), which is a potentially serious pest of Douglas-fir.

Spruce Gall Aphid

The spruce gall aphid is widely distributed throughout the West. On spruce it causes cone-shaped galls on twigs, which have limited impact on tree growth. On Douglas-fir it feeds on new foliage, shoots, and developing cones. Its presence is marked by whitish tufts. The infested needles become twisted and yellowish and usually drop off earlier than unaffected foliage, particularly on poor sites (Furniss and Carolin 1977).

Heavy spruce gall aphid infestations cause substantial reduction of shoot and leader growth. Infestations are highly variable from year to year and among trees. Some provenances of Douglas-fir apparently are more resistant to this pest than others.

When both host species are present the entire life cycle requires 2 years. A parthenogenic (asexual) life cycle of two generations per year is common on Douglas-fir where spruce is scarce or absent.

Direct control of the spruce gall aphid may be obtained by insecticidal spraying in early spring; this could prove cost effective in seed orchards. Damage-preventive silvicultural measures include the use of local seed source and cutting of heavily infested trees during precommercial thinnings. Opportunities seem to exist for breeding spruce gall aphid resistant Douglas-fir.

Balsam Woolly Aphid

The balsam woolly aphid, introduced from Eurasia, became well established in the 1960's in the mild climate of the West Coast, where it caused extensive mortality to grand fir and Pacific silver fir (*Abies amabilis* [Dougl.] Forbes) (Furniss and Carolin 1977). This insect has virtually no natural enemies, and its rapid reproduction rate is not hindered by the host. Cold temperatures are the main deterrent to its spread into high elevations on the coast and into the interior West.

One of the authors recently observed a localized infestation by the balsam woolly aphid in northern Idaho in low-elevation alpine fir stands, where it causes some tree mortality. Although harsh winters in this region will prevent an epidemic, the mere presence of this insect poses a potential threat to *Abies* spp. at lower elevations in the region; a careful surveillance is recommended.

Presence of the balsam woolly aphid is easily detected by white tufts on smooth stem bark and shoots of true firs, and by swellings (galling) of shoot tips on understory fir trees. Remains of white tufts on the boles of recently killed firs provide another visible sign of infestations by this pest. At present, there is no effective means of controlling this insect; quarantine measures to slow down its spread were not successful. As some trees in infested stands are free of aphids, genetic selection of resistant strains may provide a solution.

Cinara Aphids

The giant conifer aphids (*Cinara* spp.) feed on twigs, branches, stems, and roots of virtually every commercial conifer in the Mountain West except western redcedar and possibly Douglas-fir. Heavy infestations cause yellowing of foliage and reduce tree growth. Aphid-produced honeydew flow may cause black mold development (Furniss and Carolin 1977).

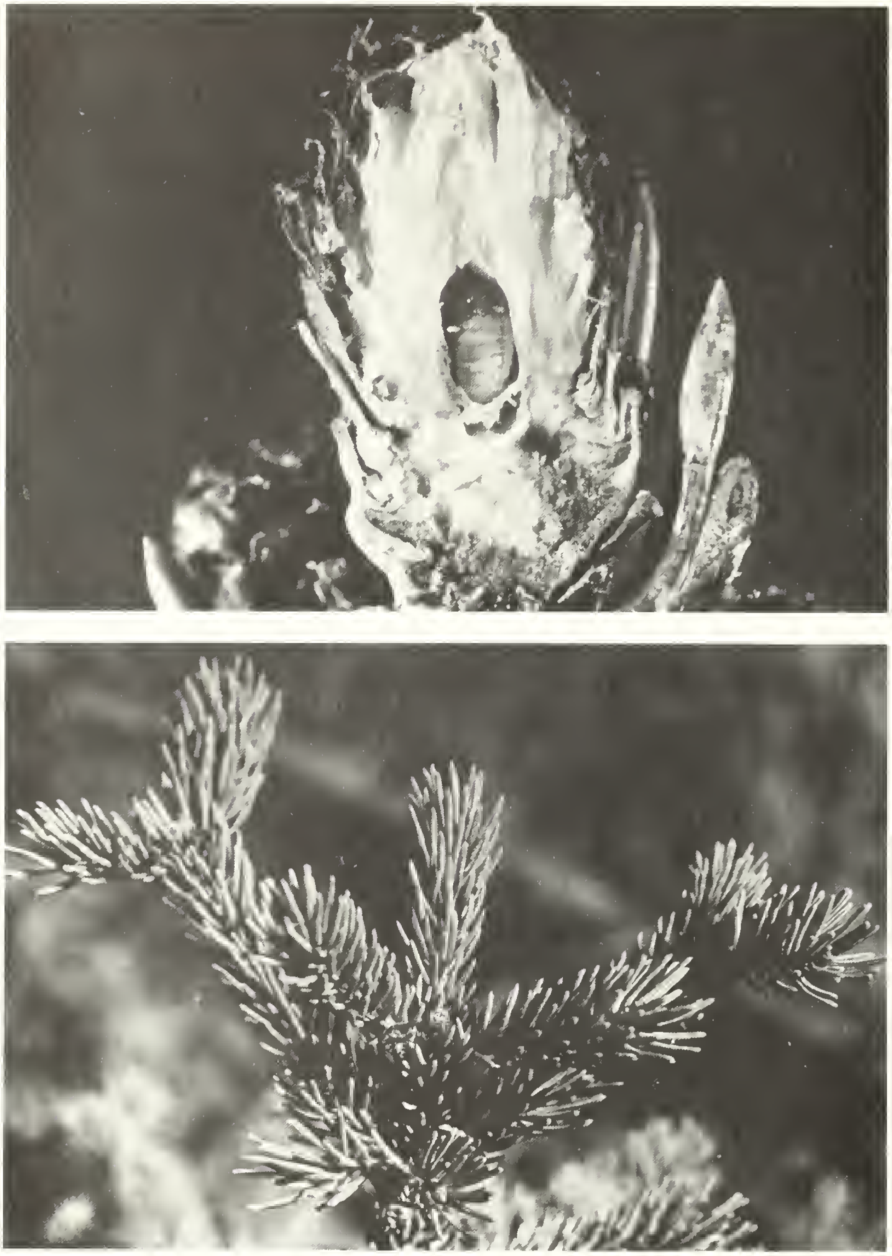

Figure 5—*Rhabdophaga swainei* damage on spruce.

There are many species of *Cinara* aphids, each associated with one tree species or genus. Several generations are produced yearly; eggs are the overwintering stage. Widespread damage by *Cinara* spp. has not been observed. Their attack is confined to certain, perhaps more susceptible, individuals, while neighboring trees may be free of attack. We observed that faster growing trees in young ponderosa pine plantations supported heavier *Cinara* infestations than their slower growing counterparts.

Inadequate information on *Cinara*'s host selection habits, host predisposition, and damage impacts precludes formulation of meaningful silvicultural strategies for damage prevention. Carrow and Graham (1968) found that nitrogen fertilization alters tree-aphid attack relationships; so monitoring of aphid infestation levels in fertilization trials seems advisable.

MIDGES

Bud Midge

The bud midge (*Rhabdophaga swainei* Felt.) is emerging as an important insect of young spruce (black, white, and Engelmann) forests in Alberta and interior British Columbia. The midges lay eggs in late May and early June on the tips of emerging shoots, especially terminals. The orange-colored maggots bore into the shoot tips and overwinter nearly fully grown inside the terminal buds. The adults emerge at the end of May, from (by then aborted) terminal buds. The shoot growing from an uninfested lateral bud on the leader assumes dominance (fig. 5). On the average, growth of this new leader is about 25 percent less than the potential height growth of the original leader. In the following year the height growth of the lateral-turned-terminal is back to normal (Cerezke 1972).

Relatively little is known about the distribution, infestation levels, and the biology of this insect. In the British Columbia interior, Cozens (1984) surveyed 14 of 49 candidate 10- to 20-year-old white spruce plantations and found that bud midge infestation affected only 2.2 percent of the trees. Trees between 1 and 10 m tall are most susceptible to attack (Cerezke 1986). In Alberta, the midge occurs at fairly low infestation levels on spruces growing under a variety of stand and site conditions. On the Kenai Peninsula in Alaska in 1983, one of the authors observed heavy midge infestation in uneven-aged white spruce stands on poorly drained sites, while young, fast-growing spruce trees on adjacent, well-drained road-fill of different parent material were completely free of attack. Much basic information is required before an intelligent control strategy can be formulated.

Resin Midge

Pitch or resin midges (*Cecidomyia* spp.) develop on ponderosa and lodgepole pines. The orange-colored maggots feed inside the outer bark tissues of new shoots where they form pitch-filled pits, or live in exuded resin masses (Furniss and Carolin 1977). Light attacks distort shoot growth; heavily infested twigs are girdled and turn red.

In the intermountain region we have observed natural open-growth stands of ponderosa pine and lodgepole pine on harsh sites showing signs (flagging and distorted crowns) of persistent midge attacks. Some trees suffer repeated and heavy midge attacks, while other trees are not infested. Planted ponderosa pine appears more vulnerable to persistent high infestations than naturally established stands. Increased incidence of flagging occurs frequently in ponderosa pine stands in the year following a thinning operation, but the impact of the midge is likely to be minor. The impact on growth and form of repeatedly attacked trees and stands is quite obvious and probably substantial, but quantitative data are lacking.

Since resin midges appear to be a potential threat to ponderosa and lodgepole pine stands on marginal sites for the particular pine species, it is advisable to use on such sites regeneration methods that rely on natural reproduction and carefully protect soil fertility and soil moisture-holding capacity. If artificial regeneration is desired, utmost care is needed in selecting seed source adapted to conditions of the planting site. During precommercial thinnings, trees with persistent midge infestation symptoms should be cut. Similarly, when selecting ponderosa pine seed trees there is need to discriminate against midge-susceptible trees.

CONCLUSIONS

1. Damage to growth and form of young forest stands by weevils, shoot borers, tip and shoot moths, needle sheathminers, aphids, and midges (of concern in this paper) is generally inconspicuous and low in terms of regional impact.

2. There is a strong indication, well-documented in case of the western pine-shoot borer and to some extent for the weevil species, that population and damage levels by the discussed insects are site and tree/stand condition specific. On high risk habitats, the damage impact caused by some of these insects to tree quality and volume yield is substantial.

3. Insecticidal controls were proven either ineffective or unacceptable because of cost and safety concerns. Pheromone-based measures proved biologically effective in the case of the western pine shoot borer and may be promising against the weevils and other moth species.

4. Damage prevention or pest hazard reduction through silvicultural measures offers the most viable solution. The first step in such prevention efforts is the identification of site and stand characteristics associated with high pest populations and damage levels. Understanding insect-host-site relationships is a prerequisite for design of biologically effective preventions. To assess the feasibility of eventual silvicultural preventions, techniques are needed for site-stand specific evaluation of losses in value yields from each of the major pest species.

5. Pest damage prevention considerations have to be made an integral part of the silvicultural and resource management planning process. Ecological site classification systems provide a logical framework through which such integration may be accomplished.

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RELATIONSHIPS OF DWARF MISTLETOES AND INTERMEDIATE STAND CULTURAL PRACTICES IN THE NORTHERN ROCKIES

Ed F. Wicker
Frank G. Hawksworth

ABSTRACT

The dwarf mistletoes have long been known as one of the most widespread and damaging disease agents of conifers in the West, including the Northern Rockies. Although the basics for silvicultural control of these parasites are well established, these principles have been effectively applied only during the last decade or two. This paper discusses the ecological role of dwarf mistletoes in northern coniferous forests. Knowledge of weak links in the life cycle of dwarf mistletoes should be utilized to develop control strategies and tactics, and to incorporate them into management practices.

INTRODUCTION

Dwarf mistletoes are chlorophyllous, dioecious, angiosperms of the genus *Arceuthobium*. Through millenia, they have evolved as highly specialized parasites of several conifers in the Pinaceae and Cupressaceae (Gill 1935; Hawksworth and Wiens 1972). Because of their many unusual anatomical and morphological features, as well as biological and ecological attributes, botanists consider them to be unique, primitive plants.When parasitism by dwarf mistletoes interferes with the normal functioning of the host plant, the consequences are impairments of health, growth, and productivity of the host. A disease relationship is then established, and the mistletoe becomes a pathogen.

It has long been known that populations of dwarf mistletoes can be regulated by silvicultural practices (Hawksworth and Shaw 1984; Johnson and Hawksworth 1986; Kimmey and Graham 1960; Scharpf and Parmeter 1978; Weir 1916a). In most situations, such regulation is most efficiently, effectively, and economically achieved during regeneration cuttings. Significant additional regulation can be achieved, however, when this objective is integrated with those of intermediate stand cultural practices. In any circumstance, the objective is clearly regulation of the pest population, not its eradication.

THE SITUATION

Four tree species important to the composition and succession of the mixed conifer forests of the Northern Rocky Mountains are significantly affected by dwarf mistletoes. These host/parasite combinations are Douglas-fir/*Arceuthobium douglasii*, western larch/*A. laricis*, lodgepole pine/*A. americanum*, and ponderosa pine/*A. campylopodum* (Dooling and Eder 1981; Graham 1960; Hawksworth and Wiens 1972).

Dwarf mistletoes occur on over 7 million acres (2.8 million ha) of commercial forests in the Northern Rockies. Infections occur in 60 to 70 percent of the Douglas-fir (*Pseudotsuga menziesii*) forests, 60 to 80 percent of the western larch (*Larix occidentalis*), and about 35 percent of the lodgepole pine (*Pinus contorta*) in eastern Washington, northern Idaho, and western Montana. Infection of ponderosa pine (*Pinus ponderosa*) is locally heavy in northeastern Washington, light and spotty in northern Idaho, but absent in Montana.

Douglas-fir and ponderosa pine may be either seral or climax in the successional stages of the sere, as both species are sufficiently shade tolerant. Western larch is intolerant of shade and is mainly represented as a seral species. In some environments, however, western larch may occur as a pioneer or fire disclimax. Throughout the Northern Rocky Mountains, lodgepole pine regularly occurs as a pioneer or seral species. In certain topoedaphic environments, it may function as a climax species (Pfister and others 1977). When periodically repeated, certain natural events (fire, glaciation, insect epidemics, windstorms, etc.) may delay succession and indefinitely prolong occupancy of the habitat by pioneer or seral vegetation. When this happens, the structure of the seral vegetation may resemble that of a climax.

The seral ecotypes of Douglas-fir and ponderosa pine are usually represented as uneven-aged stands, with continued reproduction dependent on repeated occurrence of the natural event responsible for the disturbance of expected succession. Because of their shade intolerance, lodgepole pine and western larch usually develop a mosaic pattern consisting of even-aged clusters or patches of irregular size and shape. However, either pattern may develop with any of the four species. The significance of the ecological status of the host, stand structure, and repeated occurrence of fire in the Northern Rockies, has been discussed by Wicker and Leaphart (1976).

DWARF MISTLETOE EFFECTS

Infection by dwarf mistletoes markedly alters the host physiology. Dwarf mistletoes reduce the vigor and growth rate, the quality and quantity of products, and the reproductive capacity of infected trees (Hawksworth and Hinds 1964; Hawksworth and Shaw 1984; Pierce 1960; Weir 1916b). They also reduce the longevity of infected trees by predisposing them to attack by insects and fungi. Dwarf mistletoes are capable of causing swellings and cankers on branches and stems, abnormal branching, and spike tops. That dwarf mistletoe infections extend the time necessary to reach rotation age is a most significant effect that is frequently overlooked by forest managers. A profitable venture or opportunity in forest resource management may be transformed into an economic disaster by dwarf mistletoes once they achieve pest status.

IMPORTANT CHARACTERISTICS

Managers can take advantage of certain ecological and biological characteristics of dwarf mistletoes when developing strategies and tactics to regulate populations of these pathogens. All species are obligate parasites and have a restricted host range, a low rate of spread, and a long life cycle (Scharpf and Parmeter 1978). They are prolific seed producers, but the infection process is extremely inefficient. Many responses of the host to infection are readily visible, which facilitates detection. Because of these characteristics, dwarf mistletoe control strategies and tactics can be integrated with proven economically practical, environmentally acceptable, and ecologically valid cultural systems for managing coniferous forests for multiple use.

CONCEPT OF DWARF MISTLETOE CONTROL

The term "control" is used in this paper to include activities to reduce the dwarf mistletoe population to a level where it causes little or no significant loss in forest production. The mere existence of dwarf mistletoes in a coniferous forest does not warrant their designation as pests, and eradication is not a rational objective. These parasitic plants have existed as natural components of conifer forest ecosystems for eons, perhaps as long as conifer forests have existed. Their designation as pests is valid only when their populations affect attainment of specified production goals and costs.

A decision to control dwarf mistletoes should be based on their predicted potential to cause losses. These activities are preventative tactics and, by necessity, are implemented on a case-by-case basis. As with most forest pests, present management planning usually does not exploit the many opportunities for prevention but, instead, depends heavily on therapeutic tactics implemented after the dwarf mistletoes have achieved pest status. The strategy of heavy dependence on therapeutic tactics is less efficient and less effective than strategies emphasizing prevention. Regardless of the strategy, for greatest efficiency and effectiveness, tactics used to regulate dwarf mistletoe should be integrated into the overall management system for the particular production unit and implemented in unison with planned cultural practices. When selecting strategies and tactics, the ecological requirements of the conifer species infected, their successional status, stand structure, age of stand with respect to rotation age, and population dynamics of the dwarf mistletoe require consideration. These characteristics may vary considerably from situation to situation, with time being a major factor contributing to variability. Thus, we have the ecological basis for a case-by-case decision for action programs.

BASIS FOR CONTROL STRATEGIES AND TACTICS

We recommend that the known biological and ecological characteristics of the conifer species being managed and its common dwarf mistletoe be used to devise guidelines for integrating control strategies and tactics with cultural practices, starting with the initial planning and development of the management prescription for each management unit. Because of the many stand and disease variables, such as intensity of infections, hosts affected, tree size, products being managed for, site productivity, and economics, it is unwise to use a "cookbook" approach to dwarf mistletoe control. Instead, all factors should be considered and control strategies and tactics developed on a stand-by-stand basis.

Some dwarf mistletoe facts, and control tactics based on these facts, that will help in planning control strategies are discussed below. Several excellent guidelines are available that give specific recommendations for silvicultural management strategies for dwarf mistletoes in the Northern Rockies (Dooling 1974, 1983; Dooling and Brown 1976; Kimmey and Graham 1960; Reedy and others 1986; Schwandt 1977, 1984).

Fact 1—Dwarf mistletoes have restricted host ranges; they show a strong affinity for parasitizing a single host (Dooling and Eder 1981; Kuijt 1955). When managing mixed conifer forests, such as those of the Northern Rocky Mountains where as many as 12 tree species may be present, there is sufficient opportunity, beginning with the regeneration cut and continuing through all thinnings planned during the rotation, to favor nonhost species.

Tactic 1—When managing mixed conifer forests with dwarf mistletoes, cultural practices should favor the retention of species mixture over monoculture. If other management considerations favor a monoculture ecosystem, then crop rotation (agriculture) or species alternation (forestry) should be practiced whereby nonhost species are grown for a rotation to break the pest cycle.

Fact 2—The dwarf mistletoes are obligate parasites; they can obtain their food only from living conifers. Thus, they can survive only in intimate association with their host. Death of the host, or infected parts of the host, will kill the dwarf mistletoe.

Tactic 2—When dwarf mistletoes are present in a stand, they can be removed by integrating the art of roguing with cultural thinnings of stands of any age. Roguing is the removal of undesirable plants, an art that is about as old as agriculture. The degree of success in applying such an integrated practice is strongly time dependent. From a purely cultural viewpoint, if the young stand is overstocked, the first thinning should be implemented soon after dominance is expressed. If roguing is incorporated with the initial thinning, the degree of success with dwarf mistletoe removal is maximized.

Pruning of infected branches is a proven control technique, but because of the high cost is presently restricted to high value trees, such as those in recreation areas (Lightle and Hawksworth 1973).

Fact 3—The distance of seed dispersal is relatively limited. Although seed may travel up to 70 ft horizontal distance if unobstructed, average distances are only 10 to 20 ft. Lateral rates of spread of dwarf mistletoes within a stand of uniform structure are slow—on the order of 10 to 15 ft per decade. Long-distance dispersal by birds, rodents, or man is rare and not of management concern.

Tactic 3—Regulation of dwarf mistletoe populations requires long-term planning initiated at the beginning of the rotation and projected to the end of the rotation. There is ample time to plan control activities. Crisis management is unnecessary and unwarranted.

Fact 4—Dwarf mistletoes spread most rapidly from infected overstory trees to young regeneration (but over 10 years old). This form of spread is the most common way young stands become infected. Thus, if the young stand has infected residual overstory, removal of the overstory will eliminate both the major source of infection and the major source of competition. Dwarf mistletoes are extremely rare in young stands regenerated in the absence of overstory.

Tactic 4—Remove all living overstory from, and within 70 ft of, the regenerated stand. This should be done within the first 5 years of the establishment of the new stand, and definitely no later than 10 years after the regeneration cut (Wicker 1967).

Fact 5—Dwarf mistletoe infections are uncommon in regeneration under 10 years old, even when an infected overstory is present (Hawksworth and Graham 1963; Wicker 1967).

Tactic 5—Dwarf mistletoe-infected trees may be used as seed sources for forest regeneration. However, as soon as the regeneration is established, the seed sources should be removed. In no case should they remain for more than 10 years.

Fact 6—The infection process for dwarf mistletoes is relatively inefficient. In most natural environments, probably less than 1 percent of seeds produced in any year produce a new infection. Severe epidemics of dwarf mistletoes rarely occur and require long time periods (30 years or more) to develop. They should not develop in managed stands.

Tactic 6—Vigilance and commitment are required of the land manager when regulating dwarf mistletoe populations. Population increases and attendant production losses are insidious, and this stimulates a sense of false security in our management planning. Adequate consideration must be given the ultimate potential of dwarf mistletoes to cause losses. The time to consider their potential threat is at initial detection. Contingency planning before detection is often wise.

Fact 7—Response of the host to infection by dwarf mistletoes is readily visible, and detection is rather simple. Infected stands exhibit witches' brooms, and dead-topped and dying trees. The six-class rating system is a practical and proven method to quantify intensity of dwarf mistletoes in trees and stands in a management unit (Hawksworth 1977).

Tactic 7—Collection of information about dwarf mistletoes should be an integral part of normal inventory and stand examination protocols. Except under special circumstances, separate dwarf mistletoe surveys are not recommended.

Fact 8—Rates of dwarf mistletoe intensification are reduced in managed stands. In unmanaged stands, dwarf mistletoe generally increases to the next highest class in the six-class rating system in about 10 to 15 years (Lightle and Hawksworth 1973). This interval may be more than doubled in managed stands. Depending on treatment efficiency and site productivity, increases in stand intensity ratings may be minimized for the remainder of the rotation.

Tactic 8—Require that all cultural activities incorporate tactics to address dwarf mistletoe conditions.

Fact 9—Dwarf mistletoes affect the height and diameter growth of the host trees. Effects on growth are negligible in lightly infected (class 1-3) trees (Hawksworth 1977). However, as infection rates increase above class 3, growth falls off markedly. As a general rule, growth reduction is about 10 percent in class 4 trees, 25 percent in class 5 trees, and 50 percent or more in class 6 trees.

Tactic 9—Establish rational and achievable goals of dwarf mistletoe population regulation. Eradication is not a rational goal.

Fact 10—Once the dwarf mistletoe rating reaches class 4 or higher, the capability of the tree to produce adequate quantities of viable seed is significantly impaired (Schaffer and others 1983).

Tactic 10—Trees with a rating of 4 or higher should not be used as seed sources for forest regeneration. If they are the only seed sources available, more trees for regeneration must be left than normally would be for lightly infected or mistletoe-free stands.

Fact 11—Initial stand establishment (regeneration cutting) is the best time for significant regulation of dwarf mistletoe populations.

Tactic 11—If clearcutting is being considered, use natural barriers, such as streams, roads, utility rights-of-way, and rock outcrops, to minimize spread into the new stand. Changes in species composition and spacing of host species in mixtures can also be used to limit spread of the parasite.

Fact 12—Infection by dwarf mistletoes may preclude the opportunity to grow a desired product. As a minimum, dwarf mistletoes will extend the time to produce the product, and the product will be of inferior quality and quantity.

Tactic 12—Apply the technology available for regulating dwarf mistletoe populations. Break with tradition and stop accepting unnecessary production losses.

Fact 13—To properly manage a forest, the manager needs to know (1) the resource to be managed, (2) where the resource is located, (3) the objectives of management, and (4) the health of the forest (Wicker 1978). Yield simulation programs have been developed to help the forest manager decide the optimum treatment for mistletoe-infected stands. The RMYLD program has subroutines for mistletoe-infected lodgepole pine stands in the Rocky Mountains and for ponderosa pine stands in the Southwest and Southern Rocky Mountains (Edminster 1978; Van der Kamp and Hawksworth 1985). Growth and yield models that include dwarf mistletoe effects are not currently available for most of the Northern Rockies or the Pacific Northwest, but the PROGNOSIS model is being modified to handle such stands.

Tactic 13—Use all available technology to determine and monitor the health of the forest being managed and determine optimum treatment strategies and tactics.

CONCLUSIONS

The basic biology of the dwarf mistletoes, especially their high host specificity and slow rates of spread, make these widespread parasites more amenable to silvicultural control than any other forest pest. Separate control action programs are not recommended. Dwarf mistletoe control strategies and tactics should be integrated into overall management activities within the context of good forest management and the concept of integrated pest management.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Gary Hilton)—What maximum Hawksworth rating would you leave in a seed tree cut (leave for seed source) for Douglas-fir and for ponderosa pine?

A.—A rating of 3 for both species. Trees with a rating of 4 or higher should not be used. (See Tactic 10)

Q. (from Dennis R. Parent)—How long from the time of infection to the point where a visible broom is formed?

A.—The time will vary with the host/parasite combination because of differences in broom morphology. With Douglas-fir and western larch, small brooms will develop within 4 to 6 years following infection.

Q. (from Robbin B. Boyce)—Ponderosa pine can be managed with a thinning regime without eliminating dwarf mistletoe from the stand. Can Douglas-fir also be managed to a commercial sawlog size with residual infections of mistletoe? If so, are the management criteria similar to those for ponderosa pine?

A.—I am uncertain of your use of the term "residual" infection. Eliminating (= eradicating) dwarf mistletoe from a stand is not a rational objective. Certainly, Douglas-fir can be managed for sawlog production with some dwarf mistletoe. To do so, the dwarf mistletoe population must be regulated. Actions to regulate the population should be integrated and conducted in unison with planned cultural practices, such as thinning. Whether the cultural practices for Douglas-fir are similar to those for ponderosa pine depends on numerous factors; in general, they should be expected to exhibit considerable variation.

Q. (from Dennis R. Parent)—If it takes 5-20 years for a broom to form, how can we know whether a mature tree has an infection, and if it should be cut in a sanitation thinning?

A.—Although well-developed brooms may not form for several years after infection, there are other signs and symptoms that identify dwarf mistletoe infection. These are: swelling, abnormal branching, and, of course, the mistletoe plants themselves. Also, it should be remembered that other biotic and abiotic agents (such as dense *Elytroderma* brooms in ponderosa pine, stimulation brooms in cut-over lodgepole pine, and somatic mutations in many conifers) can also cause witches' brooms, and these are sometimes mistaken for those caused by dwarf mistletoes.

ROOT DISEASE RESPONSE TO STAND CULTURE

Susan K. Hagle
Donald J. Goheen

ABSTRACT

Root disease kills trees of all ages. All species of conifers are attacked but losses are greatest in Douglas-fir and true firs. Carryover of inoculum from one generation to the next can greatly hinder timber production on infested sites. Management practices employed early in stand development will largely determine future productivity of stands on such sites. Species manipulation at the onset of stand establishment can significantly alter the course of root disease development. Thinning, both precommercial and commercial, can produce either beneficial or detrimental results depending on the application. Current literature and recent studies with regard to root disease in second-growth stands of the Intermountain Northwest are summarized and discussed.

INTRODUCTION

Mortality resulting from root disease may not be evident in a stand until trees reach large sapling to small pole size. At this time an annual loss of 5 percent of the trees is not uncommon in root disease-affected stands. At 20 to 40 years of age, this level of mortality may have imposed no more than necessary thinning on overstocked stands. However, evidence indicates that for Douglas-fir and true firs the mortality may continue at about this same rate for at least 90 to 100 years.

There comes a point, then, when this annual attrition becomes a threat to the timber productivity of many stands. In some stands this turning point may be early, perhaps in part because the site has regenerated poorly resulting in sparse stocking. In others the productivity loss may not be measurable until much later in the rotation when trees are merchantable. In these cases the losses can be minimized or averted entirely by harvesting the timber before significant volume is lost. In reality, most stands with root disease fall somewhere between these extremes.

The fate of an individual stand will depend on the species composition, existing root disease conditions, management activities, pathogen species, and probably numerous environmental influences that remain obscure.

We offer several generalities, which, like all generalities, have many exceptions. These generalities apply to the most damaging root diseases in western Montana, northern Idaho, eastern Oregon, and eastern Washington. The pathogens are *Armillaria obscura, Phellinus weirii,* and *Fomes annosus.*

Generality I. Douglas-fir and true firs are the most damaged species.

Generality II. Root disease mortality in Douglas-fir and true firs will be chronic throughout the life of the stand.

Generality III. Root disease mortality in pines, western larch, western redcedar, Engelmann spruce, and western hemlock will decrease after age 20 to 30.

Generality IV. Timber cutting will increase pathogen activity on root disease-infested sites. (Corollary to Generality IV. Root disease damage increases with each generation in managed stands of susceptible species composition.)

PRODUCTIVITY REDUCTION

Tree mortality is the most important source of reduced productivity on root disease-infested sites. How much reduction? In 80-year-old mixed conifer stands of the Marie Creek compartment of the Idaho Panhandle National Forests (Hagle 1985), basal area on the most productive habitat types varied from 178 ft^2 per acre in stands lightly infected down to 90 ft^2 per acre in the most heavily infected stands (fig. 1). The 241 merchantable stands in the compartment averaged a 3.9 root disease damage rating on a scale of 0 (no damage) to 9 (no live overstory trees left). Half of the stands had ratings of 4 or higher. Damage ratings of 4 were associated with 27 percent reduction in basal area.

Fourteen white fir and grand fir stands surveyed in Oregon and Washington had lost 8 to 39 percent of basal area to root disease mortality (Filip and Goheen 1984). Fifty-five percent of the trees in a mature white fir stand in Oregon had been killed by root disease in the 20 years

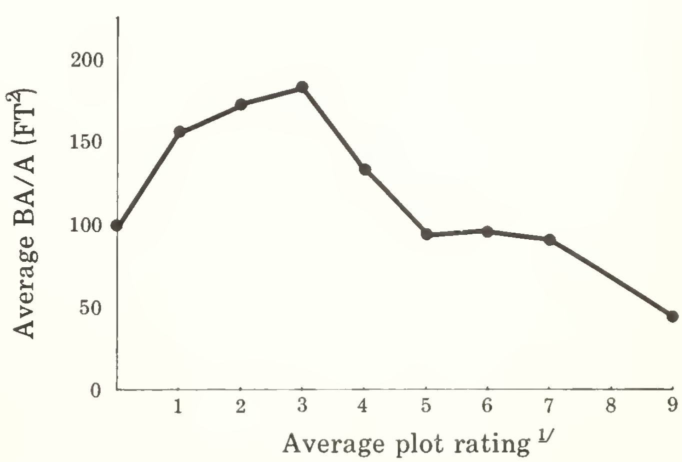

Figure 1—Average basal area per acre by plot rating for stands in Marie Creek and Alder Creek compartments, Fernan Ranger District, Idaho Panhandle National Forests. Plot rating on scale of 0-9: 0—no root disease, 9—root disease center with no living Douglas-fir or true firs remaining in the overstory.

immediately preceding the survey. Recent surveys on the Fremont and Ochoco National Forests in eastern Oregon showed high levels of root disease-caused mortality (Schmitt and others 1984). Of 98 randomly selected stands with susceptible tree species in the overstories and varying past management histories, virtually all were found to have root disease-caused mortality. Amount of loss varied from 2 to 23 percent of the trees (average 12 percent). Live basal area in root-diseased portions of stands averaged 45 percent lower than that in healthy portions of stands.

Though forest-wide surveys have not been done in other eastside Oregon and Washington forests, numerous individual stand surveys show that mortality of 10 to 80 percent of the trees with 10 to 60 percent basal area reductions is common. This suggests that losses similar to those measured on the Fremont and Ochoco National Forests may occur in other eastside Oregon and Washington forests.

Of 728 stands in the Crow Creek compartment of the Lolo National Forest (western Montana), 23 percent were classified as having some level of root disease (Byler and others 1987). Plots with root disease averaged 9-27 percent lower board foot volume than those that had no root disease.

SPECIES COMPOSITION

A general shift in species composition has occurred in the past few decades in the Intermountain Northwest. Sites that were once dominated by pines or western larch are now stocked with more climax species, mostly Douglas-fir and true firs. This change is largely due to fire exclusion (Arno 1980; Gruell and others 1982). Stand composition changes also resulted from extensive selective harvesting of ponderosa pine, western white pine, and western larch.

The relative proportions of Douglas-fir and true firs in a stand appear to greatly affect the degree of disease development in that stand. In the 728 stands of the Crow Creek compartment (Lolo National Forest), a strong relationship was found between species composition and percentage of trees damaged (Byler and others 1987). Where Douglas-fir and grand fir comprised more than 40 percent of the basal area, percentage of plots infected was significantly higher than in stands with lower proportions of Douglas-fir and grand fir. The relationship between percentage composition of Douglas-fir and grand fir and percentage of trees damaged is not simply an artifact of having relatively fewer of the more susceptible trees in the stand. The proportions of Douglas-fir and grand fir damaged increase as well.

In theory, this relationship can be explained on the basis of pathogen movement from tree to tree being more difficult if the fungus must contend with less susceptible tree species slowing or blocking its progress. Other theories to explain this phenomenon have been proposed, but this one seems to be the most popularly accepted.

The relative proportions of Douglas-fir and true firs may also have an effect. Douglas-fir comprises 37 percent of the trees in the 6,000 acres of Marie and Alder Creek compartments of Fernan Ranger District (Hagle 1985). Twenty-seven percent of the trees are grand fir. The annual mortality rate of Douglas-fir (4.1 percent) was nearly twice that of grand fir (2.2 percent) from 1984 to 1985. This annual rate of mortality is also reflected in the relative proportions of standing dead: 31.2 percent for Douglas-fir and 15.1 for grand fir of the total of each species, respectively. This may indicate that Douglas-fir is roughly twice as susceptible to root disease as grand fir. This relationship was also true in the Crow Creek compartment (Byler and others 1987). Here, 30 percent of the Douglas-fir was either dead or symptomatic of root disease while 18 percent of the grand fir was affected. Subalpine fir was killed at less than half the rate of grand fir in Marie Creek and Alder Creek compartments. Thus, the relative proportions of Douglas-fir, grand fir, and subalpine fir may also be an important factor in determining stand losses to root disease in northern Idaho and western Montana. The pattern appears similar in northeastern Washington, where stand compositions are comparable to those found in northern Idaho.

In eastern Oregon and southeastern Washington, grand fir is more damaged by root disease than is Douglas-fir. This includes infection and mortality caused by *Phellinus* (Filip and Schmitt 1979; Filip and Goheen 1984; Filip 1986), *Armillaria* (Filip and Goheen 1984; Filip 1986) or *Fomes* (Filip and Goheen 1984; Filip 1986). Subalpine fir and other true fir species in Oregon and Washington are not as susceptible to *Phellinus* as is white fir, grand fir or Douglas-fir (Hadfield 1985).

Age has considerable influence over susceptibility of conifers other than Douglas-fir and true firs to armillaria root rot. Byler and others (1985) found no significant difference in percent damaged by *Armillaria* between Douglas-fir/true firs and pines/larch in sapling-size stands. Morrison (1981) based management guidelines for armillaria root rot on the expectation that pines and larch tend to increase their resistance after about 30 years of age. This is in keeping with most of our observations. Additionally, it appears that western redcedar, western hemlock, and Engelmann spruce are most often damaged as saplings; presumably resistance increases with age.

SITE CHARACTERISTICS

Habitat type is at least loosely related to both incidence and severity of root disease in some (perhaps most) areas of the Intermountain Northwest. In the Crow Creek compartment on the Lolo National Forest, the more productive habitat types contained most of the severely damaged stands (Byler and others 1987). Douglas-fir, grand fir, western redcedar, and western hemlock habitat types had the highest incidences of root disease. Mountain hemlock and subalpine fir types had lower incidences and impact of root disease. Stands rated for root disease severity in a compartment of the Idaho Panhandle National Forests revealed a strong relationship between the more productive habitat types and greater severity of root disease (Hagle 1985). Here, grand fir and western hemlock habitat types had significantly higher severity ratings than Douglas-fir habitat types, although the incidence of root disease on plots of all three habitat types was similar. Williams and Marsden (1982) found that the Douglas-fir/ninebark habitat type had a higher probability of root disease center occurrence than all other types on the Coeur d'Alene occurrence than all other types on the Coeur d'Alene National Forest in northern Idaho. Soils with lowest year-around moisture availability occurring on wet aspects and those with highest moisture availability on dry aspects were most consistently associated with root disease center occurrence.

CUTTING HISTORY

Evidence indicates that stumps serve as food bases for root disease fungi (Filip 1979). Pathogens utilize the stumps and large roots of cut trees to maintain themselves on a site. They may require food bases to have the "inoculum potential" or energy to invade a live host. Whatever the role of stumps, they are definitely a substrate in which the pathogenic fungi are readily found after stand removal. For example, 25 of 59 stumps per acre (42 percent) had active *Armillaria* mycelia 2 years after a sanitation logging of Hellroaring Unit, a Douglas-fir, ponderosa pine, western larch stand on the Flathead Indian Reservation in western Montana. Douglas-firs with symptoms of disease were removed leaving 88 percent Douglas-fir and 12 percent pine and larch—a total of 146 trees per acre. Six years after cutting, 28 of 59 stumps per acre (47 percent) had active *Armillaria* (fig. 2). The proportion of the live stand with obvious root disease infection has steadily increased from 8 percent in 1981 to 21 percent in 1986 despite the death of 14 percent of the stand over that period (fig. 3). With an average stand diameter of 11.7 inches (29.7 cm) and an average age of 53, the volume losses are already substantial and sure to increase before the targeted rotation age of 90 is reached. In fact, the stand may already be considered to have culminated because of the high rate of root disease-caused mortality. The stand had an obvious root disease problem before it was sanitized.

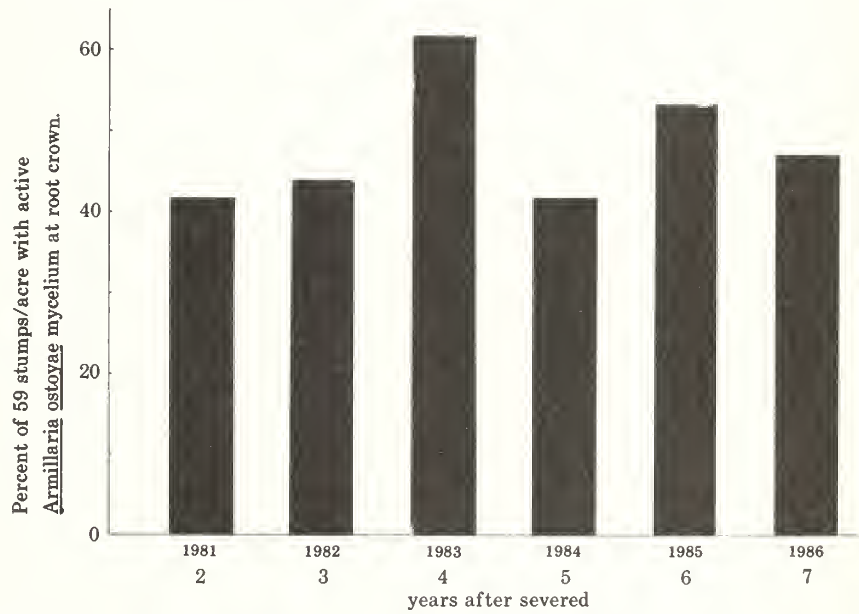

Figure 2—Average stump diameter—11.1 inches. Trees severed in 1979: species—91 percent Douglas-fir.

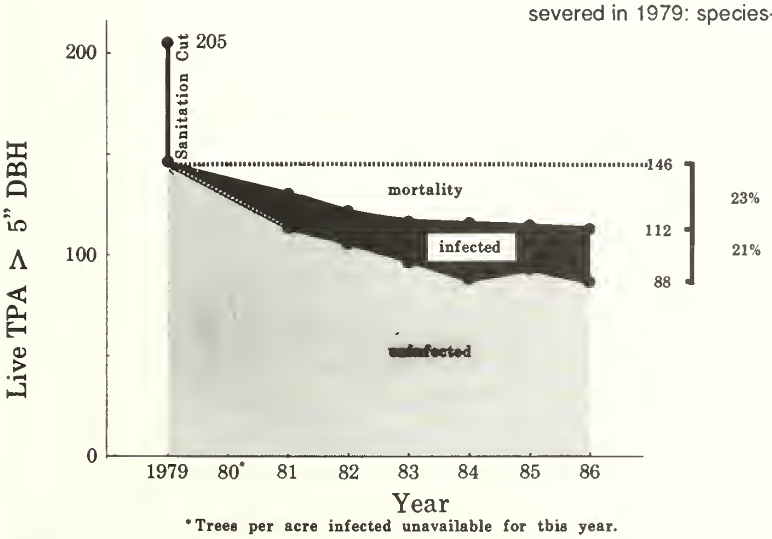

Figure 3—Live infected and live apparently uninfected trees per acre by year following sanitation cutting in Hellroaring Unit. Average d.b.h.—11.7 inches, Average age—53. (Trees-per-acre unavailable for 1980.)

The sanitation was intended to bring the disease under control by removing all trees with detectable infection and increasing the overall vigor of the stand by leaving only healthy-appearing trees. The treatment is now obviously a failure.

Numerous examples of this sort can be cited from the Intermountain Northwest. It appears that some sites, perhaps some habitat types, are "prone" to root disease problems and regularly respond this way to partial stand removal when Douglas-fir and true firs comprise a majority of the leave trees.

In eastern Oregon, stumps are important entry courts for *F. annosus*. In a recent survey, 5 percent of true fir stumps on the Ochoco National Forest and 45 percent of those on the Fremont National Forest were found to be infected by *F. annosus*. Mortality of standing trees was centered around large infected stumps (18 inches [45.7 cm] or greater in diameter). Annosus root rot was much more frequently encountered in stands that had harvest entries than in unentered stands and was most common in stands with two or more entries. However, commercial thinning that left stumps smaller than 18 inches in diameter did not increase annosus root rot.

Precommercial thinning in eastern Oregon produces four general types of effects with regard to root disease: (1) It does not decrease root disease caused by *P. weirii* or *F. annosus* in pure stands of susceptible species. It may not actually cause real increases in spread rates but often has this appearance because mortality of individual trees represents a greater percentage of the total. (2) It has resulted in significant decreases in armillaria root disease mortality in some stands. (3) In other stands it appears to have no effect. (4) It can result in significant decreases in loss to root diseases in mixed stands when Douglas-fir and true firs are reduced to minor stand components. These observations may hold true for northern Idaho and western Montana. Permanent plots to evaluate the effects of precommercial thinning have recently been established by Byler and others (1985). Results so far appear inconclusive; 1 and 2 years after thinning half of the thinned stands had higher mortality rates and half had lower rates compared with their paired, unthinned controls.

Stump-centered mortality is seen to increase with each successive cutting in a root disease-infected stand. Damage (basal area diseased) in two successive Douglas-fir stands on a site in western Oregon increased relative to comparable stand ages (Tkacz and Hansen 1982). At 60 years of age the laminated root rot-affected area of the stand was equal to that of the previous 300-year-old stand and continually increasing. Prospects for a third generation of Douglas-fir on the site would be poor.

Where mortality was monitored for more than 25 years in a stand, the area of armillaria root disease infestation following cutting remained essentially constant, but as the regeneration matured volume losses more than doubled from 6 percent up to 13 percent (Shaw and others 1976). As the stand continues to mature, losses are expected to increase. As the trees grow larger the food base grows more substantial, providing the means by which the fungus can better survive on the site. This phenomenon is observed commonly in root disease-infested sites. It is a wave pattern of mortality that takes place as stands on infested sites reach pole size. Most trees are killed before they become merchantable and are replaced by abundant regeneration; mortality then slows until some trees reach pole size and their root systems become large enough to provide the food base to fuel another wave of mortality.

This pattern is also clearly observable on sites that have no cutting history but have large infection centers. In this situation the wave occurs on much more restricted areas at a time because it is the slow advance of the fungus into the nondiseased portion of the stand that is responsible for the initial wave of mortality. This is followed by a wave of regeneration, slow mortality of seedlings and saplings, and finally a second wave of mortality as trees reach pole size. The result is a stand with zones that are representative of the temporal sequence of root disease development in a stand. These zones form concentric rings from the center to the perimeter of the disease-affected area.

The primary difference between the wave pattern in root disease-infected stands on sites with no cutting history and that on sites that have been cut is that the cutting sets the time of the wave by creating an immediate food base and stimulating the regeneration that will feed the next wave. This was the pattern observed by Shaw and others (1976).

Byler and others (1987) observed the effects of cutting history on incidence of root disease in 728 stands of Crow Creek compartment, Lolo National Forest. Ten percent of the stands had some history of cutting. In these, the proportion of plots with root disease damage was roughly double that of plots in stands with no history of tree harvest.

Stump extraction by pulling or bulldozing has been an effective method for reducing inoculum and subsequent root disease damage following tree harvest (Hadfield 1985; Roth and Rolph 1978; Thies 1984). High value sites on gentle terrain may be economically treated in this manner, particularly where Douglas-fir is the only desirable species to manage. However, few sites in the Intermountain Northwest have this combination of characteristics.

FIRE EFFECTS

High levels of *Armillaria* infection and wound-associated decay by other fungi have been found in true fir stands after prescribed underburns in southeastern Oregon (Goheen and others 1985). The damages are sufficient to recommend that true fir stands not be underburned.

Neither wildfire nor site preparation by broadcast burning has significantly reduced root pathogen inoculum on sites. Penetration of heat from fire is probably insufficient to sanitize root pathogen-infested sites (Debano and others 1976), and chemical changes due to ash leachates are not likely to greatly affect root pathogenic fungi (Reaves and others 1984). However, indirect effects such as changes in stand composition may be the most important natural control of root disease.

Root parasitic fungi depend on host tissue for survival. Although root disease fungi are especially long lived in stumps and large roots on infested sites, if the roots of a live host do not contact inoculum before the food base is decomposed the fungus must eventually decline in prevalence on the site. Tree species composition is often shifted by fire toward seral species that are, perhaps coincidentally, more root-disease tolerant in most areas of the Intermountain Northwest than are those closer to the ecological climax. In this event, the pathogen probably maintains itself on the site but fails to reach epidemic levels. Fire exclusion has historically shifted species composition of forested lands in the Intermountain Northwest more generally toward climax than that which was recorded as common at the turn of the century (Arno 1980; Byler 1984; Gruell and others 1982).

CONCLUSIONS

We believe that a dramatic increase in root disease incidence and severity has occurred in the past 4 or 5 decades. The primary reasons for this change have been fire exclusion and selective cutting, which have shifted tree species composition toward the more root disease-susceptible Douglas-fir and true firs; recent emphasis on planting Douglas-fir in some areas; and the harvest of timber which creates stumps—food for pathogenic fungi as well as infection courts for *F. annosus*.

Silvicultural control of root disease requires reversing these patterns, primarily by manipulating tree species composition to develop stands less favorable for root pathogens. Stand prescriptions calling for no more than 40 percent composition of Douglas-fir and true firs in the mature stand basal area have a better chance of avoiding severe losses and continued heavy infestation of sites with root disease pathogens in Idaho and Montana. For *Phellinus*-infested sites in eastern Oregon, Douglas-fir and true firs should be eliminated from stands as nearly as practicable. Thinning, where Douglas-fir or true firs comprise a majority of the leave trees, appears to aggravate root disease problems and should be avoided. This becomes more important as the trees which will be left as stumps, become larger.

Several recent reviews of management techniques for *Armillaria* (Morrison 1981; Shaw and Roth 1978; Wargo and Shaw 1985; Williams and others 1986) and *Phellinus* (Hadfield 1985; Nelson and others 1986; Thies 1984) root diseases have been published. These are must-reading for forest stand managers. They cover approaches we have mentioned plus some additional methods for root disease control that have been effective under some conditions. We consider those discussed here to be the most economically and physically practical under conditions found in forested stands of the Intermountain Northwest.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from B. Quinn)—Do root disease centers found in undisturbed stands expand in size over time (without harvest activity) or do the "waves" just wash back and forth within the center? If centers are expanding, how fast and why aren't whole (older) forests infected?

A.—Root disease centers do expand at margins unless blocked by nonhosts or other conditions unfavorable for growth of the pathogen(s). Root rot centers have been measured to expand at rates of about 1-2 ft/year at the margins. This rate probably varies quite a bit from year to year. So what stops it? We think that changes in species composition on sites and between sites are primary natural limiting factors for root pathogens. See especially our discussion of species composition.

Q. (from Al Barclay)—What is the lifespan of the inoculum in the soil and roots for *Phellinus* and *Armillaria*? From your description of successive "waves," I get the impression that you feel it is relatively short.

A.—Longevity of inoculum on a site varies in proportion to the size of the stump or other food base and according to the pathogen(s) involved. Hansen (Canadian Journal of Forest Research, 9: 484-488; 1979) found *P. weirii* surviving for at least 50 years in stumps averaging about 100 cm in diameter. Wallis and Reynolds (Canadian Journal of Botany, 43: 1-9; 1965) found *P. weirii* surviving in roots as small as 1.5 cm diameter 11 years after tree death. For *Armillaria*, survival times are thought to be somewhat shorter and overall more dependent on food base size. Waves in disease centers probably do not mean that microsites become free of inoculum for periods but rather that the potential for the inoculum present to kill trees changes in a cyclic manner. The key here is a matter of population dynamics of both fungi and trees. At 50 years after harvest 26 percent of those 100-cm stumps examined by Hansen had live *P. weirii,* while at 20 years 96 percent of stumps of slightly smaller size had viable mycelia. Mortality in root disease centers is continual but not constant. It is the episodes of particularly high mortality rates that appear as waves.

Q. (from Robbin B. Boyce)—Is there any evidence of a correlation between root diseases and other pathogens, such as dwarf mistletoe in Douglas-fir?

A.—Most of our evidence of interactions are of root rot pathogens found together in disease centers such as *Fomes annosus* with *Armillaria obscura, Phaeolus schweinitzii* with *A. obscura, P. weirii* with *A. obscura,* and *Verticicladiella wageneri* with *A. obscura.* We have long theorized that root pathogens, especially *Armillaria*, will kill weakened trees, but in the Intermountain Northwest we lack sufficient evidence to suggest this is usually the cause of attack.

Q. (from unknown)—Do you believe there is much benefit in reducing sources of inoculum by prescribed burning as opposed to dozer piling?

A.—Burning probably has little effect on inoculum loads in stumps. See our discussion of fire effects. Heat penetration is limited and attempts to demonstrate effects of chemical changes following fire have been unsuccessful in vitro. For example, a recent study using one isolate of *Armillaria* from western hemlock and one from ponderosa pine was inconclusive in showing effects of ash leachates in vitro (Reaves and others 1984, in reference list). Variation between isolates was greater than that among treatments. Although identified as *A. mellea*, the isolates may have been *A. obscura*—a fact that might have allowed us to apply the information to the *Armillaria* root disease we see in Intermountain Northwest conifers. The question of burning effects warrants further investigation, but at this time we are inclined to say there is no measurable effect. Additional evidence of this comes from sites that have been broadcast burned and support large inoculum loads in the charred stumps 20 years or more after site preparation.

Q. (from Rob Mrowka)—In many of the forest plans in (Forest Service) Region 6, an "extended shelterwood" is prescribed for analysis areas allocated to visual, wildlife, riparian management, and so on. Quite often these stands have root rot problems and rot-susceptible species would be retained in the overstories and understories. Have you any feel for volume losses that can be expected, when this "strategy" is implemented?

A.—Much will depend on the distribution and intensity of root disease in these stands before cutting, the species composition, size, and, to some degree, the pathogen species present. We seldom measure losses of greater than 5-6 percent per year in overstories that are 60-100 years old. This is on a stand basis. Some areas within an infested stand will have more mortality; others will have less. Depending on how prolonged the period of retention of the overwood would be, this may or may not be a significant volume loss. Disease will almost certainly spread to greater extents in the understory if susceptible species comprise most of the trees.

Q. (from Barbara Gardner Grahn)—It was recommended by another forest pathologist to treat white fir and Douglas-fir stumps with borax after cutting to prevent the spread of *Fomes annosus*. Will this do the trick?

A.—Borax has been a very effective treatment to prevent stump infection where roots of trees to be cut are not already infected. This is an important point because annosus root rot commonly develops in the roots of white firs. Borax has been used successfully in pine stands, but there appear to be some important differences in methods of disease development between pines and firs. Additional stand infection will occur as a result of stump infection in thinned true fir stands but may actually be an unimportant source of infection compared with the spread of infection occurring between previously infected stumps and crop trees.

Q. (from W. Young)—What potential does stumping a site after logging have in minimizing the transfer of root disease to the new crop? If it has potential, what should be the delay period between stumping and regenerating?

A.—Stump removal has been a very effective means of reducing inoculum and, as much as we can measure so far, reducing damage to the next crop. Terrain, stump size, and economics are the main limiting factors for stumping. Raking of large roots up to about 3 ft underground after stumping will further reduce inoculum. British Columbia Forestry Service has been a leader in developing and testing methods for stumping and root raking to control *Phellinus* and *Armillaria*. No doubt Bill Bloomberg at the research station there in Vancouver could give you advice on the subject. A delay period before planting is not recommended. Further loss of inoculum in missed roots will take many years and is not worth waiting for. The site cannot be totally sanitized, so some level of damage will have to be accepted. We are banking that the level of damage will not significantly reduce productivity.

Q. (from Dennis R. Parent)—In high site western redcedar/*Pachistama* habitat types what species would you recommend to plant besides western larch? Ponderosa pine is not acceptable, and western hemlock and western redcedar are not easily planted. Give me some ideas on what species composition to plant on high sites in northern Idaho.

A.—Western white pine is a favored species if you are going to plant (rust-resistant stock, of course). Lodgepole pine might be considered if suited to the site and product goals. In northern Idaho you probably have *Phellinus* or *Armillaria* (or a combination of both). Douglas-fir is more damaged by these pathogens in northern Idaho than is grand fir, so you may want to manage some grand fir natural regeneration **in combination with less susceptible species**. On cedar/pachistama types in northern Idaho natural regeneration is usually easily obtained with grand fir, western hemlock, and western redcedar typically most abundant. If you plant white pine, lodgepole pine, or western larch and manage a component of the other three you will have a sturdy mixture with respect to root disease. (Engelmann spruce is also fairly resistant if it is suited to the site.) John Schwandt is the State forest pathologist for Idaho located in the Department of State Lands Forestry Office in Coeur d'Alene. He is very knowledgeable about root disease and can help you in species selection as well as other problem areas.

Q. (from Roger Gowan)—In root rot pockets with mixed species pine, grand fir, Douglas-fir, western redcedar what is the lowest trees per acre you would recommend thinning in? If all species present were susceptible to root rot, would you not thin and carry a higher stocking or just thin to a higher stocking?

A.—This is a complex question; it depends largely on the current condition of the stand. The species in jeopardy are Douglas-fir, primarily, and grand fir to a lesser degree. As the stand develops in the root disease-infested area, Douglas-fir and grand fir will tend to decrease in importance in the stand. For example, in some permanent plots on the Selway District, the Douglas-fir component has dropped from approximately 600 trees per acre planted in 1957 to a current 130 trees per acre in root disease-infested areas. Douglas-fir now comprises only 17 percent of the trees in the plots with mostly cedar ingrowth making up the remaining 83 percent. If you consider the species composition of mature stands on the Selway District, you see that Douglas-fir is a minor component in all but a few stands. This sort of example suggests that Douglas-fir should not be targeted to be more than a minor component of the stand. If you can thin favoring pines and cedar first, grand fir second, and Douglas-fir last, and if this system would yield a Douglas-fir component that is no more than 10 to 20 percent of the stand after thinning, you can probably base your judgment whether or not to thin on stocking guidelines you use now. If the stand is entirely Douglas-fir and grand fir you will want to be much more careful about thinning. It appears on the Selway District that you can look forward to losing most of the Douglas-fir component on root disease-infested sites. The grand fir will hold up better, but mortality may still become a productivity-limiting factor in this species. If root disease is obvious in the stand at 10-20 years of age it may not prove worth the investment to thin such a stand; allow it to thin itself. We would like to suggest that you thin only the thick patches since these are probably between disease pockets, but there is the possibility that annosus root rot will be spread this way. So it is probably better to defer treatment, at least until we have better information in this regard.

IMPACT AND REDUCTION STRATEGIES FOR FOLIAGE AND STEM DISEASES AND ABIOTIC INJURIES OF CONIFEROUS SPECIES

Stan Navratil
Imre E. Bella

ABSTRACT

Intensive cultural practices and departures from the relative stability of old-growth stands result in changes in the occurrence of foliage and stem diseases. Practices that enhance juvenile growth may increase or reduce infection rates. Density management in plantations and young stands is a powerful tool for controlling stem diseases. For many diseases the relationships of culturally induced conditions and development of epidemics are unknown. Creation of pest-resistant stands will depend on synthesis of current and new knowledge from related disciplines. Lack of disease impact data hinders economic assessment and development of long-term, integrated control strategies.

INTRODUCTION

During the last several decades extensive natural stands of mountain coniferous species have been harvested and replaced by stands managed to various degrees of intensity. In new stands the timing and method of stand establishment, species composition, density, and juvenile growth rate are controlled with the aim of achieving rapid stand establishment and increased yield. A range of silvicultural practices, including site preparation, prescribed burning, planting, vegetation control, fertilization, and precommercial thinning is used for this purpose.

Intensive cultural practices and departures from natural stand characteristics may increase the risk of disease occurrence. We do not know enough to clearly identify the conditions that increase or decrease the occurrence of diseases, nor can we predict the magnitude of the effects.

Experience in the southern United States and in Europe indicates that diseases that are endemic and cause minor losses in immature, naturally regenerated forests may cause serious losses in young plantations and immature stands of artificially regenerated forests.

There is no doubt that successful forest stand and disease management must be based on an understanding of the principles governing the stability of ecosystems and the host-pathogen-environment interaction. Unfortunately, for many diseases our knowledge of the effects of various practices on this interaction is inadequate. We need to understand the conditions that favor epidemics and increase the magnitude of losses. We need careful operational trials and research studies to compare the influences of various practices.

In this paper we synthesize current knowledge on the interaction of cultural practices and potentially important foliage and stem diseases and we present examples of control strategies for diseases where there is sufficient information.

In preparing this paper we found a general scarcity of disease management strategies that could be incorporated into current silviculture and forest management practice.

Our literature review and talks with other workers in the field indicated several major foliage and stem disease problems requiring attention. Among stem rusts these include western gall rust affecting lodgepole pine and ponderosa pine, white pine blister rust, comandra blister rust affecting lodgepole pine and ponderosa pine, and stalactiform rust and sweet fern rust affecting primarily lodgepole pine.

From the large number of foliage diseases we selected only those known to cause serious damage, although for most of these the available information is inadequate to allow integration into current cultural practices. From other groups of diseases we selected atropellis canker and winter drying, which may pose problems in specific locations.

Since a large amount of information on white pine blister rust and its control measures is already available, we focus here only on forest management implications.

STEM RUSTS

Epidemiology of Stem Rusts and Forest Management Implications

Hiratsuka and Powell (1976) and Ziller (1974) provide excellent discussions of stem rust cycles and some information on forest management implications. Rust outbreaks are determined by an intricate interaction of host, pathogen, and environment. For rusts that have alternate and major hosts the processes are particularly complicated, involving three dissemination and infection stages, all influenced by the environment. In most years the combination of factors is unfavorable to large-scale infections. In years of favorable conditions a burst of infection occurs followed by years of low infection rate.

The forest manager needs to know the time, duration, and extent of these outbreaks. Major outbreaks of comandra blister rust in the West come decades apart (Krebill 1965) but can be widespread. The extent of outbreaks may vary with geographical region. For western gall rust in the central Rocky Mountains, a wave of infection can occur over an area of a few square miles; in the Northwest it can extend over a larger area (Peterson and Jewell 1968).

The delicate balance of host, pathogen, and environment can be easily disturbed by changes in environmental and host conditions. These are fungus and host specific and may be related to site factors. Cultural practices that affect host phenology or environment can either increase or reduce infections.

Indications are that pines in planted and managed stands are more severely attacked by rust fungi than trees in naturally regenerated areas (Hiratsuka and Powell 1976; Krebill 1975; Mielke and others 1968). Higher rust intensity in plantations could be attributed to four factors: first, changes in environmental conditions affecting infection cycles and tree growth; second, an increase in alternate hosts; third, the use of susceptible or low-resistance genotypes; and fourth, the use of planting stock infected in the nursery.

Site preparation and fertilization practices during the plantation establishment phase that affect duration, rate, and amount of shoot elongation can influence the susceptibility of the host to stem rust infections. This has been shown for fusiform rust on loblolly and slash pines (Blair and Cowling 1974).

Juvenile spacing and commercial thinning can influence infection levels in stands in two ways. If thinning includes a sanitary removal of diseased trees it can substantially reduce infection and losses in the thinned stand. Also, changes in crown size, amount of branching and foliage, tree growth rate, and microclimate after thinning may affect infection rates.

Use of resistant stock in plantations may decrease the level of infection. Variation in susceptibility of pine species and provenances has been found for sweet fern rust (Hunt and van Sickle 1984; Tauer 1978), stalactiform rust (van der Kamp 1981), and western gall rust (Hoff 1986).

Western Gall Rust (*Endocronartium harknesii* [J. P. Moore] Y. Hiratsuka)

Western gall rust, a pine-to-pine rust, is potentially more threatening to lodgepole pine and ponderosa pine than other stem rusts because its distribution is not limited by the availability of an alternate host and environmental conditions favorable to infection are needed only once a year.

A Province-wide survey of young lodgepole pine stands in the interior of British Columbia found 10 percent of the trees infected, although disease incidence was lower in some geographical regions such as the East Kootenays (van der Kamp 1981) than in others. In west-central Alberta, in stands of approximately the same age (15 to 25 years), the infection levels were higher, between 18 and 28 percent (Bella and Navratil unpublished results). The Alberta survey included lodgepole pine stands with ages from 7 to 26 years. This survey showed that gall rust infection increased with age of the stand (fig. 1). In 20-year-old

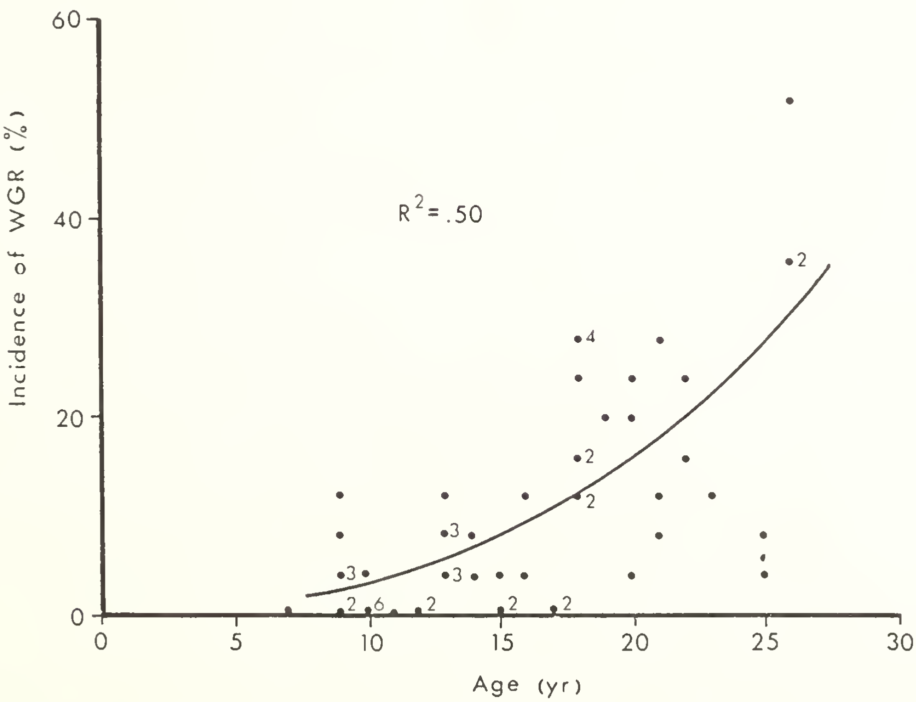

Figure 1—Incidence of western gall rust in relation to age in second-growth lodgepole pine stands in west central Alberta.

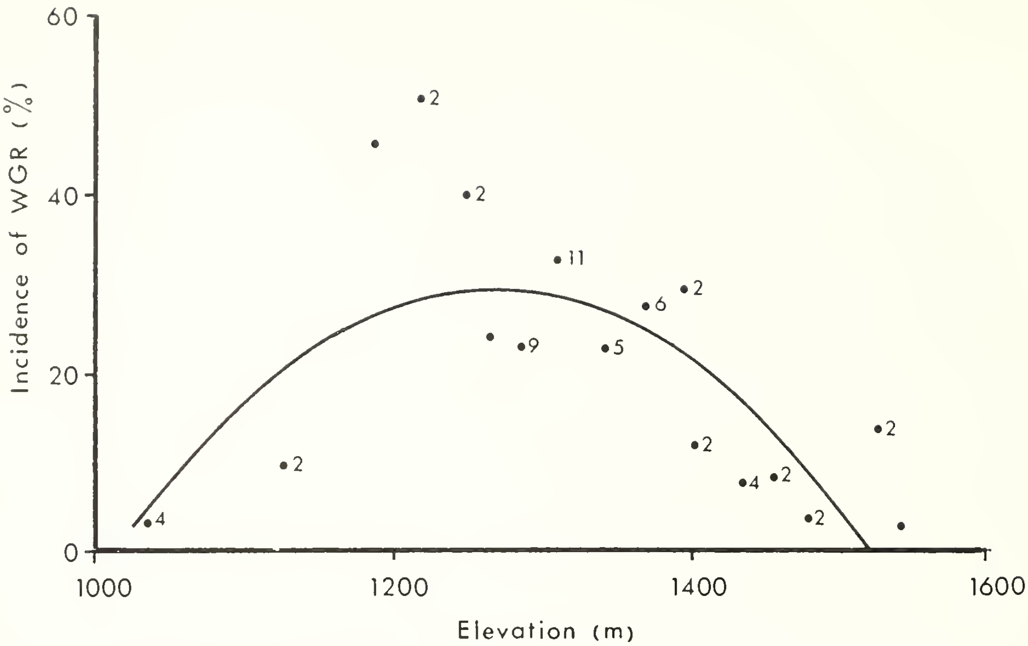

Figure 2—Incidence of western gall rust in relation to elevation in second-growth lodgepole pine stands in west central Alberta.


Figure 3—Lodgepole pine killed by heavy stem infection of western gall rust.

stands about 20 percent of the trees were infected. These rates compare well with results published by Bella (1985a) for the same general area. In this survey gall rust infection rates of 30 percent for thinned stands and 18 percent for unthinned stands were found in age classes between 15 and 25 years.

Some site variables significantly ($P < 0.01$ level) influenced infection levels. For example, east slopes had consistently higher infection levels of western gall rust than north or south slopes. In stands over 15 years old the disease incidence was 50 percent on east slopes, compared to 26.6 percent on north slopes and 33.2 percent on south slopes. Elevation also had a highly significant effect ($P < 0.01$ level) on the incidence of western gall rust. Stands in middle elevations (1,200 to 1,300 m, or 4,000 to 4,400 ft) had the highest incidence of western gall rust infection among those surveyed (fig. 2).

Because of aging and gradual disintegration of gall tissues, trees with stem galls usually die at a young age (fig. 3) or break later. Thus the mortality rate due to stem infections can be high in young stands. We found mortality as high as 40 percent of all trees in a severely infected stand. Dead trees had an average of three stem galls, compared to an average of 0.1 stem gall observed on live trees.

Considering only potential crop trees, mortality in second-growth stands was found to be relatively low, between 1 and 2 percent (Bella and Navratil unpublished results; van der Kamp 1981). Therefore, it does not appear that western gall rust is a major mortality factor in stands over 20 years old.

Although mortality losses may be at an acceptably low level for crop trees, reduction in tree growth and yield caused by western gall rust may be substantial. A study based on stem analysis of dominant and codominant trees in 16- to 22-year-old lodgepole pine stands showed that there was no reduction in tree volume growth in the first 5-year period after the initial wave of heavy infection, approximately 15 percent reduction in growth in the second 5-year period, and an average of about 25 percent reduction in growth in the third 5-year period (Bella and Navratil unpublished results).

Based on this information, the total reduction in volume yield at 40 years was 11 percent on medium sites and 8 percent on high productivity sites. This reduction in volume growth is great enough that it could at least delay commercial thinning operations in infected stands.

Studies in Canada and the United States indicate that western gall rust is a serious disease in lodgepole pine stands regenerated after harvest, but we have no information to determine whether the infection levels in these stands differ from those in stands originating after fires. Western gall rust infects trees through tender shoot tissues in their first season; cultural practices that stimulate shoot growth may increase the area of tissue surface open to infection. Thus site preparation leading to rapid nitrogen mineralization and fertilization of sites may increase infection levels; arbitrary fertilization on rust-prone sites should be avoided.

When stands are established at wide spacing there is no opportunity to later remove infected trees without significantly lowering stand yield. Conversely, high-density regeneration with a surplus of trees offers an opportunity to remove infected trees in thinnings without reducing yield. As the larger, faster growing trees are more prone to western gall rust infection (Bella 1985b; Gross 1983), special effort should be made to identify infected trees for removal. Otherwise, spacing operations that favor only larger trees in the stand, with no regard to western gall rust infection, may in fact increase the proportion of infected trees in spaced stands (Bella 1985a; van der Kamp 1981). Leaving infected trees during thinning may result in volume yield reduction of about 10 percent during the 20-year period after a high intensity infection (Bella and Navratil unpublished results).

White Pine Blister Rust (*Cronartium ribicola* J. C. Fisch. ex Rabenh.)

White pine blister rust infects western white pine, whitebark pine, and limber pine throughout their ranges. The severity of infection and losses vary with stand age, tree size, and geographical region.

In most of the inland western white pine zones of Idaho and Montana, temperature and moisture conditions are near optimum for infection and losses have been extensive (for example, Hoff and others 1976). Compared to Idaho's infection incidence, most of the interior white pine zones of British Columbia are low hazard (Hunt 1983). The difference can be explained by the occurrence of *Ribes* species that differ in their capacity for production of spores and site conditions among many other factors.

Inability of blister rust control measures to protect white pine in the past led to the suspension of white pine management in National Forests in the Northern Rocky Mountains of the United States (Ketcham and others 1968). Ultimately it was not the amount of money spent and the size of research programs, but Mother Nature that provided the framework for the current integrated control strategy. The present approach is based on mass selection of naturally selected resistant trees. It is noteworthy that some foresters have been using this approach all along (Hoff and others 1976).

Hoff and others (1976) described the method for natural regeneration of white pine that uses a mass selection approach for developing blister rust resistance. In such new stands, after infection and death of susceptible seedlings, the level of resistance is expected to be as high as 50 to 60 percent. These stands can be managed for fiber production, seed production, or both. Furthermore, by using this method the optimal adaptability of new populations will be maintained.

The value of this method can be further enhanced by combining it with other control measures such as hazard mapping, maintaining rapid early growth of white pine, and pruning branches with cankers (McDonald 1979).

Blister rust hazard zones, which are used successfully as a control strategy for eastern white pine (Lavallee 1974; Van Arsdel 1961), have not yet been developed in the West. The development of such a hazard rating system is desirable. It would improve the efficiency of thinning and pruning control measures and the use of low resistance planting stock.

In British Columbia, trees growing on slopes had a higher risk and were subjected to greater infection throughout their life than were trees in dense stands on flat sites. The large variation caused by other factors, however, precluded operational hazard prediction for different stands (Hunt 1983).

In Idaho, McDonald (1979) suggested hazard rating based on the distribution pattern of *Ribes* bushes and white pine trees. Some *Ribes* species known to be prolific spore producers are restricted to stream banks. By not planting white pine within about 40 m (45 yd) of creeks, blister rust infection can be considerably reduced on both *Ribes* and western white pine (Hunt 1983).

Juvenile white pine trees are most vulnerable to damage. Thus breeding for rapid early growth, fertilizing, and using other cultural practices that ensure rapid growth will help the trees pass through their most vulnerable stage quickly with minimum losses (McDonald 1979). Thinning, however, may not reduce blister rust hazard in western white pine stands. If thinning leaves trees with branches infected by blister rust, the thinning may increase the overall infection frequency and the likelihood of stem infections (Hungerford and others 1982; Hunt 1983). Pruning alone and in combination with thinning provides a viable approach for control of blister rust in plantations and naturally regenerated stands. In a mixed stand, white pine should be pruned when the trees are 2.5 to 5 m (8 to 16 ft) tall, removing all branches for at least the first 1.2 m (4 ft) above ground level. Infected branches higher than this should also be removed.

In plantations where white pine is the main species, two pruning treatments are recommended: the first when the trees are about 2.5 m (8 ft) tall, followed by a second pruning when the trees are about 4 m (13 ft) tall (Hunt

1982). Rust control pruning like this also reduces the infection hazard from stem decay fungi and improves wood quality.

Western white pine is a highly variable species and adapts itself well to a wide range of site conditions (Steinhoff 1981). Thus resistant trees and progenies can be used for widely separated areas. Resistant planting stock is becoming increasingly available, and outplantings of such stock have performed well (Bingham 1983). Rust-resistant stock with different levels of resistance should be matched to planting sites with corresponding hazard ratings (Goddard and others 1985).

Disease resistance is expected to improve in subsequent generations, and when this is combined with appropriate silvicultural strategies, disease losses may be reduced to acceptable levels and allow white pine management over large areas.

Comandra Blister Rust (*Cronartium comandrae* Pk.)

In the Rocky Mountains, comandra blister rust causes widespread damage to lodgepole pine and localized damage to ponderosa pine. In the area extending from northern Utah to central Montana, the rust remained endemic for almost 100 years, increased to epidemic proportions between 1910 and 1945, and subsided again in the 1950's. It has been increasing in recent years because of an increase in comandra plants, the alternate host, which previously had been depleted by ground fires (Hardison 1976).

The suggestion that increases in comandra from overgrazing caused serious outbreaks of comandra blister rust in lodgepole pine stands (Kimmey 1958; Mielke 1961) has been refuted by Laycock and Krebill (1967), who found no relationship between grazing and current prevalence of comandra blister rust in lodgepole pine. As one comandra shoot produces as many as 1.5 million spores, a few comandra plants in or near pine stands may provide an ample supply of spores. Furthermore, lodgepole pine stands even several miles from the nearest comandra population can have high rust incidence (Geils and others 1984). Comandra does not grow at high elevations, where lodgepole pine is at little or no risk (Peterson and Jewell 1968).

The comandra blister rust impact on growth and survival of lodgepole pine depends on tree size, age, and canker height. Comandra rust stem infections typically girdle and kill trees. In Wyoming, stem cankers under 6.6 m (22 ft) above ground were usually lethal (Geils and others 1984) (fig. 4).

Top-kill and spike tops from comandra blister rust can cause serious losses. In 60-year-old stands top infections and related crown loss caused a 90 percent reduction in

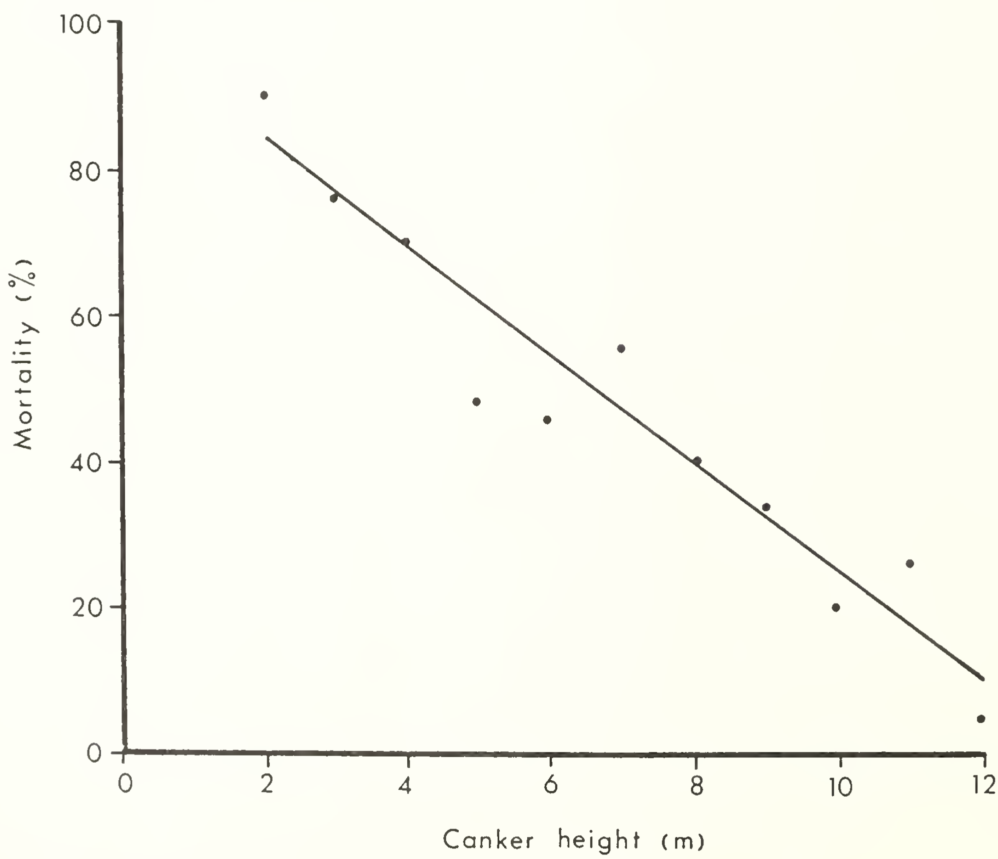

Figure 4—Lodgepole pine tree mortality in relation to the height of comandra blister rust canker (adopted from Geils and others 1984).

stem volume increment (fig. 5) (Geils and others 1984). By killing larger trees and causing spike tops, comandra rust may shift production to smaller stems and delay the time of harvest (Peterson 1962). Geils and others (1984) developed damage rating of comandra rust infected trees to aid in estimating productivity of infected stands. Control strategies specific for this disease are limited, and the optimal stand density and conditions of site as related to the amount of infection and damage are largely unknown. Pruning infected branches may be useful in reducing the chance of stem infection (Johnson 1979).

Stalactiform Rust (*Cronartium coleosporioides* Arth.)

Lodgepole pine is the primary host for stalactiform rust, while Indian paintbrush, cow-wheat, and lousewort are the secondary hosts.

Provenances of lodgepole pine differ in resistance to this rust. In British Columbia van der Kamp (1981) found a remarkable parallel between resistance in a provenance trial and disease severity at the site of seed origin. Provenances with a high incidence of stalactiform rust originated in areas where the disease is rare, in southern and southeastern British Columbia. It appears that planting stock or provenances from areas of low stalactiform rust incidence should not be used where the disease is prevalent. Such seedlings with low resistance may be subject to infections

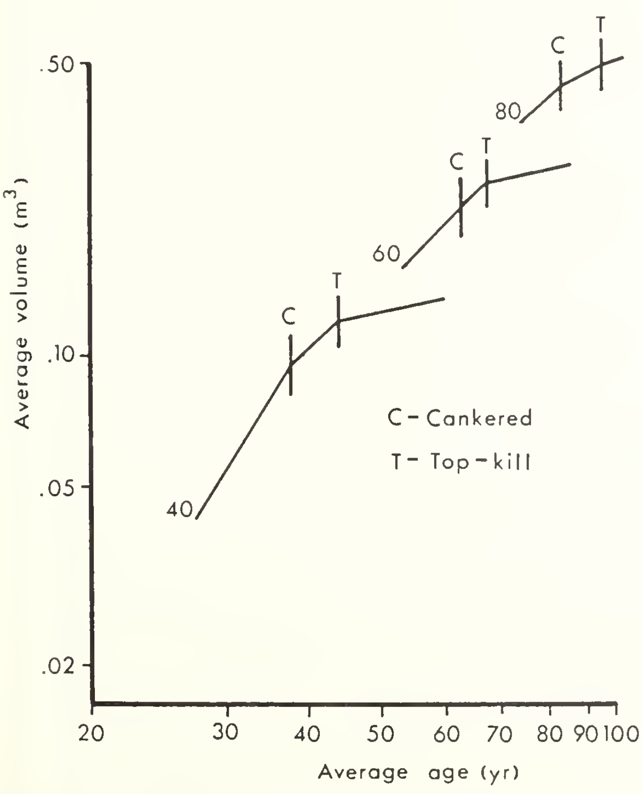

Figure 5—Stand volume in relation to age, and time of infection and top-kill for three lodgepole pine stands in Wyoming (from Geils and others 1984).

up to 20 times the severity of those of local provenance (van der Kamp 1981).

Very little is known about the distribution, severity, and impact of stalactiform rust in the Mountain West. A survey of young natural stands and plantations in the interior of British Columbia showed irregular distribution of this rust, relatively low incidence (0.5 percent) of infection, and a total volume loss under 1 percent (van der Kamp 1981).

In Idaho, stalactiform blister rust is limited to an elevational range of approximately 1,000 m (3,300 ft), between 1,500 m (4,900 ft) and 2,477 m (8,100 ft) (Beard and others 1983). In young lodgepole pine where alternate hosts such as *Castilleja* spp. were present, juvenile spacing increased the amount of infection (van der Kamp and Spence 1986). To recognize and remove infected trees, thinning should be done at maximum canker visibility, which is when aeciospores are released in the late spring or early summer.

Sweet Fern Rust (*Cronartium comptoniae* Arth.)

Sweet fern rust infects ponderosa pine and lodgepole pine. The level of incidence and damage depends on which of the alternate hosts, sweet fern or sweet gale, are present in the area. In areas where sweet gale is the only alternate host, such as British Columbia, Alberta, and western Washington, infections are below 25 percent (Tauer 1978). However, lodgepole pine provenances and lodgepole pine-jack pine hybrids outside the geographic range of sweet gale had very low, or no inherent resistance to the rust (Anderson and Anderson 1965; Hunt and van Sickle 1984; Tauer 1978). This may be an important consideration in tree improvement and in selection of resistant planting stock.

FOLIAGE DISEASES

In young stands, foliage diseases may cause considerable damage, although their incidence varies greatly from year to year. Incidence of infection depends on production, dissemination, and germination of the spores of needle cast fungi, and the availability of susceptible needle stages. As it is rare to have optimal conditions for all the successive steps from spore production to needle infection, needle cast outbreaks are rarely of long duration. The most important factor, high humidity, which is optimal for sporulation and infection, depends on yearly climate fluctuations. Increment losses from needle casts result when climatic conditions favor the development of epidemics, and mortality may result if favorable environmental conditions for epidemics persist.

Several of the needle cast diseases have been studied in depth, particularly the taxonomy of pathogens, and general control measures have been formulated. However, interactions of needle cast diseases with site, stand environment, and cultural practices are poorly understood, and no silvicultural control strategies have been derived for the Mountain West. For other needle cast diseases and geographic regions, such as Europe and New Zealand, some of the interactions have been defined. Nutrition of trees influences resistance to needle cast infection (Kurkela and

Jalkanen 1981). Potassium fertilization increased resistance against *Lophodermium pinastri* (Dimitri 1977).

Reduced air humidity at ground level subsequent to thinning may inhibit spore release from fruiting bodies on the fallen needles. Similarly, thinning-related changes in the air flow and humidity at crown levels, and in density and retention of needles, may affect infections, although their interrelationships are not well understood.

Growth impact from needle casts can range from light to heavy. In the area east of the Cascade Range in Washington and Oregon, annual losses caused by foliage diseases were estimated to be about 425,000 m^3 (15 million ft^3) (Childs and Shea 1967). Studies of the impact of needle cast on other species, such as corsican pine (Mitchell and others 1976), Monterey pine (Gibson 1974), and Douglas-fir in Finland (Kurkela 1981), showed as high as 60 percent volume-growth reduction following several successive years of infection. Low infection levels are very common but may not cause readily detectable growth loss. Many occurrences of needle cast outbreaks, though recorded, provide no measurements of impact, perhaps because of difficulties in growth loss determination. Thus needle cast infections could have a greater impact than is currently assumed.

Elytroderma Needle Cast (*Elytroderma deformans* [Weir] Darker)

Elytroderma disease affects large areas of pine stands. It has reduced growth rates and caused mortality in ponderosa pine (Childs 1968), Jeffrey pine (Scharpf and Bega 1981), and lodgepole pine. Currently, in British Columbia, *Elytroderma* has caused several successive years of severe infection and needle loss in numerous 10- to 300-ha (25- to 740-acre) stands of ponderosa pine (Wood and van Sickle 1986).

The fungus invades twigs and buds as well as needles, and survives perennially in the twigs and buds. Thus, once infection has occurred, the fungus is not dependent on favorable weather and continues causing damage for many years. In areas with continued absence of fire, elytroderma needle cast is becoming more prevalent. Without ground fires the thicket of understory trees is more readily infected, and inoculum that increases on these trees is spread to the larger trees.

The stand and environmental conditions involved in epidemic outbreaks are unknown. On high-risk sites where outbreaks are apt to occur repeatedly, tree species not susceptible to the diseases should be regenerated. Level of stocking seems to have little or no influence on the incidence of the disease, but crowded, slow-growing trees are damaged the most. Thinning may help to reduce the mortality resulting from this disease (Scharpf and Bega 1981).

Lophodermella Needle Cast (*Lophodermella concolor* [Dearn.] Darker)

Lophodermella needle cast causes foliage losses of lodgepole pine and ponderosa pine. Lodgepole pine can suffer heavy needle drop, but serious outbreaks over large areas are infrequent (Collis 1972). The wet and cool conditions that have prevailed in the Mountain West in the early 1980's have increased the incidence of this disease (Hoff 1985). On young seedlings infection is observed most frequently in moist, cool valleys (Krebill 1975).

In recent outbreaks the incidence of infection has been very high. In the Prince George region 50 percent of the natural regeneration was infected. One-year-old needles had a 50 percent infection rate, and 2-year-old needles had a 30 percent infection rate (Wood and van Sickle 1986).

Variation in susceptibility to lophodermella needle cast related to elevation was described in Idaho provenances of lodgepole pine. The stands with highest resistance were found at low elevations (from 640 m [2,100 ft]) where the climatic conditions favored infection and thus encouraged the development of resistant provenances. The most susceptible provenances were from high elevations where infection levels were lower (Hoff 1985).

Leptomelanconium Blight (*Leptomelanconium pinicola* Berk & Curtis. R. S. Hunt)

Defoliation caused by leptomelanconium blight can vary greatly from year to year. Trees have been observed blighted one year and free from the blight the next year within a given area. A large epidemic was reported in 1978 when the blight was severe on 4,000 ha (9,900 acres) of ponderosa pine in southeastern British Columbia and on 2,400 ha (5,900 acres) of lodgepole pine near Prince Rupert. A limited assessment of growth impact revealed an approximately 40 percent reduction in radial growth over a 4-year period of infection (Hunt 1985).

Other foliage diseases of forest trees in the Mountain West are summarized in table 1.

CANKERS

Atropellis Canker (*Atropellis piniphila* [Weir] Lohman and Cash)

This disease affects primarily lodgepole pine, and to a lesser degree, ponderosa pine. Its occurrence in the Mountain West is spotty, but in Alberta and in parts of British Columbia it is widespread in lodgepole pine stands and has a high incidence in certain areas (Hopkins 1963; Molnar and others 1968). The disease causes stem deformity and volume and quality losses because the cankered trees have undesirable properties for chipping and pulping (Baranyay and others 1973).

In a survey published in 1968, 52 percent of lodgepole pine stands examined in British Columbia had atropellis canker, and up to 78 percent of the stems were affected in some stands (Molnar and others 1968). In a more recent survey in managed stands of interior British Columbia (van der Kamp 1981), the disease was detected in only about 10 percent of the stands. Where present, the pathogen was very common, affecting up to 40 percent of the trees. The differences between the two surveys' results may have in part arisen from differences in stand conditions related to age and level of management.

Table 1—Other major foliage diseases of forest trees in the Mountain West

Foliage disease	Host tree species	Occurrence
Bifusella linearis (Peck) Hoehn	Western white pine	Local outbreaks
Lophodermium arcuata (Dark.) Dark.	Western white pine	Local, considerable damage in Idaho and Montana
Larch needle blight *Meria laricis* Vuill.	Western larch	Incidence and severity of infections vary, heavy infection after wet spring, in Idaho, Montana, British Columbia
Larch needle cast *Hypodermella laricis* Tub.	Western larch	Scattered, low level infections, in Idaho, Montana, NE Washington, British Columbia. Widespread and increased impact after wet spring
Red band needle blight *Scirrhia pini* Funk & Parker	Western white pine Lodgepole pine Ponderosa pine	Local, moderate to severe infections in British Columbia and Idaho
Dothistroma needle blight *Dothistroma pini* Hulbary	Lodgepole pine Ponderosa pine	Larger areas affected east of the Cascades in Oregon and Washington, low infection in Idaho
Rhabdocline needle blight *Rhabdocline pseudotsugae* Syd.	Douglas-fir	Local, light to severe infections in Idaho, Oregon, British Columbia
Swiss needle cast *Phaeocryptopus gaumanni* (Rohde) Petrak	Douglas-fir	Becoming increasingly common in forest stands in Oregon, Washington; local occurrence in Idaho
Spruce needle rust *Chrysomyxa* spp.	White spruce Engelmann spruce	Common, occasionally widespread infections
Pine needle rust *Coleosporium asterum* (Dict.) Syd.	Lodgepole pine	Common throughout the range

Sources: Forest Insect and Disease Conditions in Canada, Canadian Forestry Service; Forest Insect and Disease Conditions in the United States, USDA Forest Service

Spacing of trees appears to affect the incidence of atropellis canker in lodgepole pine stands. The results of a study in Alberta showed that the number of cankers developed after spacing treatment increased with stand density but was not affected by site (Stanek and others 1986). The number of new cankers sharply increased between stand densities of 2,000 and 4,000 trees per hectare (800 and 1,600 trees per acre) (table 2).

The authors attributed the effect of stand density to humid bark conditions that persist longer in denser stands. Stocking levels of 2,000 to 2,500 trees per hectare (800 to 1,000 per acre) are recommended from a growth and yield standpoint and to provide an adequate degree of atropellis canker control.

Table 2—Average number of new cankers formed in 14 years after spacing to different stand densities (adopted from Stanek and others 1986)

Stand density	Average number of cankers
Trees/acre	
500	0.7
1,000	1.2
2,000	2.2
4,000	10.5
8,000	11.5

WINTER DAMAGE

Winter drying damage is caused by intensive dehydration due to an imbalance between the uptake and loss of water in leaves, twigs, and upper stems. Frozen soil, unseasonably warm weather, sunny days, and strong winds contribute to, and enhance the severity of, the damage.

Winter injury affecting large areas of lodgepole pine and white spruce stands periodically occurs in the foothills and mountain passes of the Rocky Mountains. Damage usually occurs in a distinct band along slopes, and because of its reddish-brown appearance the damage is commonly referred to as red belt injury. The injury is frequently associated with chinook winds bringing warm dry air, although the exact cause of damage is not entirely understood. It has been suggested that it is caused by oscillation of warm and freezing temperatures, rather than by direct desiccation of foliage tissues (Henson 1952).

The degree of damage varies from light to severe, depending on the proportion of foliage killed. Severe foliage damage is associated with bud and bark necrosis, and the resulting tree mortality can be heavy. The extent of damage varies from sporadic, affecting a few trees, to damage over large areas of forest stands. In 1971, damage in varying intensity occurred over an area of about 300 km^2 (120 mi^2) in the high foothills of west-central Alberta (Robins and Susut 1974). Winter drying damage occurred again in the same area in 1982 and 1984.

The authors recently examined growth impact and stem volume losses associated with this injury in both young regeneration and mature stands of lodgepole pine and found that height increments of 8- to 12-year-old lodgepole pine were significantly reduced in the first and second seasons following the damage. The reduction was related to the amount of dead foliage. Height growth was reduced by as much as two-thirds when 60 percent or more of the foliage was necrotized (fig. 6).

In mature lodgepole pine stands the reductions in annual volume increments were 31 to 50 percent for 1971-72 winter damage, 13 to 50 percent for 1981-82 winter damage, and 24 to 25 percent for 1984-85 winter damage (Bella and Navratil in press). If similar frequency and severity of winter drying damage occur regularly, damage could occur as often as 20 times over a 100-year rotation period. Even a conservative estimate of 25 percent growth reduction, based on our observations, equals an annual 5 percent reduction in volume increment on the average for affected areas. However, it should be noted that our estimate of impact does not include direct losses due to tree mortality, nor any increase in the predisposition to, and incidence of, other diseases and insect infestations (Robins and Susut 1974).

To reduce growth and mortality losses during the regeneration phase, cutting methods that provide a measure of protection through the shape, size, and orientation of cut blocks, or through residual tree cover as in a shelterwood system, as well as careful selection of species to suit site conditions should be considered.

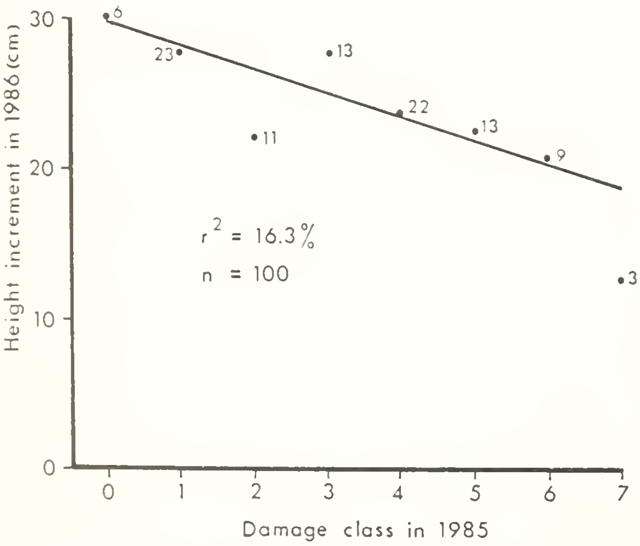

Figure 6—Height increment of lodgepole pine in the second year following winter drying damage in relation to damage class.

CONCLUSIONS AND RECOMMENDATIONS FOR DISEASE-IMPACT REDUCTION

Silvicultural manipulation is increasingly recognized as the only practical way to create and maintain pest-resistant stands. To meet this objective silviculturists need basic information such as the responses of diseases to various silvicultural practices.

1. Faster seedling and juvenile growth as a result of improvements in planting stock quality and in site preparation will be advantageous in disease management. Infections by, and losses from, white pine blister rust, needle casts, and atropellis canker can be overcome by fast growth. On the negative side, faster growth of lodgepole pine can contribute to higher infection rates of western gall rust.

2. In intensively managed second-growth stands the trend is toward low-density regimes to increase value yield and shorten rotation (Long and others 1986). Spacing and precommercial thinning are at present the most important silvicultural tools for affecting disease incidence. However, indiscriminate thinning can increase incidence of white pine blister rust, western gall rust, and others. For effective control, the timing of thinning and care in detecting and removing infected trees are essential. Thinnings in plantations should leave a surplus of potential crop trees to alleviate future disease losses and to allow for commercial thinning.

3. Control of diseases through higher resistance of trees will increase as the genotypes of seedlings improve. A good example can be found in the control of white pine blister rust by use of improved planting stock and as a result of natural selection in natural regeneration of seedlings that are more resistant to the disease. In time, this trend should result in a reduced incidence of the disease. For several other diseases variations in resistance among seed sources and geographical regions provide opportunities to breed resistant trees and will also have an important bearing on the transferability of seed and planting stock. Based on this opportunity, methods for resistance screening in tree improvement programs are being developed.

4. Silviculturists and pathologists alike are handicapped by the lack of basic knowledge of stand and environmental conditions that favor development of epidemics of foliage and stem diseases. Research must be done to provide the sound data bases essential for prediction of epidemics and losses, relating these to cultural practices and site variation, and developing site rating and planning of integrated control strategies.

5. Work on disease hazard rating of single trees and stands as related to site conditions also needs to be expanded. This information is essential for long-range management planning, to provide reliable estimates of future volume yield, and to develop related cost-effective control strategies.

6. Impact monitoring for virtually all foliage and stem diseases is grossly inadequate to develop cost/benefit rationales for direct and integrated control strategies. Our lack of impact data could lead to a serious underestimation of cumulative losses such as those from needle cast infections.

7. Prescribed fire will have a greater role in a variety of silvicultural tasks. This will also be beneficial for disease control in some cases. Indications are that higher incidence and impact of several diseases such as comandra blister rust and elytroderma needle cast are related to reduced fire occurrence over the past decades.

8. Prescriptions advocated for specific problems by specialists cannot be considered in isolation because they may be counterproductive. The primary objective of creating pest-resistant stands requires an integrated approach by specialists from forest pathology, entomology, ecology, and silviculture.

9. New approaches to uneven-aged management, use of single-tree and group-selection systems, and greater reliance on natural regeneration are fully compatible with control strategies for foliage and stem diseases. These approaches will increase stand diversity in tree size, age, and development; increase resistance of populations through natural selection; and in general result in more balanced and stable host-pathogen-environment systems.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Randal Trerise)—In young lodgepole pine stands with 4,000 to 8,000 stems per hectare and evidence of western gall rust infections, at what age (or size) would you recommend juvenile spacing?

A.—In Alberta, in lodgepole pine stands we found heavy infections occurring between 5 and 10 years of age. It takes approximately 3 years after infection for a gall to be easily detectable. To keep cost low, thinning should be done soon after the appearance of galls. As stem galls cause more serious damage, trees with stem infections should be cut.

Q. (from Judith Newman)—In areas where lodgepole pine is the predominant crop tree in second-growth stands and branch infections of western gall rust are common, do you believe a pruning program would be beneficial or would it merely open more opportunities for bole infections?

A.—Western gall rust infects the tree through young succulent shoots, thus pruning scars would not increase infections. To our knowledge, pruning programs may not be feasible for control of western gall rust.

RELATIONSHIP OF FEEDING DAMAGE BY RED SQUIRRELS TO CULTURAL TREATMENTS IN YOUNG STANDS OF LODGEPOLE PINE

Robert P. Brockley
Thomas P. Sullivan

ABSTRACT

*Red squirrels (*Tamiasciurus hudsonicus*) cause significant damage in many juvenile stands of lodgepole pine (*Pinus contorta *var.* latifolia*) in the Mountain West.*

This review paper discusses the relationship of squirrel damage to lodgepole pine stand tending treatments, in particular juvenile-spacing and fertilization. Emphases are on research studies conducted in the interior of British Columbia. Squirrels feed extensively on rapidly growing crop trees within stands of juvenile-spaced lodgepole pine. In south-central British Columbia, damage to 90 percent of crop trees in spaced stands has been recorded. Fertilized crop trees are particularly susceptible to squirrel barking injuries. Inability to assess accurately small mammal damage potential or its impact on growth and yield indicates that a conservative approach is necessary in managing juvenile lodgepole pine in areas susceptible to squirrel attack.

INTRODUCTION

Young, overly dense stands of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) are widely distributed throughout the Mountain West. Excessive stand density reduces tree and stand growth and results in lower merchantable yield and value of harvested material (Johnstone 1976). Stand density control in overstocked lodgepole pine stands is, therefore, an important silvicultural technique. The ability of the species to respond favorably to juvenile-spacing is well documented (Johnstone 1985). Redistributing the available growing space concentrates growth on fewer crop trees, thereby ensuring greater use of the productive capacity of the site. Response potential is generally greatest in young stands that have not yet experienced severe growth repression.

Lodgepole pine has also been shown to respond favorably to fertilizer application (Weetman and others 1985). Experience with various coniferous species indicates fertilization may be especially beneficial when combined with a thinning operation (Hall and others 1980; University of Washington 1979; Weetman 1975). A 4-year, 50,000-ha operational forest fertilization program is planned for the interior of British Columbia, beginning in the fall of 1986 (Diggle 1986). Most of the fertilizer will be applied to juvenile-spaced lodgepole pine.

Each crop tree in a spaced stand assumes greater importance than one in an unspaced stand, and any mortality or decrease in vigor will have a negative impact on subsequent yield and investment value. Of increasing concern to the forest manager is the apparent susceptibility of lodgepole pine to small mammal barking injuries. Snowshoe hares (*Lepus americanus* Erxleben) and red squirrels (*Tamiasciurus hudsonicus* Erxleben) have damaged juvenile stands of lodgepole pine throughout the interior of British Columbia and western Alberta (Bella 1985; Brockley and Elmes 1987; Johnstone 1981; Powell 1982; Sullivan 1984, 1985; Sullivan and Sullivan 1982a, 1982b). Of these two animals, squirrels pose the greatest threat because of their preference for larger diameter stems. Although crop trees in managed stands soon outgrow susceptibility to hare attack, they remain at risk to squirrel damage for several years. Surveys throughout the British Columbia interior indicate that lodgepole pine is the tree species most susceptible to red squirrel feeding injuries.

This paper discusses the relationship of squirrel damage to lodgepole pine stand tending treatments, in particular juvenile-spacing and fertilization. Emphases are on research studies conducted in the interior of British Columbia. Readers interested in the impacts of other small mammals (snowshoe hares, porpcupines) on managed stands should consult an earlier review by Sullivan (1985).

BARKING DAMAGE IN JUVENILE-SPACED STANDS

Barking injuries are caused by red squirrels peeling and removing bark from the basal and sometimes upper sections of trees. After feeding on the cambium and phloem tissue, the animal discards the bark strips at the base of the stem. These bark strips, together with regular, often rectangular damage wounds and a lack of tooth marks on sapwood, distinguish squirrel barking injuries from those inflicted by snowshoe hare and porcupine (*Erethizon dorsatum* Allen) (Lawrence and others 1961; Sullivan and Sullivan 1982a). Most damage occurs in late spring (May to July) during the early part of the growing season.

Regional Assessment of Damage

Recent studies have confirmed the importance of red squirrels as damaging agents in managed stands of lodgepole pine throughout the British Columbia interior.

A reconnaissance survey was undertaken in south-central British Columbia in 1984 to evaluate the incidence and magnitude of barking injuries by red squirrels in juvenile-

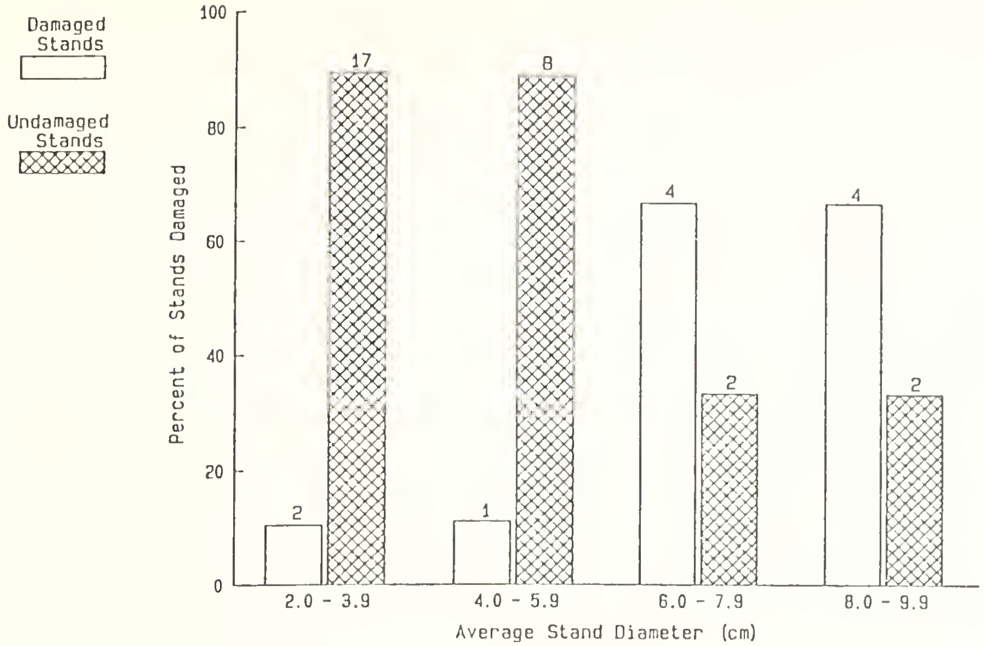

Figure 1—Distribution of squirrel damage by average stand diameter class (cm). The total number of surveyed stands in a given size class is located above each bar. The variation in damage between diameter classes is highly significant ($p < 0.01$; chi-square).

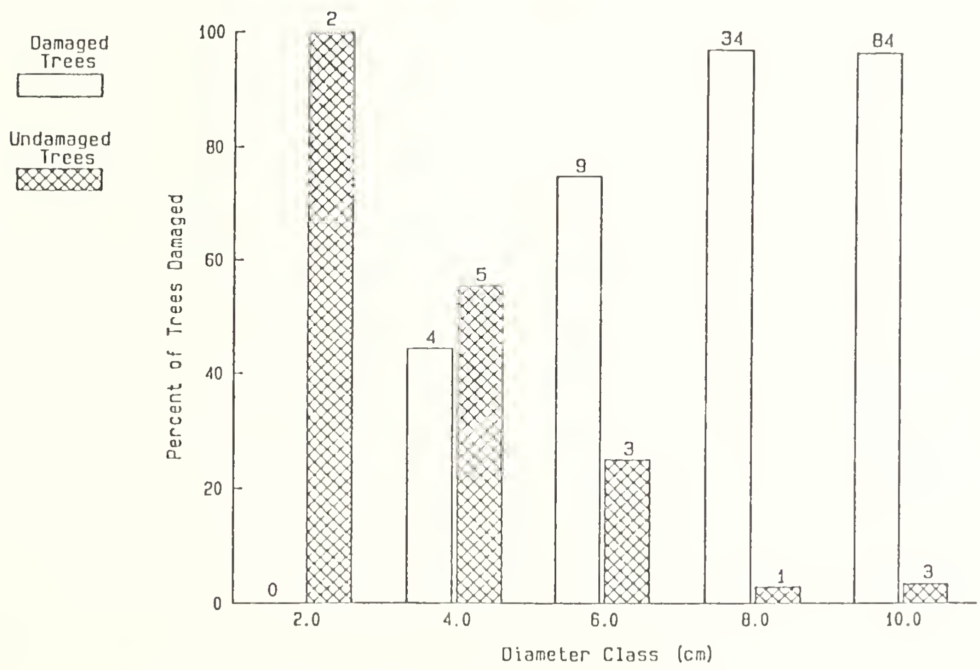

Figure 2—Distribution of squirrel damage by diameter class in a juvenile-spaced stand near Kamloops, BC. The total number of crop trees in a given size class is located above each bar. The variation in damage between diameter classes is highly significant ($p < 0.01$; chi-square).

spaced stands of lodgepole pine (Brockley and Elmes 1987). Eleven of the 40 stands surveyed (27.5 percent) exhibited red squirrel barking injuries. Within damaged stands, an average of 51 percent of the lodgepole pine crop trees had been attacked (ranging from 6 percent to 90 percent).

The distribution of damage by average stand diameter class is illustrated in figure 1. Sixty-seven percent of stands with average diameters greater than 6 cm had been attacked by squirrels, but only 11 percent of stands with average diameters less than 6 cm had been damaged. Moreover, squirrels preferentially attacked the larger diameter stems in damaged stands (fig. 2).

The preference of red squirrels for larger diameter stems is consistent with findings elsewhere in the British Columbia interior (Sullivan 1985; Sullivan and Sullivan 1982a, 1982b). However, the particular susceptibility of larger stems is probably more a function of vigor than size. On all seven representative lodgepole pine sites assessed in the Cariboo Forest Region in central British Columbia, there were more barking injuries in spaced than in adjacent unspaced stands (Sullivan and Vyse 1987). In the most heavily damaged spaced stand, 77 percent and 25 percent of the crop trees had been attacked and girdled, respectively. In another stand, the proportion (61.7 percent total) of trees damaged increased with stem size, as did the average amount of bark removed. Stems up to 21 cm in diameter were attacked.

The preference of red squirrels for larger, vigorous stems may be related to greater quantity (and perhaps quality) of nutrients in the cambium/phloem tissue on which the squirrels feed.

Impact on Growth

The impact of red squirrel barking injuries cannot be fully evaluated until the effect of damage on growth and yield is documented. Previous studies have shown that similar damage by snowshoe hares clearly suppresses diameter growth (Lloyd-Smith and Piene 1981; Sullivan and Sullivan 1986). This latter study assessed the impact of hare feeding injuries on diameter and height growth of juvenile pine near Prince George, BC. Five-year growth increments of undamaged and damaged crop trees in unspaced and spaced stands were compared. Semigirdling (sublethal) damage clearly suppressed diameter growth of small diameter (unspaced 41-60 mm and spaced 31-50 mm) trees, but had little effect on larger stems (fig. 3). Height increment was significantly reduced by semigirdling (≥50 percent of circumference girdled) in all diameter classes except the 61-80 mm class in the unspaced stands (fig. 3). Surface area or amount of bark and vascular tissue removed had little effect on growth increments in the spaced stand.

Preliminary analyses of 5-year growth increment data from a study undertaken in the Cariboo Forest Region indicate that radial increment of lodgepole pine is not adversely affected by squirrel barking injuries (Sullivan and Vyse 1987). The significance of these findings, however, is tempered by a number of factors. Stem analyses indicate that damaged trees were generally more vigorous prior to attack than were undamaged stems. Therefore, the "lost" growth of damaged trees may be underestimated unless predamage radial increment is considered in data analysis. Moreover, the impact on growth may not become evident for several years following damage. Very few stems exhibited semigirdling injuries, and repeated feeding in subsequent years will undoubtedly increase the amount of girdling on crop trees. Additional attacks may reach a threshold level resulting in physiological stress, or wounds may serve as entrance courts for disease or parasites. Damaged stems also appear to be susceptible to snow or wind breakage at the point of barking injury.

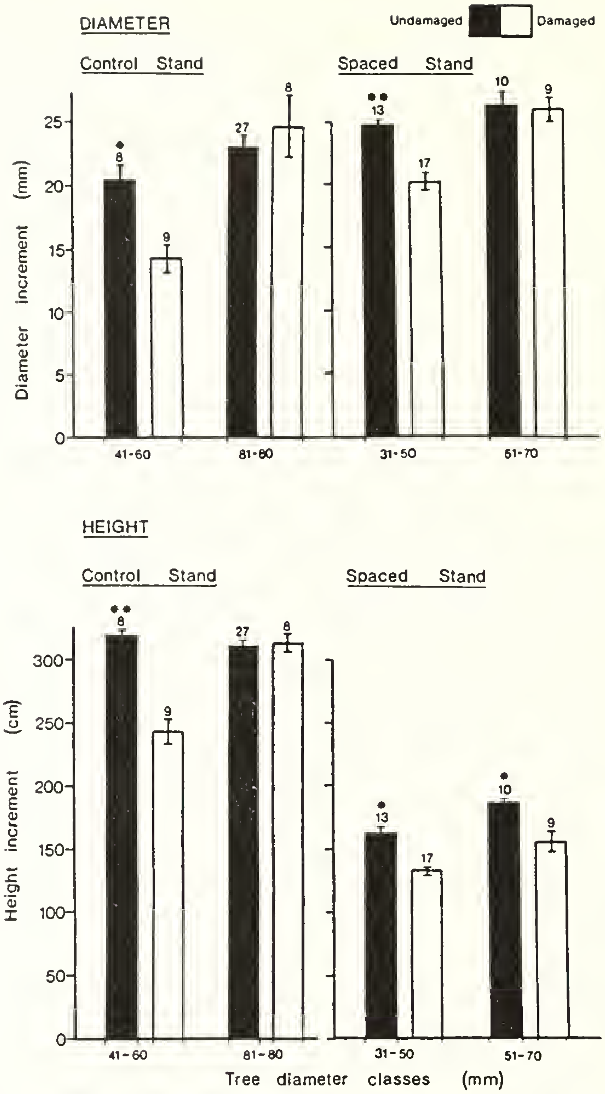

Figure 3—Impact of semigirdling damage by snowshoe hares on diameter (A) and height (B) increments in control (unspaced) and spaced stands of lodgepole pine. Sample size above each bar with range indicator ± standard error (*$p \leq 0.05$; **$p \leq 0.01$; *t*-test).

The tendency for damage to be clumped (Brockley and Elmes 1987) is consistent with findings reported for snowshoe hare (Sullivan 1984) and may result in large openings or pockets of reduced growth.

Potential productivity losses from small mammal barking injuries in managed lodgepole pine stands are particularly disturbing because damage occurs so early in the life of the stand. Long-term monitoring of young stands will enable a more complete evaluation of the impact of damage on growth and yield.

BARKING DAMAGE IN FERTILIZED STANDS

A large number of fertilization research experiments have recently been established in juvenile-spaced lodgepole pine stands in the interior of British Columbia. Results to date indicate that lack of nitrogen is an important growth-limiting factor and lodgepole pine can be expected to respond favorably to nitrogen fertilization when other nutritional and nonnutritional factors (such as soil moisture) are not limiting (Brockley 1986; Weetman and Fournier 1982). However, accumulated evidence indicates that improved palatability and nutritive quality may significantly increase the susceptibility of fertilized lodgepole pine to small mammal barking injuries. Extensive damage may adversely affect the ability of fertilized trees to respond favorably following nutrient additions.

The effect of nitrogen fertilization on the proportion of lodgepole pine crop trees damaged by red squirrels in a research trial near Kamloops, BC, is illustrated in figure 4. Three years following fertilization, squirrels had attacked significantly more trees in fertilized plots (95.5 percent and 99.4 percent for application rates of 100 and 200 kg/ha nitrogen, respectively) than in control (spaced, unfertilized) plots (81.5 percent). However, more important with respect to the effect of feeding injuries on future growth and yield are measures of damage intensity. Fertilization clearly had a marked effect on the severity of damage wounds. Thirty-five percent and 49 percent of trees in 100 N and 200 N plots, respectively, had wounds that girdled ≥50 percent of stem circumference. Only 11 percent of unfertilized trees exhibited injuries of similar severity. In fact, the majority of damage in unfertilized plots was confined to the 1-24 percent circumference girdled category (fig. 4). In another fertilization trial near Prince George, BC, squirrels removed 4.1 and 5.7 times the amount of bark from 100 N and 200 N stems, respectively, than from unfertilized trees (fig. 5). Differences in the amount of damage between the two fertilizer treatments, although not statistically significant, indicate that damage intensity may be directly related to fertilizer application rate.

Severe girdling injuries represent a considerable physical impediment to the translocation of growth substances below the point of injury and will most likely negatively affect response to fertilization.

These results are consistent with those reported previously by Sullivan and Sullivan (1982b) regarding the incidence of hare and squirrel damage in spaced and

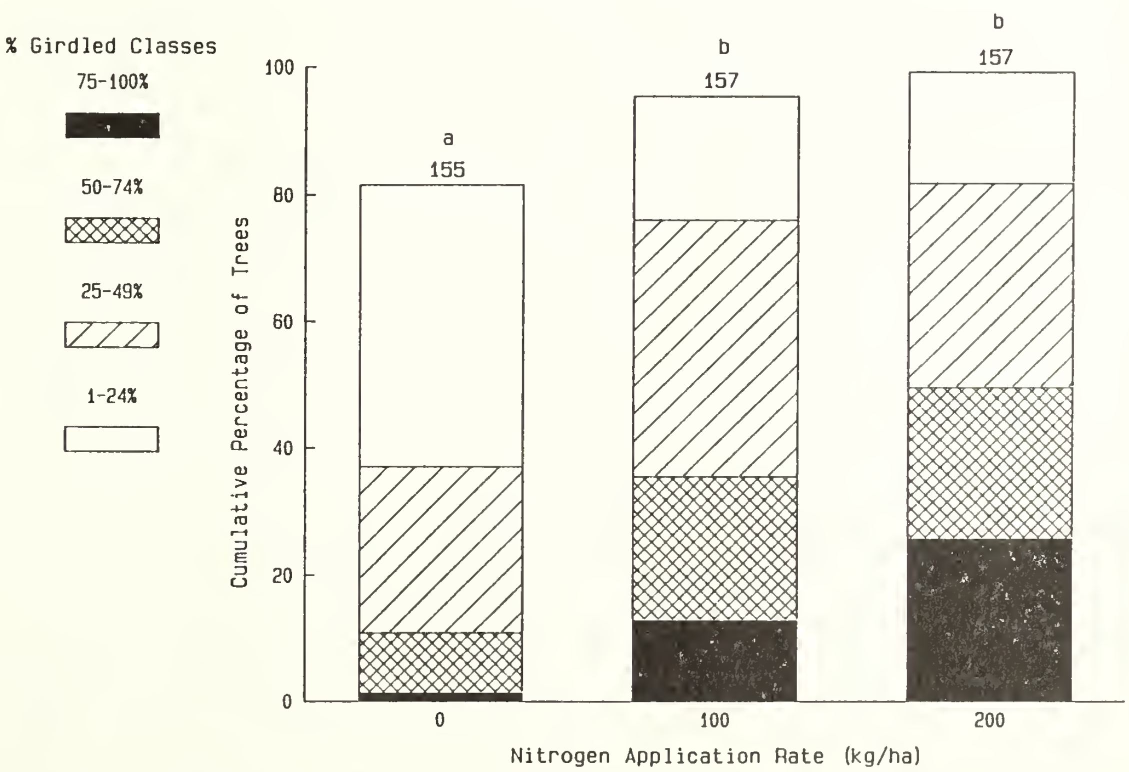

Figure 4—Squirrel barking damage in fertilized and unfertilized plots, tabulated by percentage of stem circumference girdled. Sample size is located above each bar. Bars topped by different letters are significantly different ($p \leq 0.01$; ANOVA) (from Brockley 1985).

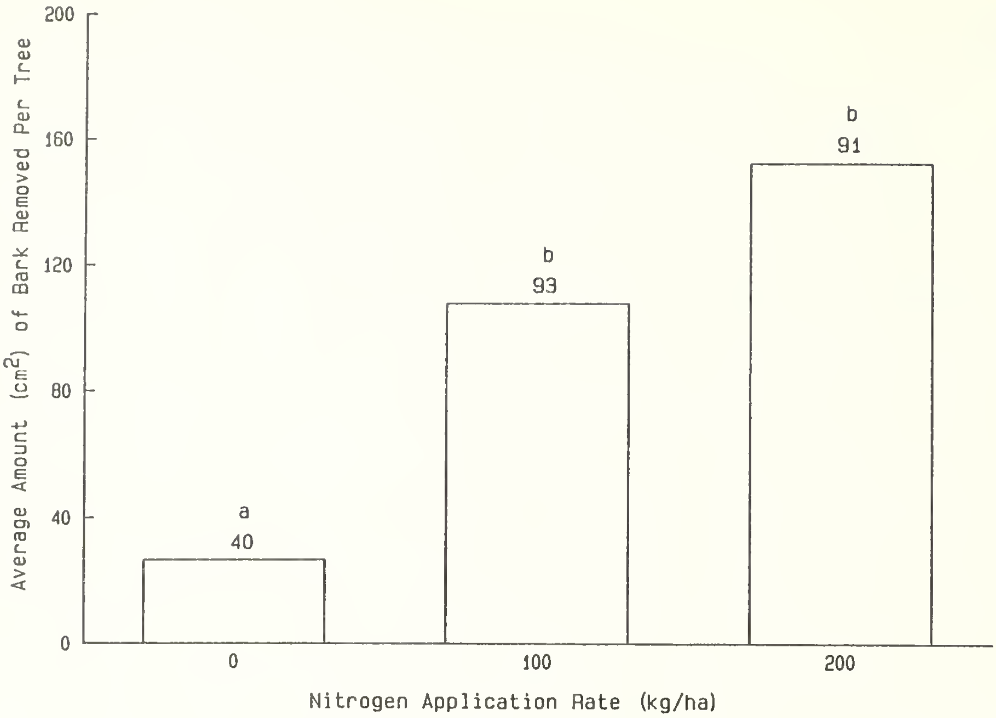

Figure 5—Average amount (cm^2) of bark removed per damaged tree by red squirrels in unfertilized, lightly (100 N) and heavily fertilized (200 N) plots. Sample size is located above each bar. Bars topped by different letters are significantly different ($p \leq 0.01$; ANOVA) (from Brockley 1985).

fertilized, spaced only, and untreated lodgepole pine stands in north-central British Columbia. It was concluded that small mammals clearly prefer fertilized lodgepole pine stems to those in unfertilized or untreated stands.

Research plots essentially create small islands of fertilized trees within a stand and, therefore, may overestimate the amount of small mammal damage that might result following a large-scale operational fertilization project. However, these research data, combined with the high incidence of squirrel damage often observed within extensive juvenile-spaced blocks, indicate that operational fertilization will result in increased damage susceptibility.

POPULATION DYNAMICS

The 9- to 10-year population cycle of the snowshoe hare has been well documented (Keith 1963; Keith and Windberg 1978). In fact, the historical record of cyclic fluctuation in showshoe hares goes back at least 200 years, making it one of the most predictable and well-defined population cycles in the animal kingdom.

In contrast, the population dynamics of red squirrels have, until recently, been poorly defined. Populations of the red squirrel appear to be regulated by the availability of cone crops in mature stands. Several studies have been concerned with the relation of territory and food supply and its implication in the natural regulation of red squirrel populations. Brink and Dean (1966) and M. Smith (1968) demonstrated the importance of cone seeds in the diet of red squirrels. C. Smith (1968) showed that territory size was inversely proportional to the available food supply. Kemp and Keith (1970) stressed the importance of overwintering food caches, and hence cone crops, in limiting population growth. More recently, Rusch and Reeder (1978) hypothesized that territorial behavior regulated densities about a mean that was determined by food supply in years of poor cone mast.

A long-term (12-year) study by Halvorson (1984) clearly outlined the correlation between red squirrel population fluctuations and cone crops. A similar study by Sullivan (in press) over a 6-year period near Prince George, BC, has also documented this association. In addition, experimental evidence relating supplemental food to increased population size of squirrels has been recorded by Sullivan and Sullivan (1982c) and (Sullivan in press).

The relationship between cone crops and squirrel densities in a mature stand of white spruce (*Picea glauca* [Moench] Voss) and a juvenile stand of pine is illustrated in figure 6. Squirrel populations in mature forests peak in the year after a substantial cone crop because of increased reproduction and survival. This high density may persist for an additional year, depending on size of cone crop and other factors. The surplus of squirrels will eventually "spill over" into stands of juvenile lodgepole pine, which are presumably suboptimal habitat. Thus, 2 to 3 years after a cone crop, squirrels will be abundant in juvenile pine stands and their density may rival that in mature stands (Sullivan and Moses 1986).

It is during the years of squirrel abundance that the proportion of trees attacked increases in spaced stands

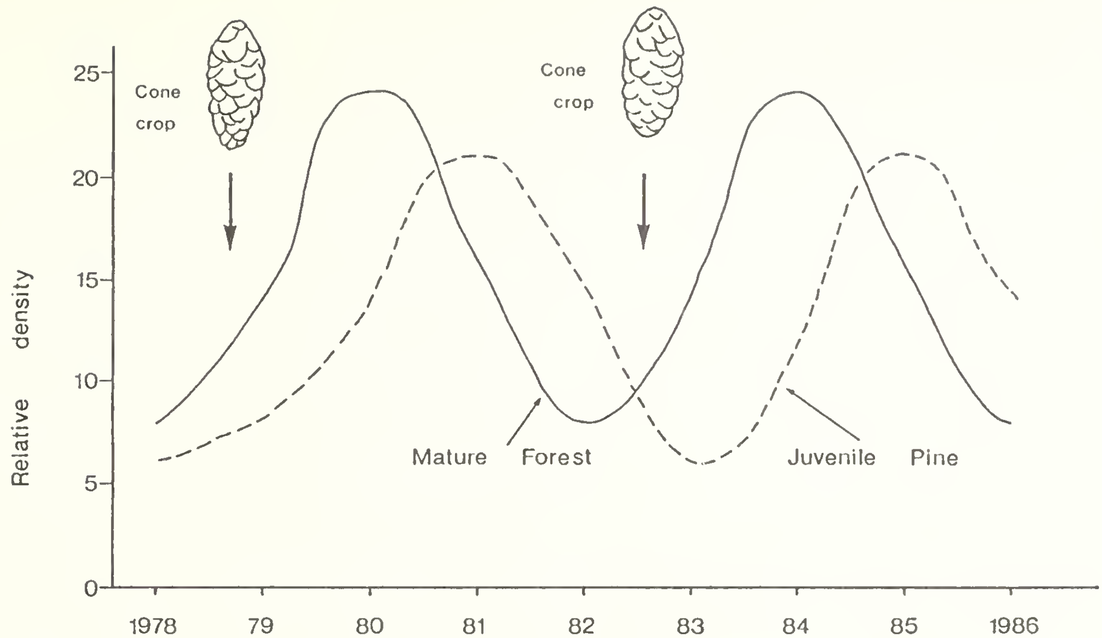

Figure 6—Population cycle of the red squirrel in stands of mature white spruce/lodgepole pine and juvenile lodgepole pine from 1978 to 1986. Populations were monitored from 1981 to 1986 with heavy cone crops recorded in 1979 and 1983.

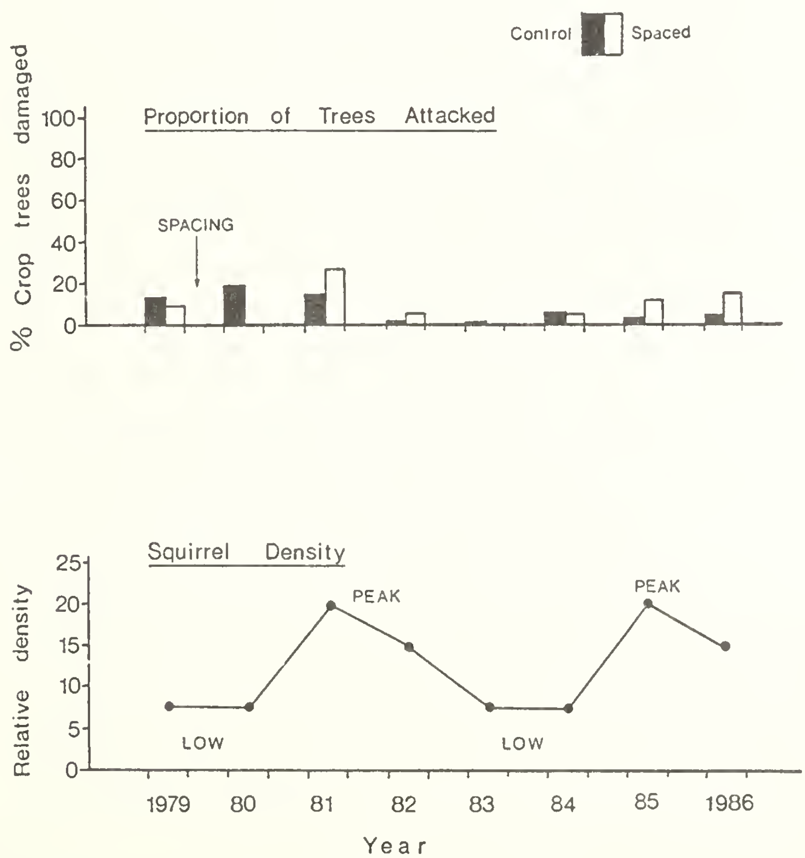

Figure 7—The proportion of lodgepole pine crop trees attacked in control (unspaced) and spaced stands from 1979 to 1986. Relative population density of squirrels in juvenile pine during low and peak periods of the cycle.

(fig. 7). This pattern provides a predictable population cycle for red squirrels in juvenile stands, at least in areas where cone crops in nearby mature stands can be accurately monitored. However, prediction of damage potential may be only partially successful for fertilized stands where even low densities of squirrels may be attracted to the high-quality vascular tissues associated with vigorously growing stems.

MANAGEMENT STRATEGIES

Strategies for minimizing snowshoe hare barking injuries should take advantage of predictable population cycles by avoiding spacing during peak population periods (Sullivan 1984). However, squirrels are somewhat less predictable than hares in their feeding attacks because of their ability to attack larger diameter stems and their strong response to fertilizer regimes in young stands. Because the probability of girdling declines with increased stem diameter, squirrel damage can undoubtedly be minimized by delaying spacing until crop trees are large enough to withstand barking wounds. Unfortunately, this is often not a viable option since productivity losses may be considerable if density control in overly dense lodgepole pine stands is postponed.

Managed stands of lodgepole pine represent a considerable investment that must be protected if favorable returns, in terms of increased yield and market value, are to be realized. Inability to assess accurately either squirrel damage potential or its impact on growth and yield indicates that a conservative approach is necessary when managing lodgepole pine in areas susceptible to squirrel attack. Mortality or reduced vigor can have a significant negative impact on site occupancy if stands are reduced to final target densities at an early age. The recent trend toward spacing very young stands (6 to 10 years) is particularly disturbing because risk potential cannot be evaluated until crop trees attain a "threshold" diameter.

A flexible two-step spacing strategy may be the most practical method of minimizing the impact of red squirrel barking injuries. A conservative initial spacing prescription would compensate for subsequent mortality and reduced vigor caused by squirrels and other damaging agents. The timing of the second entry would depend on the amount and duration of damage following the initial pass. This strategy would be especially advantageous in very young stands, in that lower live limbs and small stems overlooked during the initial treatment, as well as subsequent ingress, could be removed at the time of the second entry.

In stands where the risk of squirrel damage is high (such as when squirrel barking injuries are evident in the unspaced stand), it may be prudent to delay fertilization of spaced stands until risk potential is reduced. Spaced trees are potentially responsive to fertilizer application as long as live crown ratio is favorable and intertree competition is not severe.

The apparent relationship between red squirrel population trends and periodicity of conifer cone crops may enable some degree of squirrel damage predictability. An effective biological repellent system for use during periods of high squirrel population would strengthen management strategies. Also, the development of a systemic repellent (in which compounds added to fertilizers would be taken up by trees, making bark unpalatable to small mammals) would reduce the susceptibility of fertilized trees to barking injuries.

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CHANGING STAND DENSITY AND COMPOSITION WITH PRESCRIBED FIRE

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ABSTRACT

In many cases, fire is not an effective thinning tool. However, under certain conditions, stand density and composition can be manipulated by the prescribed use of fire. The factors that determine tree survival are reviewed along with how to effect changes in the fire situation to meet thinning objectives.

INTRODUCTION

Rephrasing the title yields the basic question that this paper addresses: can prescribed fire be an effective thinning tool? After thinking about what fire does, and what the objective is, the immediate answer may be no. After all, fire cannot be used for thinning in purely even-aged stands. Fire cannot be used for thinning in mixed conifer forests when managing for shade-tolerant species such as subalpine fir, spruce, hemlock, western redcedar, or grand fir. Fire cannot be used in pole-size stands. Fire cannot be used in uneven-aged management where downed woody fuel loads are greater than 20 tons per acre. Fire cannot be used in stands with a closed canopy where fuel ladders are present. And finally, fire cannot be used in stands where even spacing is required.

Yet, fire is a natural thinning agent in some habitat types of the ponderosa pine, Douglas-fir, and warm end of the grand fir series. Historically, surface fires burned frequently in these forests. Fire's role was to thin out shade-tolerant invaders, thereby maintaining a seral forest. Thus, fire can be used to extensively manage large areas of ponderosa pine, western larch, and to some extent Douglas-fir. Areas can be treated where the primary fuel bed is needles, grass, or low shrubs with grass. It is much harder to use fire in areas where tall shrubs and young trees are dominant and grass is sporadic.

MANIPULATING DENSITY AND COMPOSITION

Fire is a selective killing agent, and so has potential as a thinning tool. The major determinants of overstory survival are whether or not the tree species is resistant to fire and the size of the tree. Fire-resistant species such as ponderosa pine and western larch at a given height are more likely to survive a fire than Douglas-fir and grand fir. However, taller and larger Douglas-fir and grand fir will have a better chance of survival than small ponderosa pine and western larch. Young trees and trees of species where the bark is not well developed can be killed by fires of long duration at their base.

The main killing power of the fire is a result of scorch and air temperature. The amount of crown scorch depends primarily on the fireline intensity and ambient air temperature. The higher the temperature, the higher the scorch. Thus, if the objective is to kill a lot of trees or larger trees, burning on a hot day will help. If the objective is to leave a lot of trees or just kill small ones, burning on a cool day will help.

As fireline intensity increases, scorch height will increase. The equation for fireline intensity is

$$I = H \times W \times R$$

where

I = fireline intensity

H = heat of combustion

W = weight of total fuel consumed

R = rate of spread.

The heat of combustion is the energy that maintains the chain reaction of combustion. It is a constant determined by a particular fuel bed. The heat of combustion varies slightly for the wood of different tree species that may make up a fuel bed. Generally, it is a little higher for fuel beds resulting from coniferous species than for hardwood species. The important point to remember is that it is a parameter that you cannot control.

The amount of total fuel consumed primarily depends on the amount of fuel to begin with and the moisture content of that fuel. It should be obvious that burning high fuel loads when their moisture content is low will result in high fireline intensities. Thus you can control fireline intensity by scheduling the burn when fuel moistures are appropriate.

The rate of spread can be controlled by the lighting pattern. Head fires will result in high rates of spread and thus high fireline intensities. Backing fires have slow rates of spread and thus lower fireline intensities. Strip fires can be used to a limited extent to control the rate of spread, and thus fireline intensity, by varying the spacing and timing of the strips. However, to make the intensity of a strip fire less than that of a head fire, the strips must be narrow enough so that the fire runs into the next strip before reaching a steady state, or the time between strips must be considerable, to allow for a significant amount of backing. Flame length is a visible indicator of fireline intensity. Thus, adjustments can be made to alter fireline intensity during the burn by varying the lighting pattern based on flame length observations.

Experience with prescribed burns in northern Idaho has yielded the following rules of thumb: Ponderosa pine and western larch that are 12 ft or taller have a reasonable chance of survival; if 6 ft or less they have little chance of survival. Survival will vary considerably depending on the fire's intensity. For a 6-ft ponderosa pine to survive, the flame length should be 2 ft or less, the duration short, and the rate of spread under 10 ft per minute. Slow-moving backfires with rates of spread less than 1 ft per minute will leave most trees alive. Even so, some trees over 12 ft may die and some trees under 6 ft will live. Mortality will be determined by the fuel bed characteristics and the vigor of the individual tree rather than the forester's spacing needs.

Scorch height along with tree size and tolerance to fire are responsible for the majority of changes in overstory density and composition. But what is going on in the understory of grasses and shrubs during all this? Usually, not much. Fireline intensity will not affect the understory of grasses and shrubs as it does the overstory of trees. The intensity may be high enough to top-kill everything, but most of the shrubs and grasses in the understory of these habitat types resprout. Generally, there is little mortality and little change in composition or density. The factor that controls change in the understory is duff consumption, which is primarily dependent on the duff fuel moisture. Fires used for thinning would most likely be lit during higher duff moistures to avoid excessive removal of the overstory and to avoid the preparation of a seed bed. The real change taking place in the understory is the redistribution of water and nutrients.

SUMMARY

Fire can be used to effect changes in stand density and composition, especially in extensively managed areas, uneven-aged stands, and areas where the tree species are fire tolerant. Fires can achieve multiple objectives such as reducing the fuel hazard, inducing sprouting of palatable shrubs and grasses, and thinning. Repeated use of fire may be required depending on the distribution and quantity of young trees. If trees are widely spaced, waiting until ponderosa pine is 12 ft tall is prudent, while densely spaced trees may require treatment at 6 ft. If regeneration is to be removed, burning when the trees are 3 ft tall is necessary. Adjusting the timing is essential to ensure adequately stocked but not overstocked stands. By the time ponderosa pine and western larch are 20 ft tall they are not easily killed by surface fires and therefore cannot be manipulated with fire successfully.

Remember, the relative fire tolerance of a tree species, along with its size, determines the ability to survive a fire. Crown scorch determines the killing power of a fire on the overstory. Crown scorch is primarily dependent on fireline intensity and ambient air temperature. You can control the amount of crown scorch by burning when the ambient air temperature and fuel moistures are appropriate and adjusting the lighting pattern. Flame length is your visible indicator of fireline intensity.

Finally, fire cannot be used in intensive forest management where the objective is maximizing wood biomass and a tree spacing of every 6 or 10 ft in perfect rows and columns is required. You don't have that much control. But, fire is a selective killing agent, and thus can be used as a thinning tool in extensive forest management, especially where there are other land management objectives in conjunction with timber production.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Dennis Parent)—How does the cost of thinning with fire compare with other methods of thinning?

A.—By using fire in an extensive management situation over large areas, the cost should be cheaper than any other method. However, with the least cost you also get the least control over the results. To achieve more control over the results, you'll need to turn to more costly methods, and by definition you will move out of the extensive management arena and into intensive management.

CHEMICAL TREATMENTS FOR STAND DENSITY AND COMPOSITION MANAGEMENT

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ABSTRACT

Herbicides provide a viable alternative for improving both the density and composition of timber stands. Recently developed methods of injecting and implanting herbicide sprays, pellets, or capsules directly into target tree stems can reduce potential for environmental contamination and worker exposure. The cost of chemical treatment, depending on the situation, is often significantly lower than that of mechanical treatments. Chemical treatment produces a situation similar to the natural system because the target trees are left standing, to be assimilated slowly into the downed woody fuels, provide a more continuous supply of large woody material for the nutrient cycle, and protect living trees from sun scald and wind injury.

INTRODUCTION

Chemical methods of stand density and composition management involve herbicide application to kill target trees. A wide array of herbicides are available that will kill trees on both a selective and a broadscale basis. The herbicide application methods usually determine herbicide selectivity and impact on nontarget species.

A variety of effective treatments that meet stand density and composition management goals can be designed. Comparisons of chemical methods to other methods often show that no single treatment is best in meeting stand management goals, providing worker safety, or cost-effectiveness. Factors of existing stand density and composition, value of potential products, and ecological relationships must be evaluated with stand management objectives to determine the appropriate mechanical, chemical, or fire treatment.

The objectives of this paper are to give the reader sufficient knowledge to evaluate the appropriateness of chemical treatments by:

1. Describing the chemicals and application methods that have been used in the past and those methods that look promising for future use, and
2. Providing key management implications and comparisons relative to these methods.

APPROPRIATE MANAGEMENT TREATMENTS

There are five stand density and composition management treatments for which chemicals can be used, with varying degrees of success. Chemicals can be used in cleaning treatments, where sapling-size stands are being managed for composition. In dense stands chemical treatments are often difficult to accomplish. Foliar sprays cannot be used to select for desired leave trees, since most of the desired species are sensitive to available chemicals. The use of individual tree chemical treatments avoids this problem, but in dense, small-diameter stands, costs are usually high.

Chemicals can be effectively used in liberation cuts, where sapling-size trees are being removed. In some cases selective broadcast foliar sprays can be used, if the target sapling overstory provides enough protection. Where the saplings are more open, chemicals can be cost-effective if the saplings are fairly large. Due to variables such as canopy density, some of the target trees may survive and some nontarget trees may be killed. This is an accepted consequence if it is recognized and planned for.

For improvement cuts, where pole-size trees are to be selectively removed to improve composition of the stand, chemicals can be very cost-effective. They would be used where the trees selected for removal cannot be sold commercially. Trees could be treated with individual tree chemical application methods, which are more cost-effective as diameter increases.

The size and density of trees in stands that are to be precommercially thinned determine if chemical methods are effective. For these stands, where stocking reduction is the objective, broadcast foliar methods would not be appropriate. Directed foliar sprays or individual tree treatment may be effective. Individual tree treatments become more cost-effective where target trees are of larger size.

Chemical treatment can be very effective in sanitation removal cuts, where specific trees that are infected with insect or disease are targeted. However, it is not effective when the treatment also requires removal of the tree stem and foliage.

TARGET TREE SPECIES FOR THE NORTHERN ROCKY MOUNTAINS

Different tree species vary in their sensitivity to herbicides and this usually changes with size, age, and yearly phenological stage of the tree. Any tree is usually the most sensitive when it is small, young, and in an early annual growth period. Target species for stocking reduction are usually the intolerant, seral trees, which typically include lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), western white pine (*Pinus monticola*), Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), and spruce (*Picea engelmannii*). Lodgepole pine, ponderosa pine, and spruce are usually fairly resistant to injury from foliar applications of most herbicides. Western larch is very sensitive to injury from foliar applications of most herbicides. All of these tree species are susceptible to individual tree injections of herbicides.

Target tree species for composition management are often the tolerant, climax tree species, which typically include grand fir (*Abies grandis*), western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and subalpine fir (*Abies lasiocarpa*). These species are usually fairly resistant to injury from foliar applications of most herbicides. All of these tree species are susceptible to individual tree injections of herbicides.

APPLICATION METHODS

The use of chemicals for stand thinning operations is generally limited to individual tree applications. Although some work has been done with general broadcast applications of herbicides, including aerial application, broadcast applications are often not successful. The stand must be broadcast sprayed while susceptible leave trees can be covered to protect them from the spray. Because the leave trees are generally less than 2 ft tall, relatively little canopy cover is present after spraying and the treated areas are subject to reinvasion. Experience with broadcast applications on sites that regenerated after the Sleeping Child Burn on the Bitterroot National Forest showed that stem numbers approached pretreatment levels within 5 to 10 years after treatment (Bigler and O'Connell 1967).

The methods used to chemically thin individual trees can be fairly easily adapted from site preparation and release work. Methods include:

1. *Hack and squirt.* This treatment method is accomplished by making a single hack girdle or frill of overlapping cuts with a hatchet or ax completely around the target tree as close to the base as possible. The girdle or frill should be deep enough to penetrate the bark and cambium layer. Once the target tree has been prepared, the chemical may be sprayed or brushed on until the treatment area is wet.
2. *Injection cylinders.* Cylinder injectors deliver the chemical to the cambium layer after the chisel head has been inserted into the bark and the lever or pull wire has been activated. Injections should surround the tree at intervals of 3 to 6 inches between the centers of the injection wounds (Newton and Knight 1981). Larger trees require closer spacing for effective chemical absorption.
3. *Hypo-hatchet.* Hypo-hatchet injectors deliver a measured amount of chemical with each strike of the hatchet. Again the injections should be 3 to 6 inches on center. Injections can be made at any convenient height.
4. *Capsule-injection bar.* This method is currently under development in Canada (Dillistone 1982). An injection bar drives a capsule with a premeasured dose of herbicide through the bark and into the cambium layer. The herbicide slowly solubilizes and kills the target tree.

Other methods that have not proven effective in the Northern Rocky Mountains include basal spray and granular soil applications. Conifers, because of resistance to absorption through the bark, are not susceptible to basal sprays. Granular soil applications are not effective at low rates on conifers, and at high rates are not selective.

CHEMICALS

The chemicals that are available, have been tested, and are effective on conifers include 2,4-D, picloram, MSMA, and glyphosate (Conard and Emmingham 1984; Kidd and Pope 1982; Wile 1981). 2,4-D is a phenoxy herbicide that can be applied as a foliar spray, basal spray, or individual tree application. When applied as an individual tree application, 1 to 2 mL are applied per inch of diameter at breast height (d.b.h.). The residual time in the tree is short due to degradation (Beste and others 1983). There may be some translocation of the herbicide to the roots and possible exudation into the soil solution.

Picloram is a phenoxy-like chemical that acts similarly to 2,4-D, but is much more residual and is absorbed and translocated at a more rapid rate (Newton and Knight 1981). It can be applied as a foliar spray, basal spray, or individual tree application. When applied as an individual tree application, 1 to 2 mL are applied per inch d.b.h. (Kidd and Pope 1982). There may be some exudate of the chemical from the roots in the soil solution (Ashton and Crafts 1981).

MSMA is monosodium methane arsenate, an organic arsenical. This chemical is usually applied as an individual tree application with 1 to 2 mL applied per inch d.b.h. (Kidd and Pope 1982). Since this chemical is an arsenical, there is considerable concern about potential nontarget effects and environmental contamination. Consequently, use of this chemical has been declining.

Glyphosate is a phosphonoalkyl herbicide that appears to be very effective on most conifer tree species when injected as an individual tree application (Kidd and Pope 1982; Wile 1981). This chemical has a very short residual period in the target tree and is not active in the soil (Sassman and others 1984). Consequently, there is no problem with exudation from the target tree roots into the soil solution. For individual tree treatment on conifers, glyphosate is applied at 1 to 2 mL per inch d.b.h.

Chemicals that have not been fully tested on conifers, but have potential uses, include 2,4-DP, dicamba, triclopyr, hexazinone, ammonium sulphate, tebuthiuron, and fosamine ammonium. Based on chemical structure and comparison with tests on broadleaf species, 2,4-DP, dicamba, and triclopyr all appear to be promising as phenoxy or phenoxy-like chemicals.

COST OF CHEMICAL APPLICATIONS

A comparison of the effectiveness of mechanical, fire, and chemical methods must be based on knowledge of the treatment objectives, stand density, composition, and structure, and fuel distribution and amounts. Estimated costs of mechanical treatments range from $70 to $200 per acre. Estimates of burning costs to achieve thinning objectives range from $40 to $400 per acre. Costs of chemical thinning for individual tree treatments range from $50 to

$200 per acre. The cost of these operations varies widely depending on site characteristics and objectives. Estimates are direct project costs and do not include planning, analysis, or monitoring costs.

Generally, older and larger diameter material is more expensive to thin than smaller diameter material when using chainsaws and mechanical methods. Chemical thinning is most suited for stands containing mid- and larger size precommercial trees that average about 3 inches or larger diameter (Newton and Knight 1981). Since these sites are the most expensive to thin using chainsaws and other mechanical methods, chemical thinning can provide an economical alternative.

Experience with chemical thinning on the Colville National Forest during the 1960's and 1970's showed that chemical thinning costs on favorable sites were 50 to 70 percent of the costs of manual methods using chainsaws (Lehman 1986). Estimated per-tree costs for individual tree chemical applications range from 10 cents per tree for frill application to 8 cents per tree for the injection cylinder to 4 cents per tree for the capsule-injection.

EFFECTS ON STAND CHARACTERISTICS AND ENVIRONMENT

The effects of chemical treatments differ from those of mechanical treatments because target trees are left standing after treatment. Consequently, there is less downed woody material on the forest floor. Mechanical treatments typically create large amounts of continuous, large woody fuels, unless the cut material is piled. These situations may result in high fire hazards if ignition sources are available. In some cases the chemical treatments may provide a dead fuel ladder that could increase risk to the overstory. However, in most stands with larger materials that are suitable for chemical treatment, these fuels would be well dispersed. The vertical spread of the dead material also makes it easier for humans and wildlife to move through the stand. This condition may or may not be desirable.

There is a distinct difference between mechanical and chemical methods relative to the time it takes for the dead materials to be incorporated into the nutrient cycle (Bollen 1974; Stark 1982). With chemical treatments where the dead trees are left standing, additions into the nutrient cycle occur over a much longer time period, generally 10 to 20 years. In stands where there is a large amount of material that is fairly large in diameter, this is a positive attribute.

Stands that are chemically thinned are generally more resistant to wind and snow damage than those that are mechanically treated (Newton and Knight 1981). The dead standing trees also protect the crop trees from solar damage, such as sunscald and defoliation.

Stand thinning can prevent or reduce insect infestations such as mountain pine beetle (Sartwell and Dolph 1976; Sartwell and Stevens 1975). Mechanical thinning has generally been used for this purpose; the value of chemical thinning in the prevention of insect infestations has not been widely investigated. However, herbicides have been used successfully in lethal trap tree control of mountain pine beetles and spruce beetles (Holsten 1985).

Thinning by any method can indirectly affect the incidence of root disease if disease-tolerant tree species are selected as leave trees. The impact of the thinning method on the spread of root disease is less certain. Although evidence is by no means final for all of the root diseases of concern, on some sites the stumps created by mechanical thinning may act as entry points for root pathogens. Some chemical thinning may reduce the spread of root disease. For example, Laird and Newton (1973) showed that hemlock killed with MSMA showed no invasion of *Fomes annosus*, whereas hemlock killed with picloram frequently showed invasion of *Fomes annosus* through hack wounds. MSMA, an arsenical, may exert a localized fungicidal effect.

The role that stumps, hack wounds, and other physical damage play in the spread of root rot requires further investigation. Research may show that less damaging techniques of thinning, such as capsule injection, may lessen the impact of thinning on the spread of root disease.

OPERATIONAL CONCERNS

"Flashback" occurs when the chemically treated tree translocates the chemical to the root system, from which the chemical exudes to the soil and is absorbed in lethal amounts by nontarget vegetation. Flashback has not been documented in conifers or in soils of the Northern Rocky Mountains (Kidd and Pope 1982). However, there have not been many operational chemical treatments, and the possibility of flashback cannot be ruled out. Of the chemicals listed in this paper that have been tested on conifers, all but glyphosate have potential for flashback. On most sites, soil textures and chemical breakdown rates will reduce the concentration of the chemical exudate below a harmful level.

An operational problem that does cause some difficulty with chemical treatments is the absence of visual feedback—the ability to tell which trees have been treated (Kidd and Pope 1982). In dense stands that are not being marked, the applicator can have difficulty keeping on line and determining which trees have been treated. This problem can be solved by marking treated trees with a dye added to the chemical solution.

ENVIRONMENTAL IMPACTS

The use of chemicals in forestry applications often generates concerns about impacts on humans and the environment in general. A problem that may develop at the project planning stage is the negative attitude that local people may have to the use of pesticides. It is very important that concerned individuals and groups are involved at the start of any project and are kept informed of project objectives, cost-effectiveness, and environmental impacts. Full involvement not only educates the public, but also helps the manager to consider fully the alternatives and the objectives.

Individual tree application of herbicides has the advantage of largely confining the herbicide to the target species. The actual quantity of herbicide released to the environment and the duration of the herbicide in the environment will depend on the herbicide and its application method. Of methods discussed here, the hack and squirt method generally uses the most chemical. However, differences among individual applicators can be great. Hypo-hatchets and injection cylinders are designed to use less chemical. Operational difficulties with hypo-hatchets, including leaks and blocked injection nozzles, often interfere with the reliable application of chemical. Capsulized injections generally use less than half the herbicide of other methods.

Regardless of the application method, the initial concentrations of herbicides in the environment will be small. One-half gram of active ingredient is sufficient to kill a 4-inch d.b.h. tree (50 kg assumed weight). Upon translocation the herbicide concentration in the tree would average about 10 parts per million.

Research has generally not been conducted on the residence time of various chemicals when applied to individual trees. Based on research with other application methods, certain general conclusions are appropriate. The arsenic contained in arsenic-based compounds will not degrade. However, the arsenic could change oxidation state, which will change its toxicity. Arsenic would be slowly diluted in the environment as the tree breaks down. Picloram slowly degrades in the environment. Based on residue analysis associated with general broadcast applications, picloram would likely be detected for at least one or two growing seasons after application (Fryer and others 1979). Glyphosate and 2,4-D are more rapidly degraded and would likely not be detected in the general environment within 3 or 4 months following application (Norris 1981; Rueppel and others 1977). Breakdown within the tree is probably slower because of the absence of bacterial activity, although metabolic activity within the tree could help transform the herbicides.

Worker exposure and dosage during pesticide application are receiving increased study. The application methods discussed here differ significantly in potential worker impacts. In a recent study performed for the Forest Service, Lavy and others (1984) measured dose levels in workers involved in either hack and squirt, hypo-hatchet, or injection applications. By far the largest worker doses were received during hypo-hatchet operations. Typical worker dose values ranged from 0.04 to 0.08 mg of 2,4-D per kilogram of body weight, depending on the degree of personal protection used. Values as high as 0.26 mg/kg were seen in some workers who were reported to be clearing clogged hypo-hatchet feed lines by blowing or sucking on them. 2,4-D dose levels above 1 mg/kg have been shown to cause changes in kidney morphology in rats. Since, on a body weight basis, humans can be as much as 6 to 10 times more sensitive than animals to drug effects (National Academy of Sciences 1977), the measured worker dose levels, if received regularly, could have negative health consequences.

Worker dose levels as measured by Lavy and others (1984) during hack and squirt are generally one-third the hypo-hatchet dose levels. Injection bar doses are generally one-tenth the hypo-hatchet worker doses. Worker doses during capsulized injection have not been measured, but should be effectively eliminated.

Worker dose levels will also depend on the herbicide being used. Dermal absorption of herbicides that contact the skin appears to be the major dose route. As measured by Lavy and others (1984), worker doses of picloram are generally one-fifth to one-tenth the 2,4-D dose levels under similar circumstances. These differences reflect the difference in dermal absorption rate between the two compounds (Feldman and Maibach 1974; Nolan and others 1984).

SUMMARY

Chemicals and application methods are available for use in killing trees for stand density and composition management. When managers are selecting between mechanical, burning, or chemical methods, it is important that they examine their objectives and the environmental characteristics of the stands to be treated. Chemical methods are generally more cost-effective in thinning stands that have mid- to large-diameter trees that are not commercial. The stand structure is not changed to a large extent with chemical methods, and fuels are dispersed. Since the dead materials are left standing, the cycle of these materials into the nutrient system occurs over a longer period. Because chemical applications can be very target specific and use small quantities, the potential for environmental contamination is minimal. Worker exposures have been relatively high for the hypo-hatchet methods, due primarily to faulty equipment. It is extremely important, from the standpoint of minimizing both worker exposure and environmental contamination, that every pesticide application be closely monitored to assure that equipment and personnel are functioning correctly, and that the pesticide is being applied according to label directions.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Dennis R. Parent)—Have you had any experience with adjacent trees dying after precommercial thinning from transfer of herbicides by root grafts?

A.—I have not seen any evidence of damage to untreated trees when individual hack, injection, hypohatchet, or capsule-injection methods have been used. If damage did occur it would be very difficult to determine whether it occurred as a result of root exudate into the soil solution or by root grafts. Some of the chemicals that have not been extensively tested, such as hexazinone, have a fairly high potential for mobility by either method. Although the probability is low that this situation can occur, it certainly should be monitored.

MECHANICAL METHODS OF MANAGING TIMBER STAND DENSITY

Hank Goetz

ABSTRACT

This paper examines the range of methods used in precommercial and commercial thinning and their attendant advantages, disadvantages, and relative costs. Selective thinning with power saws gives land managers better control over future stands than does systematic strip thinning in precommercial situations. Depending on species, tree size, topography, and local markets, commercial thinning methods can range from manual thinning with a chain saw to fully mechanized, full-tree harvesting sysems.

INTRODUCTION

"Mechanical methods of managing timber stand density" is a rather elaborate way of describing thinning by hand or machine. Compared to fire or chemicals, mechanical means are the most common method of thinning in the Inland Mountain West of the United States and Canada. The purpose of this paper is not to examine various mechanical thinning systems in detail but to present a range of available options along with their advantages, disadvantages, and relative costs. The emphasis is on systems applicable to natural stands in precommercial and commercial thinning situations.

Because individuals and organizations often assign different meanings to the same term, it may be appropriate to define precommercial and commercial as they are used in this presentation. The second edition of the Forestry Handbook defines a precommercial thinning as one in which the trees are not utilized (Wegner 1984). In some countries, precommercial thinnings are also called "thinning to waste" or "cleaning." Although the meaning of precommercial thinning is generally accepted, there is more disparity in the use of the term "commercial thinning." The Handbook defines a commercial thinning as one in which "some or all of the wood harvested is put to use" (Wegner 1984). By contrast, the definition used by the Society of American Foresters is "any type of thinning producing merchantable material at least to the value of the direct costs of harvesting" (Ford-Robertson 1971). In the first definition, the only requirement is that some of the material be used; however, in the second case the definition is more restrictive because the value of the product must at least equal the harvesting costs. I will use the Handbook definitions of precommercial and commercial thinning.

PRECOMMERCIAL THINNING

Precommercial thinning usually is performed in stands less than 25 years old that contain trees from 1 to 4 inches diameter breast height (d.b.h.) and 15 to 30 ft tall. Stand conditions, however, may vary from area to area. Organizational guidelines, local markets, and terrain often determine whether the thinning is precommercial or commercial.

There are two general types of precommercial thinning—systematic and selective. In systematic thinning (also called strip, geometric, mechanical, or row), all the trees, regardless of size and form, are cut in a predetermined pattern of rows or groups. Although the work can be accomplished by hand, it is done most often by machines. In selective thinning, individual crop trees are left at a predetermined density but not necessarily in a uniform pattern, and the remaining trees are cut manually with a power saw.

Systematic Precommercial Thinning

In the 1960's and 1970's, systematic precommercial thinning was tested extensively in the United States and Canada, particularly in stands of "doghair" lodgepole pine (*Pinus contorta*) (Alm and others 1979; Bella 1972, 1974b; Bella and DeFranceschi 1971, 1982; Lotan 1967; McCreary and Perry 1983; McKenzie and Miller 1978; Tackle and Shearer 1959). The purpose of many of the studies was to determine the proper combination of technique and machinery to economically thin large areas in extremely dense stands. In a stand of lodgepole pine containing 100,000 stems per acre, Bella (1972) reported a 1966 treatment cost of $5 to $6 per acre using a drum chopper and crawler tractor (excluding initial chopper cost); the average tree was 1 inch d.b.h. and 9 ft tall. McKenzie and Zarate (1984) summarized information about 33 models of mechanized precommercial thinning and slash treatment equipment. The units varied in cost from $10,000 for a farm tractor-mounted slasher to $350,000 for a self-contained mobile chip-harvesting machine. In addition, they listed results, including direct costs, of 75 field projects in which 16 of the machines were used. Although the costs vary widely according to type of machine, prescription, and terrain, the majority are in the $80- to $100-per-acre range.

Strip thinning can be an economical method of treating large areas of small trees on gentle terrain; however, the system does have disadvantages. A major concern is the growth response of trees in the leave strips. Alm and others (1979) reported unsatisfactory release in stands of jack pine. McCreary and Perry (1983) reported that after strip thinning in a 35-year-old stand of Douglas-fir, trees more than 10 ft from the edge of the strip did not respond. Bella and Franceschi (1982) concluded that growth after a roller chopper operation in lodgepole pine was only half that expected with a medium to heavy thinning using selective methods. A strip thinning in lodgepole pine, which left rows 2, 6, and 12 ft wide, showed significant diameter and volume release only on the 2-ft-wide strips. To accomplish this release, however, 86 percent of the area was left unstocked, and the overall volume increment was only 20 percent that of the unthinned area. As a result, Lotan (1967) concluded that this method was not recommended for thinning young, overdense stands of lodgepole pine without additional efforts to achieve desirable spacing. Other concerns that have limited the application of mechanical thinning in Canada include the survival of low branches in the cut strips and damage to edge trees in the residual strips (Johnstone 1985). These problems, and concerns about the slash hazard created, have also curtailed mechanized, systematic precommercial thinning in the United States (Deden 1986).

Although the value of mechanized strip thinning alone is questionable, some recent investigations indicate that this method may be viable when used in conjunction with selective thinning in the leave strips. From work in British Columbia, Johnstone (1985) reported that the combined approach should reduce by half the cost of conventional thinning with chain saws in dense stands. Seymour and others (1984) conducted a study in Maine in young spruce-fir (*Picea* spp.-*Abies* spp.) stands with 14,000 to 38,000 stems per acre; they calculated costs of $135 per acre using a rotary swather to cut strips 8.7 ft wide and than selectively thinning the leave strips with chain saws and brush saws.

Selective Precommercial Thinning

Selection of individual leave trees is the norm for most thinning operations in the Mountain West, and it is used in a wide range of species, size classes, and terrain conditions. Most organizations have developed specific spacing guides for their areas. Representative residual densities range from approximately 1,000 trees per acre in stands of small lodgepole pine in interior Canada (Hedin 1982; Johnstone 1985) to 200 stems per acre in lodgepole and ponderosa pine (*P. ponderosa*) in the United States (Betts 1986; Maus and Goetz 1986).

The most popular technique is hand felling with chain saws. Other tools have been tested, however, primarily in dense stands of lodgepole pine reproduction in Canada. In one study, ratchet-action shears, originally developed for horticulture work, were used to thin stands that were 3 to 10 years old; the trees were approximately 3 ft tall with a diameter of 1 inch at ground level. The crew averaged 5.5 trees per minute or 0.16 acres per 7-hour working day (Hedin 1982). Brush saws have also been used to thin slightly larger stems; production varied from 5 to 25 hours per acre depending on crew experience, stand density, and tree size (Bella 1974a; Hedin 1982). Seymour and others (1984) reported production rates of 8 to 17 hours per acre in the study cited previously, where brush saws were used in conjunction with a rotary cutter. Brush saws can be a useful and productive alternative to the chain saw for thinning stands with stems from 1 to 3 inches d.b.h.

The costs of selectively thinning with chain saws depend on a variety of factors, including crew experience and motivation, stand density, tree size, method of slash disposal, and terrain. The typical treatment is felling and then bucking the slash to a given height above the ground—usually about 2 ft. For example, in western Montana, it costs approximately $60 per acre for contract crews to thin trees from 2 to 6 inches d.b.h. with minimal slashing. By contrast, in dense pole stands, where all the material has to be slashed within 2 ft of the ground, costs can reach $170 per acre (Klug 1986). On the Wenatchee National Forest in Washington, crews are thinning stands of lodgepole pine up to 15 ft tall to a 14-ft spacing for $100 to $200 per acre. These figures reflect the direct cost of the thinning and do not include overhead and administration, which increase costs another 30 to 40 percent (Betts 1986; Klug 1986; Reynolds 1986). Total costs then range from $78 to $280 per acre.

Additional slash work, such as removing material from roadside strips or piling and burning, will increase costs. In a test conducted on the University of Montana's Lubrecht Experimental Forest, a series of plots in a stand of pole-sized ponderosa pine were thinned and a variety of methods used to dispose of slash. Data from this study demonstrate the increasing costs per acre associated with different slash disposal methods: (1) drop and leave, $45; (2) lop and scatter, $87.50; (3) pile and burn, $287; (4) full tree removal and chipping, $210 after sale of the chips (Maus and Goetz 1986). On the Colville National Forest in Washington, average costs increased from $150 to $260 per acre when contract crews were required to pull back slash 66 ft from roadsides (Reynolds 1986). The thinnings were in Douglas-fir (*Pseudotsuga menziesii*) and western larch (*Larix occidentalis*) stands with trees ranging from 2 to 4 inches d.b.h. and 10 to 20 ft tall.

Although selective thinning with power saws may not always be practical in extremely dense stands, this versatile method has advantages that justify its popularity. First, unlike fire or systematic thinning, this method gives the land manager direct control over the composition of the future stand. Second, cutting is cheaper than many methods of chemical thinning, and it ensures that competing trees are, in fact, eliminated (sprouting trees may be an exception). Miller (1984) compared the costs of selective thinning with chain saws to basal spraying and stem injection in a 12-year-old stand of hardwoods, where approximately 14 stems were removed for every crop tree left. The cost per crop tree was 42 cents for chain saw removal, 61 cents for stem injection, and 80 cents for basal spraying. Third, foresters can adapt this technique with relative ease and low cost to a range of local conditions. Most organizations use contract crews who are responsible for selecting leave trees at the prescribed density following written guidelines or sample-marked field plots. Operator selection has proven to be an efficient and cost effective method of choosing crop trees (Kammenga 1983).

COMMERCIAL THINNING

Traditionally, commercial thinning implied that the value of the trees removed was sufficient to pay for direct harvesting costs. The material was most often sold for sawlogs, pulpwood, posts, or poles. In recent years, however, market opportunities for small-diameter trees have increased significantly in many areas of the Mountain West. Because of advanced technology, smaller logs can now be sawed economically into traditional lumber products or chipped for use in reconstituted panels such as oriented strand board. The energy crisis of the 1970's also opened new markets for industrial boiler fuel and residential firewood. As a result, land managers have the opportunity to thin stands that once were considered too small for commercial thinning. The value of the products removed defrays thinning costs, either partially or completely. Changing utilization opportunities are affecting not only traditional terminology but also methods and systems available for commercial thinning.

The basic premise of commercial thinning is that the residual stand will respond, and the trees will grow more rapidly and contain more valuable products at final harvest. The type of selective thinning method used will depend on local market conditions, tree species, size of material, stand area, and topography. The systems can vary from one person with a chain saw and pickup cutting tree props to a fully mechanized system that generates a range of products from hog fuel to peeler blocks. Between these extremes are systems that use inexpensive, portable machinery suitable for the rancher, woodlot owner, or part-time contractor.

Conventional Systems

With conventional systems, trees are felled manually and skidded with choker-equipped machines. The trees can be limbed and bucked in the woods or at the landing. Shortwood systems are used extensively in Europe and, to a lesser degree, in eastern North America; however, in the Mountain West, most contractors prefer tree-length or full-tree systems. An obvious exception is in lodgepole pine, where some operators manufacture posts and tree props in the woods and transport the finished product by hand or machine to the loading area.

Gonsior and Johnson (1985) summarized the major disadvantages of conventional harvesting systems:

> Costs are extremely sensitive to average piece size and density. Felling costs per unit of volume may be lower than for some types of mechanized operations, but a penalty is paid in skidding. Skidder operators must locate and hook each piece. The process is time consuming and makes it difficult to fully utilize machine capacity.

One method that can be used to increase skidder capacity is to prebunch the stems with a winch (Host and Goetz 1983; Maus and Goetz 1986; Seymour and Cadzik 1985). A study in Maine (Seymour and Cadzik 1985) compared production and costs of skidding and skyline yarding with and without prebunching in stands of small-diameter spruce and fir. Although winch prebunching improved skidding production by dramatically reducing cycle times and increasing loads, the savings were only slightly greater than the cost of the prebunching operation. The study also noted that costs increased threefold as the average tree size declined from 8.5 to 5.5 inches.

Despite some inefficiencies, conventional systems will continue to be used for commercial thinning because of lower investment cost for equipment. In addition, unlike some of the more mechanized systems, conventional equipment can work on small units in a variety of stand conditions and terrain.

Mechanized Systems

Due to smaller log sizes and increased labor costs, mechanized harvesting has become more popular in our region over the past 10 years. All phases of logging (felling and bunching, grapple skidding, delimbing and bucking) can now be mechanized. In addition, some operators are processing material into boiler fuel or pulp chips at the landing with portable debarkers and chippers. Depending on local conditions, commercial thinning operations can take advantage of any or all of the mechanization options. At minimum, most will employ a feller-buncher and grapple skidder; and, if hog fuel or pulp chip markets are available, debarking and chipping equipment can be added to the mix. The recent introduction of steep-terrain feller-bunchers, such as the Timbco and Spyder, has enabled mechanized logging to move from gentle terrain to steep slopes; however, cable yarding often must be used on the steeper slopes, and this is more expensive than ground skidding on gentle terrain (Goetz and Maus 1986; Gonsior and Johnson 1985; Murphy 1979; Seymour and Cadzik 1985).

According to Gonsior and Johnson (1985), the major advantage of mechanized harvesting is that harvesting costs can be reduced in terms of dollars per unit of volume; although hourly costs increase significantly, volume production also increases. Because mechanization allows an operator to harvest smaller trees with greater efficiency, more stands should be available for commercial thinning. Smaller trees, however, usually have a lower value, so the final product mix is critical in fully mechanized operations. Mandzak and others (1983) conducted a study of a fully mechanized operation in young, overstocked stands of ponderosa pine and Douglas-fir that contained some sawlog-sized trees. The operation produced both sawlogs and full-tree chips for boiler fuel. They concluded that profitability was closely related to the balance between sawlogs and hog fuel production.

There are some distinct disadvantages associated with mechanized logging systems. First, the high equipment costs will limit the number of contractors available for commercial thinning. Second, a large and stable local market is necessary for small-stem products. Third, the higher costs of moving and setup will require larger thinning blocks than may be necessary for conventional systems. Finally, mechanized commercial thinning often requires more attention to unit layout and marking than is necessary with conventional systems. The forester must consider the limitations and capabilities of the machines, particularly the feller-buncher, when designating leave trees, skid trails, and landing locations. Compromise and cooperation among the silviculturist, contract administrator, and operator are absolutely necessary. As in precommercial thinning, it may be more desirable and efficient for the operator to select leave trees.

Small-Scale Systems

There are commercial thinning situations where conventional or mechanized systems are too costly or otherwise inappropriate. Many landowners choose to do their own thinning and want to remove the slash to reduce the potential damage from fire or insects. Objectives other than maximum timber production (forage production for livestock or wildlife, recreation, esthetics) may be of primary importance. In the past 10 years, we have tested various small-scale systems on the Lubrecht Experimental Forest that can be used to cut and remove full trees less than 8 inches d.b.h. on gentle or steep terrain. The emphasis has been on low-cost, portable, and versatile equipment suitable for the woodland owner or part-time operator. Detailed descriptions of the studies are available from the School of Forestry, University of Montana, Missoula (Maus and Goetz 1986; Goetz and Maus 1986).

On terrain with slopes of less than 20 percent, we used a three-person crew—a sawyer and two stackers—to fell and bunch stems smaller than 5 inches d.b.h. Production rates varied from 30 to 80 ft^3 per person per hour, depending on tree size. Forty stems per crew-member-hour has been the consistent average. A variety of small feller-bunchers have proven more efficient than hand crews for stems 6 inches d.b.h. and larger. The machines cut and piled 70 to 110 trees per hour, compared to hand-crew production of 20 to 30 trees per person per hour. On steeper terrain the crew was reduced to two people—a sawyer and stacker-pusher. Production rates were very sensitive to tree size, increasing from 43 to 99 ft^3 per crew-member-hour when the average tree increased from 1 to 8 ft^3. By comparison, production reached 240 ft^3 per crew-member-hour in a lodgepole pine clearcut where the average tree was 7.5 ft^3.

Our main skidding machine has been a conventional farm tractor, modified somewhat for woods use, and equipped with a shop-built grapple. We have also used two kinds of winches (a 6-hp, radio-controlled model and one that is mounted on the three-point hitch of a farm tractor) to prebunch trees for the tractor grapple. At distances from 400 to 750 ft, the grapple-equipped tractor skidded an average of 170 ft^3 per hour. The trees contained 1 to 3 ft^3. In contrast, production with the radio-controlled winches, prebunching a distance of 100 ft, averaged only 70 ft^3 per crew-member-hour for similar-sized trees. Lanford and Hoffman (1983) reported a 30 percent increase in production when a farm tractor was equipped with a grapple rather than a winch. Although the production per crew-member-hour is significantly lower with the winches, they are useful for prebunching material from short, steep slopes or other areas otherwise inaccessible to the grapple tractor.

On steep terrain, we used the Bitterroot Miniyarder to remove full trees from thinnings and to log small lodgepole pine clearcuts. The Forest Service Equipment Development Center in Missoula designed and built the two-drum, live skyline yarder. The unit, powered by an 18-hp gasoline engine with a hydrostatic transmission, has a 17-ft boom and can be mounted on a 3/4-ton flatbed truck or trailer. The skyline drum carries 600 ft of 3/8-inch cable, and the mainline has 800 ft of 1/4-inch line. Parts and rigging for the machine cost approximately $7,500. In thinning operations we used a three-person crew—one operator and two people in the brush who set chokers and moved the skyline stop. In clearcut applications, only one person worked in the woods. We preferred the trailer-mounted version because it was mobile and easy to set up on narrow roads and ridgetops.

Yarding production was sensitive to tree size, crew size and type of cutting. Production in thinning operations went from 46 to 78 ft^3 per crew-member-hour when the average piece size increased from 1 to 8 ft^3. The average yarding distance was approximately 300 ft in both cases. By contrast, the two-person crew produced 92 ft^3 per crew-member-hour yarding 8-ft^3 trees at the same average distance in the clearcut. Other studies with the Miniyarder have produced similar results. A two-person crew salvaging material from a fire-killed stand of lodgepole pine in Colorado averaged 54 ft^3 per crew-member-hour (Lynch 1986). The average piece size in this study was 11.7 ft^3. Baumgras and Peters (1985) reported an average rate of 34 ft^3 per productive crew-member-hour yarding fuelwood from an Appalachian hardwood clearcut site. The average piece size yarded by the four-person crew was 5 ft^3. They also noted that the low owning and operating cost of the yarder and its limited capacity made crew size important to economical operation. Brown and Bergvall (1983) tested the same machine with a four-person crew yarding red alder (*Alnus rubra*) in Washington. On an operational basis they expected to produce 50 ft^3 per crew-member-hour with an average piece size of 5 ft^3. The yarding cost per cord was similar for all three studies: $28.42, $27.71, and $33.36, respectively.

Successful application of small-scale systems requires initiative and innovation by the thinning crew. Problems must be overcome by "working smart" rather than by horsepower. A closely coordinated and systematic approach is a necessity in the entire operation from stump to landing—the felling-bunching phase is particularly crucial. Economic viability depends on tree size, crew size, silvicultural prescription, and value of the end product.

CONCLUSIONS

It appears that contracted manual felling with a power saw will continue to be the most common method of precommercial thinning in the Mountain West. The system is versatile and can be applied over a range of species, size classes, and terrain. Contracted thinning can be a problem for public agencies that are forced by organizational policy to accept unrealistically low bids. When the contracts are inevitably defaulted, agency administrative costs rise, and the thinning is not accomplished in a timely fashion. One solution may be to negotiate professional service contracts with firms that have the experience and ability to do the work right the first time. Although initial contract prices may be higher, long-term savings should result from lower administrative costs.

Commercial thinning opportunities depend primarily on local markets. A successful operation in one area may not be feasible for the same species and material size in another location. Although the trend is toward mechanized harvesting systems, they require a stable market and large areas of similar-sized material for economical operations. Mechanization also necessitates negotiation and compromise in thinning-unit prescription and design. Conventional systems will continue to dominate in the areas with limited markets or where the thinning units are small and scattered. Although not feasible for large commercial operations, the small-scale approach using inexpensive equipment will fill an important niche for the landowner/operator or the land manager with special slash disposal requirements.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q.(from Anonymous)—How do the costs of small cable systems (for example, Wyssan) or short-span or multispan systems compare in commercial thinning? Advantages? Disadvantages?

A.—A significant cost consideration in using one of the three yarding options would be the rigging and setup time. The traditional Wyssan system would be the most expensive because the winch is set on the uphill side of the unit and gravity is used to yard the material downhill on a standing skyline to a landing. The material must be fully suspended during yarding, so numerous intermediate supports may be required to elevate the skyline. However, once the system is in place a large area could be thinned from one setting. By contrast, a short- or single-span skyline system can be rigged relatively quickly, but the terrain profile will limit its application. A multispan skyline configuration requires more rigging time than a single span, but it can be used over a wider range of terrain profiles. We have used the Bitterroot and Clearwater yarders in both single and multispan configurations. Depending on individual circumstances, two people can rig an intermediate support for the Christy carriage in approximately 45 minutes. Based on our experience with commercial thinning, I believe that the slight extra cost of rigging a multispan setting is more than offset by the increased capability of the system.

Q.(from Anonymous)—What about manual felling and horse logging for small-dimension material?

A.—I believe that it would work when the trees were limbed and topped in the woods and skidded either tree length or log length to the landing for manual bucking, decking, or loading. This approach may be most feasible in a post and pole or shortwood pulp operation. However, in full-tree thinning situations, horse skidding would not be practical unless a machine were available to pile brush at the landing. I am not aware of any studies that have directly compared productivity of grapple skidders and horses under similar circumstances. Although my experience with horse logging is limited, I feel that the grapple units would substantially outproduce the horses. Small-stem harvesting is expensive, and it is more effective to handle bunches of small trees rather than individual pieces.

SESSION 4.

The Decision

Andy Lukes
Session Coordinator

The previous sections of this proceedings addressed the resource opportunities, the analysis tools for diagnoses, and then the practices in probably the most comprehensive collection of papers ever presented on the effects of stand culture in western North American forests. All of that information leads to this section, which elucidates the decision process. This process must consider all of the previous information, integrate it with management objectives and economics, weigh the costs and benefits for society as a whole, and then result in the decisions. When implemented, this entire process represents the scorecard of our success as professional resource managers. If we can learn through education and experience, we can attain success in the management of our future forests.

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DECISION MAKING FOR FUTURE PUBLIC FORESTS

Jeff M. Sirmon
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ABSTRACT

Forest Service managers must consider nontechnical factors—social, political, and economic—as well as technical factors before reaching a decision. Early National Forest managers were directed by simple statements of purpose and responsibility and decision making largely was a matter of professional judgment. A series of laws have introduced public involvement and analytical planning frameworks, and sometimes specified management, narrowing the decision space for the manager. Today more options must be considered for public land decision making to be effective. The capability of the land provides the boundaries within which decisions can be made. Then, an approach of gathering data, analyzing options, and consulting with the public provides the best opportunity for a good decision.

INTRODUCTION

Thank you for the opportunity to participate in this symposium. I'm honored to be part of what I think has been an excellent discussion of the future forests of the Mountain West. My talk today will center around decision making for National Forest land.

It has been interesting to listen to some of the earlier presentations. Many excellent technical solutions have been offered to specific situations faced by forest managers. However, the best technical solution is not always the best management action. In the Forest Service, our job is not just management of forest lands, but management of publicly owned and used forest lands. Consequently, Forest Service managers must consider nontechnical factors—social, political, and economic—as well as technical factors before they reach a decision.

Decision making is relatively simple when you are making a decision that affects only you. Life gets slightly more complicated when your decision affects the rest of your family. By the time your decision affects neighbors, visions of lawyers begin to dance in your head. So imagine what it's like when your decisions deal with this Country's public lands and their use. The results of those decisions affect local individuals and communities; county, State, and regional economies; and the well-being of the entire Nation.

I'm not sure who first said, "You can't please all the people all the time," but I'm sure he or she didn't have the Forest Service in mind. I'm kidding, but as stewards of more than 190 million acres of National Forest land, we are obliged to manage the resources to supply the greatest good . . . to the greatest number . . . in the long run. That is our mandate by law and by tradition.

HISTORICAL PERSPECTIVE

Let me give you a brief historical perspective that might help you understand our decision-making processes. The Organic Act of 1897 stated that the National Forests were established to improve and protect the forest, maintain favorable conditions of water flows, and furnish a continuous supply of timber for the use of the American public. That simple statement of purpose and responsibility made forest management decisions relatively easy.

The phrase I used earlier, "the greatest good to the greatest number in the long run," was the instruction on conflict resolution offered by then Secretary of Agriculture James Wilson to Gifford Pinchot, the first Chief of the Forest Service. That direction, and the small number of laws affecting public land management, made decision making relatively simple in the early days of our Agency.

Because of this simplicity, and because the Forest Service used, and still uses, a decentralized management approach to the extent possible, decision making by forest managers was primarily based on professional judgment and "doing what was right" for the land and its resources. Decisions were based largely on current, short-term needs or desires for forest uses.

That approach, although frowned upon by some today, was effective. And at the risk of boasting, I think the Forest Service did a good job of making it work. At that time, most of the land designated for National Forests was neglected land. Today, the National Forests are productive, valuable lands . . . lands it seems everybody wants, and lands in which all Americans recognize a vested interest. So, the forest managers' professional judgment must have been pretty darn good.

Unfortunately, the times are no longer as simple; the laws directing management of public lands are no longer as few; and the level of interest in how these lands are managed is so great, and often so diverse, that new decision-making techniques are required.

I mentioned earlier that the National Forests were created through enactment of legislation—the Organic Act of 1897. That was the simple beginning. Now, not only are National Forests created through legislation, but much of

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their management is directed by law. Obviously, when you're talking about decision making for public forests, the pertinent legislation defines the decision space. Let me briefly mention some of the legislative landmarks that govern many of our decision-making practices.

LEGISLATIVE MANDATES

The first pertinent legislation I'll mention is the Weeks Law of 1911. It provided authority to acquire land to add to the National Forest System. As more land outside the public domain was acquired, decision making became more complicated.

In 1960, Congress passed the Multiple-Use Sustained Yield Act. This law instructed that the National Forests would be administered for "outdoor recreation, range, timber, watershed, and wildlife and fish purposes," and that renewable surface resources would be managed to achieve a sustained yield of resources in perpetuity without harming the land's productivity.

This was the most comprehensive directive issued to forest managers since the Organic Act in terms of how the public forest land should be managed. However, the impact of this law on our decision-making technique was not profound, because, in fact, this law basically endorsed what our professional land managers understood and practiced—that a forest can produce a wide variety of services and products for a sustained period of time. Additionally, while this law helped to define the decision space, it didn't direct, or "straightjacket," the decision-making process.

The next key law that affected the forest manager's decision space was the Wilderness Act, passed in 1964. I am proud to say that long before this law directed establishment of preserved wilderness areas—in fact 40 years before when a wilderness area was administratively designated on the Gila National Forest—the Forest Service was imposing management restrictions on some areas of land. However, the Wilderness Act was perhaps the first legislation that directed or restricted the forest managers' decision-making process. That is, it said, "You will manage some lands in a particular way."

In 1969, Congress passed the National Environmental Policy Act (NEPA), one of the most far-reaching management directives. In part, NEPA requires all Federal agencies to prepare reports on the environmental impacts of proposed major programs and actions and to evaluate alternatives to them.

Perhaps NEPA's major impact on National Forest management has been defining how alternatives are constructed and evaluated. It has added new dimensions to the decision-making process by stressing reliance on interdisciplinary teams within the agency and participation by the public. After passage of NEPA, the professional judgment skills of the forest managers were supplemented by analytical processes, public involvement techniques, and consultation with lawyers.

The movement toward imposing a comprehensive analytical process on public land managers continued with passage of the Forest and Rangeland Renewable Resources Planning Act of 1974, better known as RPA. This law also further formalized the Forest Service's reliance on long-range planning as a guide to decision making and program budgeting.

The most recent major piece of legislation that affects the flexibility of our decision-making process is the National Forest Management Act of 1976, which amended RPA. This law requires each National Forest to develop a comprehensive, long-range management plan. It also gives directions on how the plan will be developed, including detailing certain common decision-making procedures. We are just now completing the first round of Forest Land Management Plans for all 156 National Forests.

Of course, laws are not the only impacts on the land managers' decision-making process. The budget is a good example of another nonresource factor affecting decision making. However, the point of my brief review of the history of legislation that affects our decision-making process is to emphasize that laws often narrow the decision space for forest managers, and I feel safe in predicting this trend will continue in the future.

Although new laws have tended to narrow the forest managers' decision space, the managers' responsibilities haven't necessarily gotten easier. The demands on forest resources are more complicated today than ever before. That means that more options must be considered if sound decisions are to be made. The information presented during the last 2 days has helped expand our awareness of options for effective decision making in management of public lands.

THE DECISION-MAKING PROCESS

Having said all that, let me discuss how the decision-making process will be used to shape the future of our public forests. Perhaps a good way to explain the process is to visualize a three-legged stool. Let the seat represent the resource management decisions. One leg of the stool represents the gathering and analyzing of data to develop a series of alternatives for management of the land and resources. We talked a lot about this during Technical Session II. The second leg of the stool represents the evaluation of all the data. The second technical session also touched on this part of our decision-making process in the discussion of modeling. The third leg represents the public's involvement with the decision makers. Not only is public involvement mandated by law, it's also mandated by common sense. The National Forests are public lands, and the public should be involved in deciding what goods and services are produced on these lands.

Abraham Lincoln said, "Public opinion is everything. With it, nothing can fail. Without it, nothing can succeed." I'm not sure I'm convinced that nothing can fail with public support, but I know very little can succeed for the public land manager without that support.

Getting back to my analogy of the three-legged stool, I'm sure you know precisely what happens when one of the legs of a stool is missing. The surface on which you would normally sit is unstable, and your backside is destined for a meeting with the floor. In forest management, the balance of the stool only comes with decision making that is responsive to the social and economic needs and desires of the public, tempered by the capability of the land and its resources to produce.

We must understand that, within obvious boundaries, the land base does not dictate uses to which it should be put. The land and resources provide opportunities for any number of uses and combinations of uses. People—legislators, interested citizens, and Forest Service managers—must help make the allocation and use determinations.

A good illustration of my three-legged stool analogy is our Forest Land Management Planning process. In this process, we identify the resource base, thoroughly analyze the data, ask the public for assistance in determining what they believe is the best use of the resources for the greatest number over the long run, and we decide a course of action.

THE PLANNING PROCESS

Long-range planning is not new to the Forest Service. In one form or another it has been part of our standard operating procedure from the beginning. Consequently, when we were directed by the National Forest Management Act to formulate long-range,comprehensive plans, we had a large resource database. To that historical base we added current data and new analytical techniques.

The interdisciplinary planning team incorporates the data into analytical models that allow us to better understand the effects of particular types of management approaches. While the data are being gathered and analyzed, the public is asked what their preferences for use of the forests are.

Based on the data, analysis, and public comment, the planning team develops a list of management alternatives. After the options, or alternatives, are developed, the managers make a preliminary decision and select a preferred alternative.

The preferred alternative and a full range of the other capable and feasible alternatives are then presented to the public for review and comment in the form of a Draft Environmental Impact Statement, or EIS for short. The review period for a Draft Land Management Plan EIS is 90 days.

Perhaps I should explain that the comments from the public are not seen as votes, but rather they are seen as advice. In other words, the alternative that gets the largest volume of support is not necessarily the one adopted. To use the public involvement in that way would be abdicating our responsibility as professional land managers. It would turn our management into a popularity contest. Often, the reasons given for a particular point of view are more useful in the decision making than the point of view itself. The volume of response is, however, an indication of the degree of public interest in an alternative, and it is considered in the evaluation.

Basically, the chief value of this review period is to make sure we have heard and understood the public comments offered at the beginning of the decision-making process. And of course, we review the plans internally to provide for comment by all the disciplines represented in the Forest Service—the foresters, engineers, landscape architects, wildlife and fish experts, recreation specialists, archaeologists, economists, sociologists, and so on.

Finally, the data obtained from the review process are gathered and analyzed and a final decision on the alternative to be implemented is made. This is documented in the Record of Decision that accompanies the Final EIS and Plan. All this—the record of decision, the Final EIS, and the Plan—are matters of public record, so the public can assist in monitoring our implementation. We've also developed an administrative appeals process that allows anyone to appeal a decision within 45 days of the date it was made and published. This process also allows for negotiated settlement of conflicts over the plan of action to be taken.

That is a rather quick overview of our planning process. I've used the planning process as an example of a decision-making technique because the different components of the decision-making process are fairly easy to see; and because the planning process pervades all aspects of our management.

RPA

I have not intended in any way to slight the importance of the national decision-making process that is defined by RPA. In fact, RPA and Forest Land Management Planning processes are interconnected and complement each other.

Both RPA and Forest Planning provide a description of the present uses, projected needs, and a general picture of the land's potential to produce. In RPA, this picture of the land's potential to produce is called the Assessment. In the Forest Planning process, it is called the Analysis of the Management Situation, or AMS.

Both processes define issues based on public comments and evaluate potential ways, or alternatives, to deal with these issues. Both processes evaluate these alternatives for their social, economic, and environmental effects and present them to the public for judgment before an alternative is implemented.

Both processes provide the public and the decision maker with a much clearer understanding of what will be accomplished in the near future and what will be monitored so future decision making will be facilitated.

One key difference between the two processes is that RPA, though compiled from data gathered at the Forest level, paints a broad vision for the management of the National Forest System while the Forest Plans hone in on management of one specific geographical area.

The important point, whether talking about RPA or Forest Planning, is that Forest Service decision makers have a process, which was designed to make long-term decisions, that has provided a good base for making short-term project and activity decisions. In the past, our decision makers had neither. Now they have both, and this systematized decision-making process will assist managers in the future.

THE DECISION MAKER

Let me stress the word "assist," because one fact is unmistakable That is that there is no prescribed formula for decision making. Universities can teach decision-making techniques, but no one can provide a "cookbook" that covers all the intangibles that affect decisions. Our decision-making processes are designed to isolate factors to help the manager reach a decision. But after all is said and done, the manager must still rely on professional judgment to know when that "three-legged stool" is correctly put together. The manager still has the task of defining a course of action that is legally permissible, financially and technically feasible, and publicly and politically acceptable.

I started today by saying that decision making that involves more people than yourself is complicated. But anyone involved in public land management, or public service of any type, must be prepared to deal with difficult, complex decisions. Laws help define a decision space. And the capability of the resource—the land in our case—provides boundaries within which decisions can be made. Then, the three-legged stool approach—gathering data, analyzing options, and consulting with the public—will provide the best opportunity to make a good decision. That's true today, and I believe it will be true in the future.

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Speakers answered questions for the audience following their presentations. Following are the questions and answers on this topic:

Q.(from Anonymous)—Over the past decade, some people contend that the Forest Service has become more a manager of increasingly complex processes initiated by NEPA, RPA-NFMA, rather than managers of the resources themselves. How would you respond to this? How could this perception be changed?

A.—Beginning with the National Environmental Policy Act of 1969, and continuing through the 1970's, 15 pieces of legislation were passed that affect National Forest management. This congressional direction has caused Forest Service planning to become more complex. It also involves the public to a much greater degree than before. I believe the end result, however, is better plans with better public understanding and acceptance.

I also believe that with the completion of Forest Plans we will be able to focus more of our energies to on-the-ground resources management.

Q.(from George J. Rogas)—How do you balance the desire to have specific land management prescriptions (Jack Ward Thomas-Wildlife Habitat Needs) and the flexibility needed to incorporate a changing knowledge base into the interdisciplinary process?

A.—The Forest planning process provides for interdisciplinary involvement in developing prescriptions for specific areas of land. Some areas, for example, such as riparian zones require a specific prescription because of the resource values involved. Other areas may have prescriptions that permit more flexibility. The planning process is dynamic and provides for accommodating new knowledge or demands. This may result in amendments or revisions of National Forest Plans. This amendment process, however, must also use an interdisciplinary approach and include full public involvement.

CRYSTAL BALLING FUTURE MANAGEMENT OBJECTIVES FOR WESTERN CANADA'S INTERIOR MOUNTAIN REGION

William Young

ABSTRACT

Western Canada's interior mountain region is comprised of the southern interior of British Columbia and the southern portion of the Rocky Mountain slopes of Alberta. The area is characterized by a diverse resource mix that is second to no other region in Canada. Future resource managers must be cognizant of this diversity and the ever-present challenge to achieve integrated use objectives for the optimum benefit of all western Canadians. With wise management and use, the forest lands of Western Canada's interior mountain region should continue to maintain and enhance a viable ranching industry, forest recreation opportunities, a diverse wildlife resource, important fisheries values, and a quality water resource—all the while contributing to the maintenance of a healthy and viable forest industry.

INTRODUCTION

I appreciate the opportunity to be part of this symposium to undertake a little "crystal balling" of the future forest management objectives for Western Canada's interior mountain region.

WHAT AREA IS INVOLVED?

Initially, I had some difficulty defining the "interior mountain region" in Canada since this geographic description is not used in Western Canada. However, after some telephone and correspondence exchanges with the symposium organizers, I arrived at this definition. I've defined the interior mountain region in Western Canada to include all the area east of the Coast Range and including the eastern slopes of the Rockies in Alberta. To the north, I have extended the area part way up the North Thompson River drainage, along with the inclusion of the entire Columbia River drainage. In other words, I have specifically excluded the Cariboo-Chilcotin Interior Plateau and the boreal forests of north-central and northern British Columbia and Alberta.

ARE THERE ANY MAJOR DIFFERENCES BETWEEN THE RESOURCES OF THE WESTERN CANADA AND WESTERN U.S.A. INTERIOR MOUNTAIN REGIONS?

Like those of you from below the line who have spent some time in southern British Columbia and Alberta, I have spent a little time in the forests of the adjoining United States. I am always struck by the similarity of the resource and its use in both areas—from trees to wildlife or from cattle grazing to watershed management. Notwithstanding this general similarity, it is true that a specific resource of the forest may not be as abundant in one area as in another. For example, mountain caribou are not really uncommon in the forests of Western Canada's interior mountain region. On the other hand, the small Selkirk caribou herd that apparently strolls southward over the 49th parallel from time to time is on the United States endangered list of wildlife species.

Cooperative management and research initiatives in both countries are attempting to maintain or increase this small population. I recall a field trip with British Columbia and United States biologists and foresters when we saw a magnificent specimen still in Canada but only 1 mile north of the border. As we watched this animal in awesome silence, it proceeded to relieve itself amidst a shower of caribou pellets. As one, the Canadian and United States wildlife biologists pulled out plastic bags from their pockets and rushed to the site to gather their gems, leaving the foresters of both countries standing—dumbfounded. Finally, one forester from Idaho in a dry, monotone voice broke the silence with the statement, "There's nothing like a pile of manure to separate a group of biologists and foresters."

Thus, in assessing future management objectives for the Mountain West forests, I believe that with a few minor exceptions we are talking about similar uses of a similar resource—witness the motto of the Western Forestry and Conservation Association—"One Forest Under Two Flags."

ARE THERE DIFFERENCES BETWEEN THE POLICIES GOVERNING THE WESTERN CANADA AND WESTERN U.S.A. INTERIOR MOUNTAIN REGIONS?

Yes, there are differences, although apart from one major difference, I have found that the policies governing the management of the forest resource on the public lands of the interior mountain region in both countries are remarkably similiar.

For example, the British Columbia 5-year program process is modeled after the U.S. Department of Agriculture Forest Service's RPA process. Even the determination of rates of timber harvest is more compatible than most would believe. While the "even-flow philosophy" may be incorporated into United States legislation, "departures" can occur for sound management reasons. Thus, comparisons of adjoining management units along the border of the two countries with a similar skewed age class imbalance and infested with the lodgepole pine bark beetle would find that the final approved rates of timber harvest determined for the two areas would not be unduly different.

However, there is one major difference between the Western Canada and Western U.S.A. interior mountain regions. It is land ownership. While the United States region has a mixed ownership, the Canadian counterpart has not. In fact, the British Columbia/Alberta area being discussed is unique in the western world in that well over 90 percent of its forested area is public land. In British Columbia, at least, this decision to retain forest land in public ownership while allotting harvesting rights to the private sector was made 100 years ago.

Thus, it seems to me that management decisions pertaining to the use of public forest lands in Western Canada will have much more impact on western Canadians than similar decisions on **public** forest lands in the United States would have on United States citizens due simply to the significantly higher percentage of private land ownership in the United States.

Regardless of this difference in the ownership pattern between the interior mountain forests in Western Canada and Western United States, both countries must plan for the wise management and use of these forest lands and be determined to avoid the "Christopher Columbus style" of management.

WHAT CHALLENGES ARE FACED IN PLANNING FOR THE WISE MANAGEMENT AND USE OF THE INTERIOR MOUNTAIN FORESTS OF WESTERN CANADA?

The interior mountain region of Western Canada is probably the most diverse region in Canada. The topography ranges from moderate, plateau-like lands to some of the most rugged topography in the world.

The climatic conditions range from near desert-like lands to virtual rain forests. The area is home to Canada's most diverse wildlife resource. Part of the area feeds the Fraser River—one of the world's most important salmon rivers. Much of the area lends itself to use by cattle and thus is the home of a ranching industry of some significance. Major parts of the region such as the Kamloops-Okanagan area, the East Kootenays, and the eastern slopes of Alberta's Rocky Mountains are under major pressure for forest recreation opportunities. Not the least of the challenges is the maintenance of water quality and quantity in the thousands of small drainages that supply water for domestic, agricultural, and recreational use—especially in the drier portions of the region.

Of course, the diversity that I have mentioned equates to a quality of life and is the reason that many western Canadians choose to live in and visit this region. Yet, I submit that this diversity presents complex integration challenges that are not broadly comparable to those of any other area in the world—except, of course, the parallel interior mountain region of our United States cousins.

It is this diversity and the need to integrate a complex multitude of resource values into a sound integrated resource management strategy that completely dominate any vibrations that I get from my crystal ball. Such strategies should strive to ensure that the forest lands of Western Canada's interior mountain region produce a varied array of forest benefits for western Canadians. Again, any such strategy must be cognizant of the pitfalls of the "Christopher Columbus" syndrome.

WHAT DOES THE CRYSTAL BALL REVEAL OF FUTURE RESOURCE MANAGEMENT DECISIONS FOR THE INTERIOR MOUNTAIN REGION OF WESTERN CANADA?

Within the overriding integration challenge that I have alluded to, let's review the future through the eyes of the various sectors.

Timber Management

I project that timber management will maintain an important role in the region—albeit not necessarily the dominant role in some areas. I see the impact of forest land alienation for other uses, along with the management impacts of other resource interests having a negative effect on the maintenance of the current rate of timber production. On the other hand, corresponding positive influences can come into play. For example, expanded stocking control programs in the often overdense forests of the area (namely lodgepole pine and dry belt Douglas-fir—yellow pine immature forests) will have a very positive effect. I foresee the development of the necessary fiber utilization facilities that are essential to fully utilize the hemlock component of the vast areas of decadent hemlock-cedar forests in the area. A planned replacement of these forests, which are largely deleted from the determination of rates of timber harvest, will have a significant positive effect on future rates of timber harvest.

In assessing the potential of Western Canada's interior mountain forests, my crystal ball reminds me that some of the region's forests are found on the more productive forest lands in Western Canada—second only to the West Coast forests.

Wildlife Management

My crystal ball tells me that the goal to maintain species diversity throughout the Provinces and within the interior mountain region will continue. Populations of pioneer species such as caribou and grizzly bear will be maintained at an acceptable level. On the other hand, I foresee population increases in species such as elk, deer, and moose where the wise management of the region's forest and range lands has demonstrated that such is possible. Coupled with this, I see a much stronger punitive approach to the indefensible act of poaching along with a more enlightened public approach toward predator management. In effect, I foresee a public recognition that the pressure on some wildlife populations can be primarily through poachers and predators, not through habitat impacts or hunting.

Fisheries Management

I see a trend away from the protective stance of fish habitat protection to one of habitat management and enhancement. This trend will become particularly evident in the management of salmonids. In particular, I can see habitat management being undertaken in conjuction with forest harvesting.

My crystal ball tells me that with this shift in emphasis, much can be done during forest harvesting to enhance and improve fish habitat. In particular, the inclusion of fish habitat requirements as a component of forest harvesting plans will help realize this objective.

Cattle Grazing

I see the continued emphasis on the integration of resource uses furthering a viable ranching industry in Western Canada's interior mountain region. With sound cattle management procedures, I foresee an increase in cattle use after logging in areas such as dense lodgepole pine stands that hitherto offered no range potential whatsoever. I see this potential being realized through the strict **scheduling** and **control** of cattle grazing on regenerated logged areas, so that forage values would be utilized without depreciating the potential of the new forest.

I foresee the current dispute between cattle and elk use being resolved through the realization that it is an allocation issue and not a resource management issue. There should be little problem in increasing the total forage potential for elk and cattle without any undue effect on each other or other resource uses—including timber production. Thus, it is the allocation, and not the realization, of this potential that needs to be resolved. My crystal ball tells me that these differences will be resolved and that cattlemen, biologists, and hunters will work together on initiatives to increase the forage potential. In so doing, they and other forest land user groups will gradually embrace the theme that: "We may get into the odd argument as to who should have the bat or ball, but we are as one regarding the maintenance of the ball park."

Forest Recreation

I foresee no slackening of public needs for forest recreation opportunities. In fact, increases in population, tourism, and more free time will create increasing demands on Western Canada's interior mountain region.

Resource managers will have a major challenge to demonstrate to the public that integrated use will supply forest recreation opportunities and that parks and designated wilderness areas are not the only areas in which such experiences can be enjoyed. My crystal ball tells me that this is one of the most important issues that resource managers must discuss with and demonstrate to the general public.

Water Management

I foresee the need for a major emphasis in this area if integrated use (including timber harvesting and cattle grazing) is to exist in drainages that are considered important sources of domestic and agriculture water. Further, I see that the integration of timber harvesting and water management in many drainages may result in less-than-the-maximum production of wood. Today, this is one of the major concerns in the management of the region's forest lands. My crystal ball is sending me some fuzzy messages here, but it is clear that water management requires increased attention, including improved inventory data and research support.

Land Use

I foresee increased emphasis being given to land use zoning whereby resource use priorities, in time and place, are identified. Some zoning will involve new parks, ecological reserves, wilderness or natural areas, and the like, and may preclude some other uses. However, I foresee that wise management and use of the majority of the region's forest lands will demonstrate that through a commitment to multiple use—including the declaration of prime use in time and place—all compatible resources can be accommodated. I foresee this matter to be the single key challenge to resource managers. The public must be convinced that such integration and compatibility of resource uses can produce the optimum benefits to society.

In particular, my crystal ball tells me that resource managers and users of the region must promote and demonstrate the benefits of multiple use through:

1. cooperation rather than conflict;
2. consensus rather than dissension;
3. integration rather than balkanization.

Silviculture Investments

I foresee silviculture investments increasingly being planned to accommodate other resource uses compatible to the timber resource.

For example, stocking control measures in the region's dry belt Douglas-fir—yellow pine forests will increasingly consider forage production and access for cattle and wildlife. Similarly, the intensive management of the often overly dense lodgepole pine stands must consider forage and access barriers in precommercial thinning activities if the potential for cattle and wildlife habitat is to be realized.

I trust that although my crystal ball incessantly sends out its integration signals for the future of Western Canada's interior mountain region forests, no one has inferred that emphases on forest stand improvement through forest genetics, improved site preparation techniques, brushing and weeding programs, precommercial thinning programs, as well as improved utilization of the timber resource, are not essential. In fact, my crystal ball tells me that the expansion and enhancement of such programs are even more essential within an integrated resource management strategy for Western Canada's interior mountain region.

Some of the integration programs will have negative impacts on the timber production potential, but favor the common good and optimum return from the forest land base. Thus, the enhancement of intensive forestry practices and increased utilization of the forest resources are the essential components needed—at the very least, to keep these impacts to a minimum; at best, to increase the rate of timber harvest.

Finally, my crystal ball is issuing a couple of strong warnings to western Canadians—warnings that may also be applicable to the Western United States.

It warns that the strategies of the future should be:

- planned, rather than ad hoc
- deliberate, rather than haphazard
- goal-oriented, rather than drifting
- flexible, rather than rigid.

In its one last message before fading away, my crystal ball gives this advice to planners, strategists, and resource managers planning the future use of Western Canada's interior mountain forest lands:

Strive to avoid the management style of Christopher Columbus who:

- when he started, didn't know where he was going;
- when he got there, didn't know where he was;
- when he was finished, didn't know where he had been.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Arnold J. Browning)—Will Western Canada continue to harvest at current levels of cut for the next 50 years?

A.—I would estimate that the rate of timber harvest will not decrease appreciably from current levels over the next 50 years in the provinces of Alberta, Saskatchewan, and Manitoba. In British Columbia (where 45 percent of Canada's timber is harvested), the general imbalance of age classes and the large acreages of mature and relatively short-lived species (such as lodgepole pine and white spruce) will mean some reduction in harvesting levels from those currently in place.

While the level of the reduction will be dependent on the social/economic/technical assumptions projected and the severity will vary throughout the Province, the best Province-wide analysis indicates a reduction of approximately 10 percent from current levels of harvest. This estimate involves the public and private forest land within forest management units only—although, forest lands not included are a negligible factor in British Columbia.

THE FUTURE OF THE FOREST INDUSTRY IN THE MOUNTAIN WEST

William A. Atkinson
John R. Olson

ABSTRACT

In July and August 1986, the authors contacted a selected group of forest industry leaders in the Mountain West regarding their thoughts on the direction of forest management, timber supply, legislation, industry structure, markets, and information needs. This paper reports the results of this process and provides an up-to-date view of concerns and challenges faced by the forest industry over the next few decades. Industrial foresters deal with a multitude of natural and human-caused threats to the viability of a major source of employment and economic wealth for the region; their success is by no means assured. Survival of the industry in anything resembling its current form will require a much greater level of effort on the part of all stakeholders than has heretofore been the case.

INTRODUCTION

Forest industry is a major source of employment and economic wealth for the Mountain West. This paper discusses how forest industry leaders in the Mountain West regard the direction of forest management in relation to wood supply, cultural practices, and other factors pertinent to the industry in the next few decades.

In July and August 1986, the authors contacted a selected group of forest industry leaders in the Mountain West regarding their thoughts on the direction of forest management, timber supply, legislation, industry structure, markets, and information needs.

This paper reports the results of this process and provides an up-to-date view of concerns and challenges faced by the forest industry over the next few decades. Industrial foresters deal with a multitude of natural and human-caused threats to the viability of a major source of employment and economic wealth for the region; their success is by no means assured. Survival of the industry in anything resembling its current form will require a much greater level of effort on the part of all stakeholders than has heretofore been the case.

This paper will be presented in three parts: The recent past, the current situation, and directions for the future.

THE RECENT PAST

It will come as no surprise to any of you that the forest products industry in the Mountain West has had a rough time in the recent past. The early 1980's brought a severe recession to the wood products industry as a whole. During 1980-82 we experienced higher interest rates which depressed housing and resulted in lower demand for lumber and wood products. In addition, a great deal of new solid wood production came on line in Canada, and in the Southern United States, generally from efficient low-cost mills. Lumber, plywood, and log prices declined rapidly throughout the United States and, even today, are considerably below 1979 levels. What this meant for the industry in this region was mill shutdown and curtailed production; particularly affected were the older, nonefficient, high-cost mills. Even some efficient mills were forced to shut down because of low prices for their products. To compound problems, during this period the Canadians captured about one-third of the domestic United States lumber market by taking advantage of both a weak Canadian dollar relative to the United States dollar and the startup of new, efficient, low-cost mills.

We have also seen the forest products industry in the Mountain West concentrating harvests more heavily on its fee lands. Fee timber became the cheapest and most available wood around. Heavy cutting of fee lands actually began with the decline in harvests from public lands, beginning in the early 1970's. This came about as a result of both a reduction in available public timber and increased cost of harvesting on these lands. Table 1 clearly shows a marked decline in public timber harvest between 1969 and 1979. To compensate for this decline and to maintain cash flow, harvests on private industrial lands increased dramatically.

If these weren't enough problems, the 1980's also brought a number of disruptive takeovers and forced mergers. The forest products industry has been a prime candidate for this kind of activity because stocks in forest products companies are generally valued low relative to their assets. To make this situation worse, a very small

Table 1—Total timber harvest from private and public[1] lands by year (Keegan and others 1982, 1983)

Year	Idaho		Montana	
	Private	Public	Private	Public
	Billions of bd ft			
1969	0.547	1.113	0.362	0.900
1979	0.809	0.881	0.570	0.550
1984	0.861	0.848	0.566	0.501

[1]All Federal (BLM, USFS) harvest included.

percentage of stock in timber companies is controlled by any one stockholder, so it is difficult to organize a group of owners to fight a serious takeover attempt. Due to the economic climate of this period, we also saw forest products companies paying lower dividends and realizing low profits, which further depressed stock prices. This situation obviously led to a good deal of instability within companies, confusion regarding management direction, and a more serious drive to be profitable. Costs are being cut to the very bone, there have been major layoffs of staff, unprofitable operations have been closed, and new agreements have been negotiated to reduce labor costs. These are simply a response to the need to survive as an economically viable organization.

THE CURRENT SITUATION

This section begins by reviewing some basic statistics about the forest products industry in the Mountain West, particularly Montana and Idaho. This will provide a perspective on the industry and how it fits into the economy of these two States.

In 1985, the forest products industry in Idaho and Montana generated approximately $1.5 billion in product sales from the 2.8 billion bd ft of timber harvested. In the same year, the industry directly employed approximately 23,000 people (9,300 in Montana and 13,700 in Idaho) and generated over $500 million in salary and payroll (Keegan 1986).

In 1985, Idaho's forest products industry accounted for approximately 19 percent of that State's economic base (Polzin 1986). In Montana the contribution from the industry to the economic base of the State for 1985 was 17 percent (Polzin 1986). Regionally within the two States the industry is of even more importance. In northern Idaho (northern Idaho is the area north of and including Idaho County) and western Montana (western Montana counties are Lincoln, Flathead, Sanders, Lake, Mineral, Missoula, and Ravalli), the forest products industry historically has accounted for more than 40 percent of the economic base (Keegan and others 1981, 1983). In 1981, the forest products industry provided 45 percent of the labor income generated by western Montana's economic base. This is approximately 44 percent of the total economic base, including agriculture (Keegan and others 1983). Clearly, the forest products industry plays a major role in the economic well-being of this region.

In order to be as up-to-date as we possibly could for this paper, we started several months ago to survey the forest industry in the Mountain West. We identified a number of key leaders in the industry, in the associations that represent industry, and in the universities, put together a questionnaire to these people, and followed up by phone calls and personal conversations. A listing of questions asked in our survey follows this paper. We found that although industry does not speak with one voice (it never has), in general, people in the industry are concerned about the same kinds of things. There was a general consensus of opinion on a number of items dealing with timber supply, legislation, the structure of the industry, forest management, and markets. We will take a look at wood supply from fee lands. Then we will discuss industry's perception of wood supply from public lands.

Timber Supply in the Mountain West

Private Timber Supply—Although there is obviously some geographic variation, we can expect a major reduction in harvest levels from industrial lands, something on the order of 30 to 50 percent, starting as early as in 5 to 10 years. This results from the high level of fee harvest necessary to replace public wood whose supply was reduced or which was made very costly, and harvests of low cost fee timber to improve profit and maintain cash flow. Because of the high rates of cutting on private timberlands, the supply of merchantable timber has been depleted; this will lead to major reductions in harvest levels in the future. Every company surveyed will experience this. As fee harvests decline and large, high-value trees disappear, characteristics of logs available for conversion are obviously going to change. Most of the volume will be in small logs, less than 15 inches in diameter. However, these small logs will be relatively sound, and they will contain relatively good wood, but there will not be a lot of high-grade clear lumber. There will also be a shift from the higher valued species such as white pine, ponderosa pine, and Douglas-fir to more true fir and lodgepole pine. This is significant because it is obviously more difficult to make a profit from lesser valued species. In addition, small logs will mean increased logging costs, which means we must be as efficient as possible in both logging and conversion. It is likely that some mills will not have enough wood, resulting in more shutdowns and layoffs. We should expect a sorting out of manufacturing plants in the region, resulting in closure of all remaining inefficient outdated mills. On a more positive note, there will also be modernization of those mills that still have wood supply. We will see continued pressure to reduce operating and labor costs. Sales of mills to independently run companies will no doubt continue, and only the most efficient low labor cost and low wood cost mills are going to survive.

What is happening in the Mountain West needs to be put into perspective with the tremendous cost competition today from Canada, from the South, and from the Northwestern United States. Everyone is trying to be the low-cost producer of wood products. It's going to be a tough league to play in over the next few decades.

The age class gap on industry lands and resulting reduction in harvests will extend 30 years or so until the understory (advanced regeneration) comes on line to provide economically harvestable volumes of merchantable timber. Clearly, the management of existing understory will be crucial to both the mid- and long-term timber supply picture on industrial lands. The reduced wood supply from industrial land and the associated decline in value of the wood is a major trend that must be recognized and dealt with.

Public Wood Supply—The other major wood supplier in the Mountain West is the Forest Service, U.S. Department of Agriculture. What happens on National Forest lands regarding levels of timber management and harvest

Table 2—Ownership of commercial timberlands in Idaho and Montana (Keegan and others 1982, 1983)

Ownership	Commercial timberlands	
	Idaho	Montana
	Percent	
Private industrial	7	11
Other private	15	21
Public, Forest Service managed	68	57
Other public	10	11

will directly affect what happens on industrial lands, in mills, and in local communities. Table 2 provides some idea of how important the public commercial forest landbase is to the forest products industry in this region. Sixty-eight percent of the commercial timberland in Idaho is publicly owned and managed. In Montana this proportion drops slightly to 57 percent. In comparing this information with that shown in table 1, one can see that at least 50 percent of the roundwood harvest comes from only 7 and 11 percent of the commercial timberlands in Idaho and Montana, respectively.

One would think that the harvest planning efforts of industry and the Forest Service ought to be integrated in some way, but you don't see a lot of that happening. There is great concern on the part of industry that National Forest harvest levels will fall even more. The Forest Service generally seems focused on its nontimber resources; a great deal of emphasis is on wildlife, wilderness, recreation, and water. Decisions that the Forest Service makes in the next year or so regarding its level of available wood supply will influence the course of the industry and the economy of this region for the next few decades. It seems to us that it is totally naive and wrong for the Forest Service to carry out harvest planning in a vacuum, without looking closely at wood supply from other sources. We understand that the Forest Service was directed by the then Assistant Secretary of Agriculture, Peter Myers, to study the role of National Forest timber supplies in sustaining local communities. Nowhere is this more important than in the Mountain West. Certainly, a good part of the original rationale for public ownership of forests had something to do with supporting local forest-dependent communities. Social goals are not strangers to the Forest Service. Perhaps we ought to declare sawmill workers, loggers, and small towns endangered species. Maybe then their plight would carry more weight in setting National Forest harvest levels.

Several other concerns about the management of National Forests were expressed in our survey. Industry commends the salvage of vast acreages of mountain pine beetle-killed lodgepole pine but is not impressed with the overall handling of the infestation. We all knew it was coming. The problem doesn't lie with entomologists but with managers. There should have been more management action taken based on anticipation of beetle attacks—more roading, harvesting, and more timber stand improvement to improve health and vigor of stands to reduce acreage most susceptible to attack.

This seems to be a prime example of a common problem of our profession in this technological age—the failure to execute what we know we should do.

Concern was also expressed in our survey about below-cost timber sales. Some respondents think this may ultimately have more of an impact on wood supply potentially available for harvest than the harvest levels coming out of new forest plans. The Forest Service clearly has got to operate as efficiently as possible by minimizing costs of putting up timber sales as well as costs to the purchasers so they can make a living logging the timber and keeping the mills operating. There is widespread belief (and good evidence) that it costs the Forest Service a good deal more to do anything than it costs private industry.

Legislation

Without doubt, trends in the coastal States of the United States are toward more restrictive forest practice legislation. We anticipate the same thing will happen in the Mountain West. Environmentalists will turn to forest practice legislation after battles over Forest Service plans, roadless areas, wildlife set-asides, and the like are resolved. The big issues in the Mountain West appear to be water quality protection, management of streamside zones, and chemical application. It is extremely important that the people who are dealing with forest practice legislation keep in mind that we are in a cost-control environment and cannot afford to raise the cost of forest management and harvesting so high that the region becomes uncompetitive.

It would be most enlightening if we prepared economic impact statements along with environmental impact studies every time a new regulation is proposed that will impact management and harvest operations of the timber companies. In the State of Washington a prototype study of this kind currently evaluates proposals for new riparian zone legislation to identify economic impacts of changes in the forest practice law: how many jobs are going to be lost; what are the impacts on communities; how much forest land will be out of production? This information will then be used along with environmental information to analyze the various proposals that have been put forward. People in the Mountain West need to be thinking about similar approaches to both the decline in Federal forest harvest and to any new forest management legislation that might be on the horizon.

The other aspect of legislation that came up in our survey is the new Federal tax bill. The basic changes will be elimination of capital gains rates and reduction of normal income tax rates. There will be no change in the current deductions allowed for forest management—expensing of most management costs, including interest and property taxes, is still going to be possible. The thought of losing this option actually scared the forest products industry more than the loss of capital gains itself. In addition, loss of the investment tax credit and longer equipment writeoffs in the new bill will hurt all capital-investment industries and increase the total tax bill for the forest products industry. At this time there remains a good deal of uncertainty about what the impacts of all this are going to be. However, it is safe to say that recent changes in the tax law alone are not going to lead to the demise of private forest management or the forest products industry in the region.

Industry Structure

For reasons already discussed, it is clear that survivors in the Mountain West are either going to be integrated large companies that have a stable wood supply and can benefit from opportunities to invest capital to lower their costs, or they are going to be small independent operators who find market niches and who can also maintain low production costs. Even though the forest industry in general continues to be vulnerable to takeovers and forced mergers, it seems to us that the major threats to the industry are business related and not takeover related.

Forest Management

A major part of our survey of forest industry dealt with management practices. We found that industry foresters are generally dealing with reduced budgets for forest management. They are being much more selective in choosing which practices to carry out, and everything is now analyzed for financial return. Clearly, emphasis is on less costly practices aimed at getting the most from what already exists; for example, more reliance is being placed on natural regeneration or the use of salvage operations or firewood cutting to improve the timber resource.

Industry foresters in some cases are having to relearn the art of silviculture and be more creative. There is renewed interest in the concept of intensive versus extensive management, with intensive forestry to be practiced only on selected high-return sites. There is also increased need to decide what areas warrant intensive management and to be able to stratify such differences within ownerships. Respondents generally reported that they are short-staffed; most certainly this is going to continue with those still employed shouldering more responsibility. However, new technology such as personal computers and geographic information systems is being used to help offset staffing shortages and aid in land stratification for investment analysis.

Private industry is learning how to operate with reduced staff, for example, by becoming more decentralized. We see more simple, few-layered organizational structures. Back in the 1970's, forestry programs were often run by the head office, which led to communication problems, some bad decisions, and too often poor on-the-ground practices. Though decentralization of forest management is being driven by cost cutting, it generally is regarded as a good thing because the person on the ground should be the best judge of a situation.

Our survey question about quality control in forest management brought forth varied responses. Some feel quality control is synonymous with experienced foresters. Due to staffing reductions however, there has been a deemphasis on monitoring contractor performance for activities such as planting and thinning. The ground forester, though experienced and knowledgeable, is often unable, because of time limitations, to carry out responsibilities as in the past. Most respondents sense a growing need to improve quality control but cite time and manpower availability as the greatest limitations in achieving this goal. Along these lines, new technology in the area of data management has great potential, freeing up the experienced forester from tedious and time-consuming tasks. Clearly, a relook at our priorities is in order to ensure that what gets done on the ground meets expectations.

We also asked about research and other information needs. One significant conclusion is that tree improvement in the region appears to be in trouble. In some organizations it is being kept alive solely by the interest and professionalism of foresters, but they cite that they often are just barely keeping a basic program going. The obvious problems with tree improvement are the high up-front costs, the long time before payoff, and the difficulty in quantifying gains. Keep in mind that realization of tree improvement gains also requires artificial regeneration, which is expensive; and that the trend today in the region appears to be toward more natural regeneration. Respondents agree that tree improvement continues to be extremely important in the Southern United States, reasonably important in the Pacific Northwest, but of somewhat lesser importance in the Mountain West.

Industry foresters also feel that they need more and better information to determine financial attractiveness so they can decide which cultural treatments are economically viable. This analysis requires an improved ability to forecast treatment responses and future returns. Forecasting growth and yield is a difficult problem in the Mountain West, where you have multistoried, many-aged stands of numerous species growing on a variety of sites. Compare this with the Southern United States where you often have even-aged plantations of one species. It seems to us there needs to be more business management input into decisions regarding growth and yield research. Just how accurately do we need to be able to forecast growth and yield of a stand? Researchers generally provide a different answer to this question than operational managers or financial analysts. You also get a difference of opinion, depending on whether you talk to economists or biometricians, about the importance of their respective disciplines in the process. Economists often feel that the weak link in financial analyses is in the growth and yield numbers; biometricians feel they have reasonably good growth and yield numbers compared to estimates of future values or discount rates.

Another area of importance identified in the survey is basic information about the local, State, and regional economies. We need to understand them all better, including how the forest industry impacts these economies and how changes in the wood products business impact society at large. What is the relative importance of timber, recreation, tourism, and government to community stability? All indicators show that we are going to see major political battles over resource management issues in the Mountain West. There is a great need for accurate and accessible information on the economy of the region. Another survey question dealt with how industry foresters plan to get this research and management information in the future. There is clearly strong support for cooperatives directed by the universities. The key lies in the ability of the regional universities to lead and direct such efforts and to provide measurable returns to cooperators. In addition, private consultants are now organizing co-ops in specific areas, for example, growth and yield. Another innovative practice that we see a great deal is the rise in the use of personal contacts with successful practitioners. These contacts are not necessarily researchers but people who know what they are doing based on experience. There seems to be a greater need to develop a structured approach to foresters' interactions, a way to pass on knowledge. The old philosophy that supported proprietary research has given way to more shared expertise between organizations. A good example of this is the Inland Empire Vegetation Management Working Group, which is identifying expertise and field contacts in the region so that foresters can get together on a one-on-one basis. In the future, computerized data bases will further enhance and facilitate these interactions. Also important to note is that in-house research as we knew it has changed in emphasis and appears to be focused on more technical support functions. Most organizations surveyed indicated that they will rely more on outside sources for basic research information in the future. There clearly will be more reliance on public institutions to conduct basic research and organize the transfer of technology. This means a bigger role for extension foresters who now need to include large private corporations, as well as small landowners, as clients.

Markets

The final portion of our questionnaire dealt with current thinking on markets. There seems to be two camps when it comes to markets for forest products. One camp feels that there is a basic need to develop products and markets that add value to small logs and less valuable species and will allow us to utilize raw material not now being used. The other group feels that we are always going to be dealing primarily with commodity products and that we should recognize that fact and decide to make a business success out of manufacturing a commodity. In today's economic climate, the only way we will be able to do that is to become very efficient and achieve low cost in both production and distribution. Certainly our resource base is changing, but the lack of large trees and large logs is not really a technical problem. Technology is available to deal with small trees and has been for a long time. The challenge will be to apply this technology and avoid attempts to "reinvent the wheel."

There is obviously some room for market niches and new ideas; pelletized fuels, for example, and laminated beams from lodgepole pine. Flakeboard products are another possibility, but here we must compete with producers that are closer to the major markets and have a very low cost fiber resource at their disposal. It is our feeling that these specialty markets and niches are going to be important but are not going to bail out the industry. We are going to have to survive basically on the same products that we are making today, but we will have to get better at doing what we are doing.

DIRECTION FOR THE FUTURE

In this final section of the paper we would like to offer a few conclusions and comments on the future. It is obvious that the forest products industry has moved into a new era. We are not going back to the 1970's, and the industry must find new ways to conduct business, new ways to organize, new ways to produce and market products. We are seeing new relationships develop between people and organizations. The forest industry in the Mountain West competes in national and global markets with other timber-producing regions that are also working very hard to produce their products at low cost. Many have a number of competitive advantages that are not available here in the Mountain West. Every issue is in essence a cost issue, and this region must compete to survive. The ability to control costs will determine the future of this industry.

We feel there needs to be more public awareness of the seriousness of the wood supply situation in the region. The direction taken in forest management and harvest levels by both public and private timberland managers is going to have a major impact on the livelihood of communities, workers, and their families. People need to be made aware of the issues and the impacts they may have on their future. There clearly are some things that can be done about wood supply. We must continue to encourage the Forest Service to seriously consider opportunities to increase harvests where feasible, at least during the coming wood supply crunch.

As far as industrial forest management goes, we certainly approve the move to decentralization. The person on the ground ought to be the one to make the best decisions, but we must make sure that he or she really is making the best decisions. Too many foresters risk being hidebound in tradition, or are doing things the way they did when economics were different. We must strive to be more creative. We need the challenge to be cost efficient and objectively evaluate management options. Most importantly, there must be more accountability in forest management. As with other segments of the industry, the person making the management decision should be accountable for the results of that decision. We need to record reasons for making decisions and collect followup information. This is primarily a business management problem. Too often there is no structured followup, no real measure of results which should accompany auditing of expenditures and financial analysis of investments. This is required to both evaluate the success or failure of our decisions, and also to guide future decisions. Accountability is an important part of becoming as cost effective as possible.

Finally, to end on an upbeat note, industry shouldn't give up in the Mountain West. Our major competitive regions have their own problems, which are generally related to wood supply. The South, Northwest, and Canada all have their own age gaps coming up.

Much of the Mountain West can grow trees economically if we let nature give us a hand—in fact, we may be able to grow wood cheaper here than most anywhere else. Industry should maintain its core forestry staffs, continue to upgrade technology, support research and development, and above all hang in there.

Industry, Forest Service, and all owners of timberland should have similar objectives when it comes to growing timber—grow and harvest it as efficiently and economically as possible. To this end we suggest a great need to combine forces, utilizing existing knowledge and experience to ensure survival of the forest industry in the Mountain West.

ACKNOWLEDGMENTS

The authors would like to thank the respondents for their candid and open response to our questionnaire. This paper reflects the opinions and concerns expressed by those responding as well as those of the authors.

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QUESTIONNAIRE ON INDUSTRIAL MANAGEMENT IN THE MOUNTAIN WEST

Information will be used to prepare a paper for the conference: "Future Forests of the Mountain West," Missoula, MT, September 29-October 3, 1986.

W. A. Atkinson and J. R. Olson

PART I. Timber Supply Fee or Company-owned Lands:

What do you see as trends in:

- supply of timber and harvest levels
- distribution of tree and log sizes available for harvest
- species composition available for harvest
- wood quality (any concerns regarding growth rate, form, degrade, etc.)
- disease/insect impact on current and future wood supply
- fire potential and impact on wood supply

National Forest:

What do you see as trends in:

- supply of timber and harvest levels
- distribution of tree and log sizes available for harvest
- species composition available for harvest
- wood quality (any concerns regarding growth rate, form, degrade, etc.)
- disease/insect impact on current and future wood supply
- fire potential and impact on wood supply

PART II. Regional and National Legislation

- What do you see on the horizon relative to legislation that might significantly impact forest management activities in the region or your operating area (i.e., forest practices legislation, environmental issues, etc.)?

PART III. Industry Structure

- How do you view the stability of individual timber companies in the region today—and in the future?
- Do you see any trends relative to mergers, breakups or takeovers in the Mountain West?
- How are organizational structures (and general management philosophies) changing within your organization and the region in response to a changing industry in general?

PART IV. Forest and Timber Management

- Have your basic forest management practices changed in recent years (e.g., natural versus artificial regeneration)? Specifically, what kinds of activities will be justifiable and employed in the future (what's being abandoned or curtailed?)
- How is new technology being employed in your organization to assist managers in the decision-making process (e.g., Geographic Information Systems, data management systems)?

- How does your organization rank the importance of tree improvement/genetics? Will this area receive more or less attention in the future? Why?

- Are (or will) concerns about wood quality impacting decisions to conduct intensive thinning and/or fertilization programs or other intensive management practices in the future?

- Generally speaking, are your forest management budgets declining, increasing, or static? Do you feel future management strategies will be more extensive or intensive?

- How does your organization achieve "quality control" with regard to cultural practices? How are investments tracked and evaluated for success or failure?

PART V. Yield Prediction/Financial Analysis

- Are you satisfied with current growth forecasting technology?

- What types of improvements would be of highest value to you?

- What level of accuracy do or will you require in growth and yield forecasting capabilities?

- How do you rate the importance of growth and yield forecasting and financial analysis with regard to justification of forest management investments?

- Generally speaking, how are management **options** being evaluated and compared (e.g., harvest-plant-PCT versus harvest-natural regeneration) within your organization?

PART VI. Information/Research Needs

- What are your highest priority areas of information need today. . . ? What about 5-10 years from now?

- How does your organization currently gather management or research information (in-house, co-ops, universities, etc.)? What do you see as a likely trend in the future for gathering this type of information?

- How is the type, kind or accuracy of information you require changing? Why? How is it being integrated into the decision-making process?

PART VII. Markets and Manufacturing

- What new products do you see on the horizon, and how might they impact the industry in this region?

- What new marketing strategies are being employed in this region and how are (should) they be changing in response to these difficult times?

PART VIII. Anything Else?

- If you were giving this paper, what would you emphasize?

- Any other thoughts?

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from anonymous)—The point was made that public land managers should increase allowable wood harvest during the coming wood crunch. Where is this increased harvest supposed to come from? Should we rob the future to pay for the present?

A.—The Forest Service manages approximately 65 percent of the commercial forest land in Idaho and Montana. Forest industry owns about 10 percent—and yet harvest levels are approximately the same. Granted, industry harvest level is not sustainable, but it is not that far off. There is absolutely no reason why Forest Service harvests cannot be increased substantially without "robbing the future." All that is required is a judicious application of the science of forestry.

Q. (from anonymous)—Elaborate on accountability. Is it based on profitability or long-term land management and long-term land productivity?

A.—Accountability is independent of management goals and is needed regardless of management goals. Accountability means that people making decisions are responsible for those decisions, and that they cannot escape this responsibility because results are not measured. Accountability also means tracking past decisions and learning from them so that decisions are improved in the future.

In the past it was difficult to keep appropriate records to accomplish accountability, but new data management capabilities remove this excuse.

ECONOMIC VALUES AND TIMBER CULTURAL PRACTICES

Dennis L. Schweitzer
Robert N. Stone

ABSTRACT

Economic values depend upon human desires and rules of government. They can be estimated through direct observation or through logical inferences. The most critical economic characteristic of cultural treatments is the time lag between application and results. Trends toward wood fiber markets suggest traditional investment strategies in cultural practices should be carefully reconsidered.

INTRODUCTION

There is a fable from India about six blind men from Indostan. One day they fell in with a mahout, the keeper of an elephant. He told them of the many virtues of his wonderful animal: an elephant is big, it is strong, it is brave. But they did not understand, for they could not see. So the mahout led them to the elephant so they could understand what it was through their hands.

The first man from Indostan touched a leg and declared an elephant is like a tree, a big tree. But the second touched a tusk and disagreed; the elephant was more like a spear. Then the man who touched an ear shouted they were both wrong, for it was like a fan, and the others claimed in still louder voices that elephants were like snakes, or walls, or ropes.

The well-meaning mahout was astounded by the clamor. That night, he was moved to write a poem (Saxe 1963):

> And so these men of Indostan
>   Disputed loud and long,
> Each in his own opinion
>   Exceeding stiff and strong,
> Though each was partly in the right,
>   And all were in the wrong.

Economic values can be like that elephant. If we are not careful, we can end up arguing because we are talking about different things. The role of this paper is to serve as sort of a mahout of economic values—to make sure we all are touching the same places. The focus here is on describing what this "elephant" is; the two papers by Schuster and Loomis (this proceedings) discuss how to ride it.

ECONOMIC VALUE AND WEALTH

Economic values are measures of wealth, and economics is the discipline concerned with the creation, expenditure, accumulation, and distribution of wealth. To the extent that more wealth leads to more happiness, economics is rightfully called the discipline of happiness.

Wealth is a human concept. The measure of wealth, generally in dollars, is the quantification of the ability of humans to acquire what they wish. This ability depends upon property rights, systems of taxation, and other legal "rules" that humans choose to govern themselves. As a consequence, there is a close linkage between studies of economics and of politics. Indeed, the discipline of economics was originally called the discipline of political economy.

Wealth has no meaning in the physical world. An elk or a tree has no inherent economic value. Each only has economic value if a person or a group of people, such as a company or government, is able and willing to surrender some amount of wealth to acquire or use it. This means that economic value depends upon whose "ability and willingness" is relevant. Because price varies with circumstances, it is not possible to paint a dollar sign on an elk or tree and pronounce for all time that "this is what it is worth." As understanding an elephant depends on the part that is touched, economic value depends on the circumstances of sale and on who does the buying.

It is likely that some of you who are skilled in assessing wealth have noticed that we are talking about the "economics of exchange" or "market economics." There are other approaches that alter or broaden the definition of wealth so the importance of nonsalable environmental conditions can be assessed (Brown 1984; Peterson and others 1987). Such approaches enrich our understanding of how human activities fit into the natural world. This paper deals only with market economics, for it is most relevant to evaluating and choosing among cultural practices.

ESTIMATING ECONOMIC VALUES

Although the economic value of a forest product is determined by the buyer, it is the same for the buyer and for the seller-landowner: it is the amount of wealth transferred or price paid. Determining the economic rationality of forest investments first requires estimating the economic values of the resulting products.

For privately owned forest lands, legal property rights can be thought of as a "fence" around the property. The economic value of logs or camping then can be thought of as the fees that people would pay to the owner to go through a "gate" to acquire the products within the fence or to use the land. A similar fence and gate can be hypothesized for federally owned forest lands. But there is a difference in determining economic values. Forest lands usually are more valuable to society than they are to individual landowners.

Only potential changes in the wealth of landowners are relevant to making investment decisions. The private sector is concerned only with economic values that can be captured as cash receipts. As a consequence, some socially valuable forest products might not "count." For example, if commercially valuable water flows off forest land but cannot be controlled and sold, it cannot be used to increase the wealth of a private landowner. Therefore, it has zero economic value to the landowner.

In contrast, all of society owns Federal lands. Increasing the wealth of any member of society is relevant. If acquisition of water from forest lands increases the wealth of any member of society, such as a farmer, its economic value is relevant to Federal investment decisions, even though no money changes hands. The absence of cash transactions causes difficulties in estimating the cash prices that users would be able and willing to pay rather than do without the water; however, this difficulty is an empirical, rather than a conceptual or logical, problem.

Because economic values of forest products and conditions are determined by the ability and willingness of people to give up dollars to acquire or use them, the actions of people must provide the starting point for estimation. The most straightforward approach is to observe what people are paying in similar circumstances. This is the basis for appraising stumpage with "transaction evidence" and has been used by Federal agencies to estimate livestock grazing fees and oil and gas land leasing fees.

A second approach is to base estimated fees on the "value added" to industrial products that are developed from the raw materials of forest products. Starting with historic or projected sale prices of industrial products such as lumber, all identifiable costs of production, including margins for profits, are subtracted. The residual is as-sumed to be the economic value of the forest product. This technique is the basis for the "residual value appraisal" system for stumpage and has been used to value commercially caught fish and water used in hydropower generation and in agriculture.

These same approaches are used when fees have not been paid under comparable circumstances and when no marketed end products are produced. The fees hunters, fishermen, and other recreationists would be able and willing to pay to use public lands when no fees are actually charged are frequently estimated through carefully designed questioning techniques. Recreationists ready to enter the forest might be asked what they would pay. Alternatively, their "costs of production" in the form of travel and related expenses might be subtracted from the total amount they would be able and willing to pay for a recreation trip from their home; the difference yields an estimate of the fee they would pay to enter the forest. These techniques are particularly important for the National Forests, for the nationwide economic values of recreation have been estimated to be larger than those of timber production. (Loomis discusses these approaches in detail in a paper in this proceedings.)

As estimation departs from observing actual cash transactions, more reliance must be placed on processes of logical inference. If the ultimate purpose is to estimate economic values in the distant future, there is no empirical evidence that current cash transactions yield the most correct estimates for such projections.

NET ECONOMIC VALUES AND CULTURAL PRACTICES

The economic value to a landowner of a marketed forest product is simply the price that is received. To calculate its net economic value, costs of producing the product must be deducted from the price.

The cost of a cultural practice is one kind of cost of production on forest lands. An investment in a cultural practice makes economic sense—that is, it increases a landowner's wealth—only if the net economic value of the forest product with the practice is greater than the net economic value without the practice. This can be true if adding the cost of a cultural practice reduces total production costs or if adding the cost increases income to the landowner.

Reducing Costs

One approach to reducing total production costs is to use cultural practices to increase the size of trees intended for harvest. This can reduce costs of delivering a given volume of wood to a mill. For example, the cost per unit volume for felling and bucking is less for large than for small trees. In the National Forests in northern Idaho, an increase in diameter of harvested trees from 12 to 13 inches reduces felling and bucking costs on average by 17 percent, or by about $4 per 1,000 board feet (USDA Forest Service 1986). Skidding and loading costs, and perhaps hauling and mill conversion costs, are also reduced.

A second general use of cultural practices is to reduce economic losses caused by pests. A sanitation cutting might be used to reduce insect or disease damage. Such treatments occasionally have high payoffs because their application has a multiplier effect; by incurring the costs of treating relatively few stands, the economic values of many stands might be protected.

A third cost-reducing use of cultural treatments is to accelerate the production process so the time of product sale and receipt of dollar income is brought forward. Dollars earned today are worth more than dollars earned tomorrow.

The economic advantage of speeding up harvesting has nothing to do with the physical characteristics of the trees or logs. Instead, it is a consequence of the desire of people to use wealth to acquire what they want at the earliest time possible. Dollars received today can be loaned against greater future repayments: a landowner can earn interest from a bank or from individuals. The reverse is also true. Holding assets such as commercially valuable trees without selling them requires borrowing dollars and paying interest to meet current needs, or forgoing interest that could have been earned.

Because the time between investments and harvests is long, the time-costs of money associated with cultural practices are large. If some practice occurs 50 years before harvest, an interest rate of 10 percent increases out–of-pocket costs about 128 times; costs double every 7 years. This means a cost of $10 per acre now will amount to a cost of about $1,280 per acre at the time of harvest, after interest costs are added. Even the more modest interest rate of 4 percent (net of inflation) used by the National Forests increases original investments eight times in 50 years. To be economically desirable, both out-of-pocket expenditures and interest costs must be offset by eventual cost reductions or increased receipts.

The way that humans choose to use their wealth is responsible for the pervasive occurrence of very large time-costs in timber production. Since many of the same humans are interested in timber production, it is not surprising that ways have been found to offset or reduce the influence of those costs.

Private sector costs of cultural treatments have been reduced directly through government cost-sharing programs and indirectly through tax law to the extent that investment costs can be credited against taxes that would otherwise be payable. Similar apparent reductions in costs occur for Federal ownerships through the "earned harvest increment" or the "allowable cut effect." Under baseline Federal policies of even flow or nondeclining yields of timber, it is permissible to immediately increase harvests in many forests if (and, generally, only if) growth-stimulating investments are made in presently unmarketable stands. As a consequence, the dampening effects of investment costs are muted.

Cost "reductions" that result from such social rules are imaginary. The costs still occur and must still be paid. But to achieve social goals, we have collectively acted as "government" so that private landowners will not have to bear all or any of the costs and so that Federal managers will not be overly inhibited by the costs. We have acted so that all taxpayers will share in paying the costs. Although these costs come under scrutiny in academic and Federal planning and policy studies, they are not relevant to day–to–day decisions about cultural treatments.

Increasing Receipts

In addition to reducing the entire package of production costs, the costs of cultural practices also might lead to increased receipts.

One way that cultural practices might be used to increase receipts is by creating new products that can be sold. Certainly commercial thinnings, whether for timber or firewood, are economically preferable to noncommercial thinnings. Cultural practices also might be used to create conditions so fees can be charged for recreational use of the forest. For example, if wildlife habitat is improved, it might be possible to charge fees to hunters to offset investment costs.

As is true on the cost side, the receipts that are relevant to deciding on cultural practices are partially defined by the rules of government. It is within our power, acting collectively as government, to establish rules that make the receipts from selling timber products large enough to encourage investments. This could be done through direct price subsidies, as is common in agriculture. Alternatively, indirect subsidies could be used to increase domestic demand and prices, perhaps in the form of import restrictions or tariffs or tax laws favoring new home construction, or public timber harvests could be limited to improve prices for private landowners.

The social costs of price subsidies are the differences between the prices landowners would receive under such rules and the dollars that people would be able and willing to pay in the absence of those rules. These costs would have to be paid by people through broad-based taxes or by consumers in the form of higher prices. Nevertheless, the market prices resulting from application of the rules would be the economic values that are relevant to evaluating cultural practices.

Whatever the effects of such rules, a landowner might intend cultural practices to change the physical characteristics of trees so that eventual market prices will be increased. However, the long time between such an investment and the eventual harvest suggests that careful thought be given to identifying the characteristics of wood products that will bring price premiums in 20 or 50 or 100 years.

There is evidence that future market demands will not be like those of the past (Sedjo and Lyon 1986). We know that markets in the United States are becoming more closely linked to international markets in respect to rates of growth, prices, and types of wood products. Increases in worldwide consumption of industrial wood products have been slowing since about 1950; anticipated surges in demand by Third World countries have been indefinitely postponed by political instability and by monstrous international debts. New sources of wood products have been sufficient to keep real prices (net of inflation) essentially constant in that 35-year period. Finally, worldwide markets have been moving steadily away from solid wood products to fiber products.

Any general movement toward fiber markets is important when considering investments in timber production, particularly in the Rocky Mountains. Most wood products produced in this region are at a competitive disadvantage, for they must be transported substantial distances to consumers. In the absence of government intervention, some sort of price premium must be received to offset the costs of transportation. Historically, that premium resulted from relatively strong demands for solid wood products and from the lack of adequate supplies closer to consumers.

The importance of both these factors is decreasing. Premiums for solid wood products have steadily diminished as less expensive wood-conserving and wood-extending technologies have been introduced (Duerr 1986). For example, in the Lake States innovations in processing technologies have led to so many substitutions of aspen for red pine that cultural investments in red pine generally are no longer economically rational. Historic price premiums for the species have been sharply reduced. New processing technologies also are changing other low-value or weed species and stands into economically competitive sources of supply. The volumes that are available, and that are relatively close to consumers, are substantial. For example, currently there is no market demand for the timber on about one-third of all the lands in National Forests in the northeastern quarter of the United States.

These trends and the availability of these potential supplies suggest the reliance on cultural practices to produce large, defect-free trees for markets many years in the future should be reconsidered.

CONCLUSIONS

From an economic perspective, the most critical characteristic of cultural practices is the time lag between application and results. The longer this period, the riskier the investment. Time-costs of money quickly increase, and assumptions about future payoffs become shakier.

Those who are most successful in forecasting the future are most likely to see their wealth, and their happiness, multiply. But no one can ever be certain what the future will be. Lewis Carroll (1966) wrote a story entitled "The Hunting of the Snark." After eight characters tell us what they think a snark is, we discover what a snark really is—it is a threatening and slippery creature called a "boojum." That's not a bad description of future market values. We know they are important and can be threatening; although experts frequently announce what they will be, we can never be certain.

Because economic values are a human creation, they are defined by what humans want. Depending on the uncertain rules of government, the costs and prices facing different landowners can vary greatly. This means that a cultural practice that appears to be an economic winner under one set of circumstances may appear to be a loser elsewhere. But we will have to wait for the future to be sure.

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METHODS AND TOOLS FOR ECONOMIC EFFICIENCY ANALYSIS OF STAND MANAGEMENT OPPORTUNITIES

Ervin G. Schuster

ABSTRACT

Foresters are being held increasingly accountable for the economic soundness of their actions, including stand management activities. A quality investment analysis of management opportunities can help promote economic efficiency and viability. Several topics important to proper investment analysis are discussed. Discussion points focus on topics in analytical methods and tools, including tiering of analysis, risk and uncertainty, computer software, and more. References and illustrations are provided.

INTRODUCTION

Foresters in the Mountain West have never been more keenly aware of the need for their actions to make sense—especially dollars and cents. The Federal deficit is soaring. A timber buy-back program is now in place. There is talk of revising the tax code regarding timber. Industry is concerned with costs and competitive position. The Forest Service, U.S. Department of Agriculture, is embroiled in a below-cost timber sale issue. Actions of Mountain West foresters are being closely scrutinized; they're being held accountable. Tough questions are being asked. Folks want proof that foresters are making good, sound decisions, that their actions are economically justifiable and efficient.

It should be so. Foresters typically use someone else's funds to finance their management activities. Industrial funds could be used in some alternative, money-making activity or returned to the shareholders. Public funds are taxes, resources diverted from a productive private sector. Ensuring that foresters use available funds wisely, that they adopt the best combination of inputs and levels of outputs, that they produce the most benefits from a given budget, or that they minimize the cost of a given level of production is what economic efficiency analysis is all about. Technical efficiency and cost effectiveness are prerequisite to, but commonly obstruct, economic efficiency.

When foresters spend money on stand management activities, two types of consequences result—goods and services are produced and income and employment are generated. Economic efficiency analysis measures the value of resource inputs relative to the value of outputs produced. It cares not about associated income and employment nor who is made better off or worse off. Those are topics of economic impact analysis, which I am not going to address.

Efficiency analysis of stand management activities should be distinguished from analysis of day-to-day production activities where the time interval between input and output is short (perhaps a day or week). In stand management, the production process is long (perhaps a growing season, several decades, or centuries), long enough for management opportunities to be treated as investment opportunities or capital investments. Economic efficiency analysis of investment opportunities assesses whether the investment being considered is productive enough to warrant devoting today's resources to the production of commodities to be consumed in the future rather than the present. If a stand management investment is not that productive, the resources are better devoted to other investments or to producing immediately consumable commodities.

Investment analysis uses a variety of concepts, the supporting tools of compounding and discounting, and a host of associated formulas and procedures. These fundamentals will not be repeated here. Rather, I will discuss several topics that typically "fall through the cracks." The following potpourri of topics begins with a discussion of some analytical methods, including tiering of analyses, and ends with a discussion of some analytical tools, including computer programs.

ANALYTICAL METHODS

Tiering of Analyses

If only the stand management opportunities being evaluated were as uncomplicated and straightforward as those portrayed in texts, investment analyses would be simple and unchallenging. But they are not. Stand management decisions cannot be evaluated in isolation; for both public and private foresters, decisions are increasingly interwoven. This affects the nature of the analysis. There are at least three types of decision interactions: (1) the problem of independent versus mutually-exclusive decision alternatives (see Gunther and Haney 1984), (2) the problem of stand-level versus forest-level analysis (see Schweitzer and Schuster 1977); and (3) tiering.

Tiering is sometimes referred to as hierarchial or nested decisions. An analogy can be made to a set of mixing bowls that fit or stack into each other. Like the bowls, tiered decisions are conditioned by and fit into each other. Decisions at one level establish the context and constraints for decisions at another level. The terms "strategic" and "tactical" can also be used. Stand management decisions are typically tactical decisions that implement strategic decisions made at a higher level. Consider a Forest Service decision affecting a stand. Decisions about how a stand will be managed must be conditioned by and fit into the way a sub-National Forest area is to be managed; the approach to management for that area is conditioned by and must fit into the Forest Plan; the Forest Plan fits into the Regional Plan or guides; and Regional activities fit into the Resources Planning Act Program. Similarily, a parcel of private forest managed as an autonomous "profit center" will have a different decision context than if it was managed as part of an integrated whole.

What does tiering have to do with investment analysis? Everything! Decision tiering affects the nature of the investment analysis at each level or tier. Decisions are quite different for a stand where there are no constraints on management than for one that fits into a specific type of timber strata and plays a certain role in achieving a nondeclining yield target, and for which a general management prescription has already been identified, possibly in a Forest Plan. Whereas the analysis for the first situation may be wide open, the latter may be limited to a cost minimization problem. There may be no analysis at all if the higher level decision was very specific. If a high-level organizational decision was made to produce products requiring a specific quantity and quality of wood, the stand management decision could simply identify the least-cost way of producing the specified quantity and quality. Present value of costs is then the appropriate decision criterion; present net value or rate of return is irrelevant.

There are no general approaches or solutions to the tiering problem, because there is no general way for tiering to take place. Organizations differ not only in structure, but also in goals and objectives. This affects the context in which decisions take place. Moreover, the decision context changes over time for a given organization. This explains why a given stand management opportunity may be a good idea for one organization and not for another. It also sharply limits our ability to learn from each other. Each decision situation must be assessed to determine exactly what kind of analysis is appropriate. The assessment will not be easy. It's very confusing and difficult to clearly think through the proper nature of tiered analyses.

Economic Versus Financial Analysis

A distinction is often made between investment analyses of a financial nature and those of an economic nature. Some noneconomists find this confusing, since economics and money are commonly considered to be synonymous (or at least compatible) and money is the ingredient of a financial analysis. Three features distinguish a financial from an economic analysis: (1) opportunity costs, (2) externalities, and (3) nonmarket benefits. When present, these features shift the focus of the project analysis from serving the organization or individual (the financial analysis) to serving society (the economic analysis). This seems to be a laudable goal. But on balance, it is not clear whether a properly conceived, quantified, and executed investment analysis of stand management opportunities based only on financial considerations will be improved or eroded by efforts to reflect an "economic" perspective. Let's look more closely.

An efficiency analysis should measure or describe the relationship between the value of the benefits produced and the value of the benefits foregone when a particular action is undertaken. Opportunity cost measures the benefits forgone, the amount of some other commodity that could have been produced with the resources being used. Some incorrectly believe this is a separate cost, a cost to be added to other costs. It is not. Opportunity cost **is** the cost of production. Dorfman (1972) indicated that "in monetary terms, the opportunity cost of producing anything is the value of the resources that it absorbs, because that value reflects the usefulness of those resources in other employments." Input price (costs) estimates opportunity cost. If the forester accurately portrays the financial value (price) of all inputs used in the management activity, opportunity cost has been accounted for.

One difficulty with the concepts of externality and nonmarket benefits is that the information needed to quantify them is not readily available. Externalities exist whenever the production or consumption process of one economic unit (a producer or consumer) is affected by actions of another, either positively or negatively. Nonmarket benefits refer to the value of outputs produced and provided to consumers at little or no charge. Both externalities and nonmarket benefits must be estimated indirectly, neither being directly measurable. We find ourselves in the awkward position of having to trust that a financial analysis is improved by adding unobserved and unverifiable data. A second difficulty occurs if these adjustments are mainly applied to the benefit side of the analysis. Ultimately, efficiency analysis compares the values of benefits to those of costs. Routinely available cost information provides a measure of society's opportunity costs, based on market signals that reflect reality, the complexities and imperfections of society. Estimates of nonmarket benefits reflect no such reality. When costs reflect one thing (market information) and benefits reflect another (market plus nonmarket information), the comparison between a project's costs and benefits becomes ambiguous and the interpretation much more difficult.

Temporal Value Adjustments

Foresters would have less difficulty conducting and interpreting results of an investment analysis if they remembered what the analysis formulas are doing. They are simply converting an ambiguous set of future costs and returns to their unambiguous present-day equivalents. The fact that costs and returns for the typical investment problem occur at different points in time creates the ambiguity. People prefer the present to the future. An amount in the future must be numerically larger than in the present for the two to be judged equivalent. We all discount the future, some more than others.

The degree to which the future is of less value than the present is reflected by the rate at which the future is discounted—the discount rate. Investment formulas convert a value at one point in time to its equivalent value at some other point in time using the appropriate discount rate. If returns each year are worth 4 percent less than the previous year, a person would judge $10 today and $505 promised in 100 years to be equivalent and would be indifferent between the two if given a choice. The two values are equivalent. Formulas used in investment analysis make temporal value adjustments. While the formulas vary widely in complexity and can even become somewhat confusing, all result in the same equivalency conversions.

Dollar Ambiguities

Whenever an economist talks of real dollars, some listener is muttering, "Doesn't that fool know they are all real!" I've been in too many conversations with noneconomists to believe that the concepts of real and nominal dollars are widely understood.

If economists talked of "constant purchasing-power dollars," instead of "real dollars," more people might understand. Constant purchasing power is exactly what the concept of "real" means. Reference to real dollars wasn't too important or common until the decade of the 1970's when the annual rate of inflation soared into double-digits. The future purchasing power of money was distorted. A dollar would be worth (could purchase) less because the general level of prices had increased. This change confused and confounded investment analysis results. Now we use dollars that have been indexed to eliminate the effects of inflation; the rate of inflation is assumed to be zero. It is now common to index both prices (costs and revenues) and discount rates used in analyses.

If indexing does not take place, the analysis is said to be based on "nominal" values. The word, nominal, is used in the sense of something existing in name only, not in reality. In reality, a dollar is supposed to be a unit of value measure. The nominal dollar refers to a unit of value measure that is a dollar in name only; the actual value (what it can purchase) of nominal dollars varies widely. Therefore, it is difficult to compare nominal values from different years. Economists sometimes use the words "current" or "inflated" as synonyms for nominal. Whether an analysis uses "nominal" or "current" or "inflated" values, reference is being made to actual, real-world, observable, unindexed values.

One problem foresters have with these concepts is analytical consistency—both achieving it and recognizing it when achieved. Analyses must be based on either all real or all nominal values, but not a mixture (see Gregerson 1975). Perhaps most important, the choice of the type of discount rate (real or nominal) specifies the appropriate approach for the rest of the analysis. For example, if a nominal discount rate is used, all future costs and benefits used must be expressed in nominal dollars for the year they occur, reflecting the influence of inflation. (At 10 percent annual inflation, stumpage selling for $100 per MBF today will sell for $1,378,061 per MBF in 100 years!) Organization policy may constrain choice of discount rate. For example, Federal agencies must use real values (Schultz 1972); the Forest Service has specified 4 percent as the real discount rate for agency use (Row and others 1978).

Both real and nominal analyses require the forester to deal with the question of real value change over time—either costs or revenues. Changes in a commodity's real value are always determined relative to a change in the general level of prices—inflation. If a commodity's price increases faster than prices in general, it is said to be experiencing real price increase; if slower than inflation, then its real price is decreasing (see Adams and Haynes 1985). Real value change is identified by comparing changes in a commodity's (nominal) price to changes in (relative to) the general level of prices. Accordingly, reference is occasionally made to changes in "relative prices" rather than changes in real prices (see USDA 1980). It's the same concept. An analysis assuming "constant relative prices" is assuming no real price changes. Increasing relative prices means the real price for some commodity is increasing; decreasing relative prices means the opposite.

Whenever an analysis is conducted in real terms, the numerical indexing requires the forester to make two choices—type of index and base-year. The index is used to measure changes in the general level of prices, inflation. Types of indexes include the Consumer Price Index, the Producer Price Index (formerly the Wholesale Price Index), and the GNP Implicit Price Deflator. The values for these indexes can be found in a number of places (see USDC 1986 or U.S. Congress 1986). Different indexes give different portrayals of the inflation rate, sometimes very different. Organization policy may govern selection of index.

But the forester is typically free to choose the base-year. All indexes have a base-year, identified by the year with an index value of 100.00, commonly 1967, 1972, and 1982. Selection of base-year is important since it establishes the year for which all values are based, the reference point. Analytically, any year will do; results will have equal validity. But base-years differ in terms of the forester's understanding or comprehension. For many of us, our frame of reference is today, the present. It's difficult to comprehend a present net value based on 1967 dollars—the numbers look too small. Except when overridden by agency policy, the forester should always adopt the most meaningful base-year (probably the previous year) and convert all index values to that year.

It is not difficult to convert from one base-year to another. The listing below shows an original index with a 1982 base and the same index converted to a 1985 base. To make the conversion, simply divide all original index values by the original index value for the desired new base-year; multiply by 100. For example, the 1984 value for the index converted to a 1985 base was calculated: (110.0/105.0)100 = 104.8. Once conversions have been accomplished, new index values can be used as would the old, except reference is made to the new base-year.

Year	Original (1982 base)	Converted (1985 base)
1982	100.0	95.2
1983	105.0	100.0
1984	110.0	104.8
1985	105.0	100.0

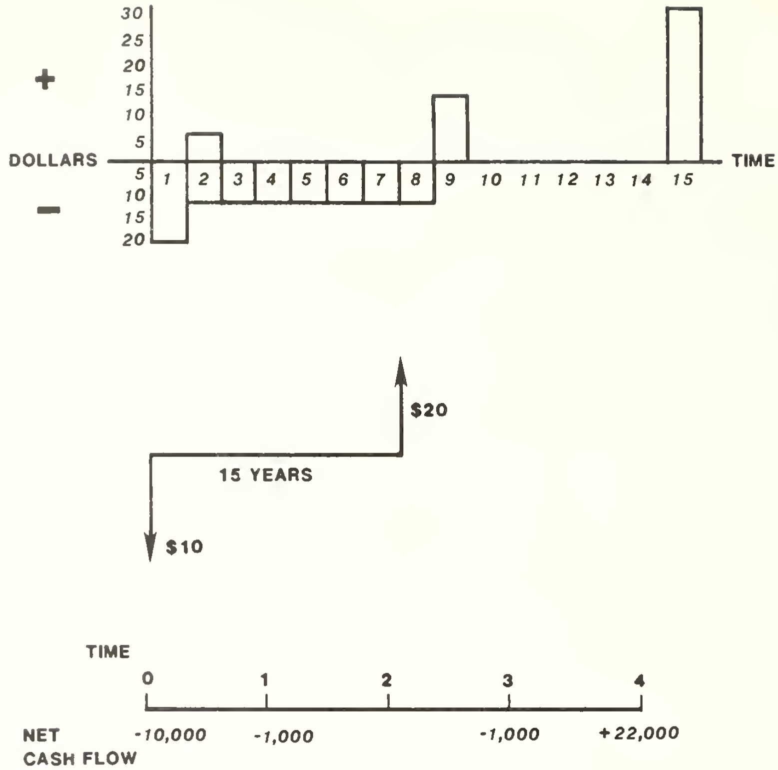

Figure 1—Three alternative cash-flow diagrams.

Cash-Flow Diagrams

Foresters need to get into the habit of describing their investment analysis problem in terms of a cash-flow diagram, before they try to analyze the problem. The diagram will help clarify the problem. Muddled thinking will quickly become apparent.

There are several types of cash-flow diagrams available, and many more that could be created. It doesn't really matter which one is selected; the forester should simply be comfortable with the one selected. Figure 1 illustrates three approaches. Actually, reference to "cash flow" is somewhat misleading. In practice, the values entered on the diagram can represent any return, actual financial transactions or simply value flows that may or may not be revealed in market actions. The choice is up to the analyst. My preference is for the upper panel because it seems to portray problems clearly and I am comfortable with it. The middle panel has the advantage of not requiring so much horizontal space. The lower panel really is a listing of the values over time; it is shown here to illustrate a potential error. Note that the cash-flow axis is labeled "net." This is not recommended procedure, since use of net values will distort benefit-cost ratios by systematically understating costs. When returns exceed costs and only the excess (net revenue) is used, costs are essentially portrayed as if they did not exist.

Certainty, Uncertainty, and Risk

What do military cost-overruns and the Edsel have in common? They are both testaments to our inability to correctly predict the future. Hopefully, the analyses associated with these production decisions explicitly reflected the lack of certainty inherent in the future. Investment analyses supporting stand management decisions unfortunately usually adopt the analytical fiction of a known future. That's too bad. Management opportunities then appear unrealistically lucrative; too many are implemented; and subsequent assessments reveal too many of them to have been improper. This is analytically inexcusable. A decade and a half ago, Schweitzer (1970) demonstrated how various types of errors can make bad investments look good, and vice-versa.

Typically, foresters are only too keenly aware of how unsure they are about the possible consequences associated with management activities. This is in contrast to a state of certainty, where each possible action results in a single, known outcome. Uncertainness surrounding outcomes of stand management opportunities may be traced to production (technical and economic), organizational, and political considerations. Fire, insects, diseases; unexpected costs and revenues; changing organizational goals; and legistative restrictions are but a few items that cause plans to not be realized. When certainty does not exist, routine, unadjusted investment analyses are then inappropriate.

There are too many analytical adjustments for us to deal with here (see Fight and Bell 1977). But three are very feasible, well within the ability of foresters to implement. First, discount rate adjustment is probably the simplest analysis modification. A higher discount rate is used in less certain situations compared to those with more certainty. Different discount rates would be applied to the alternatives evaluated, if they differ in degree of certainty.

Organizations that require use of a standard discount rate may have to add a "risk premium" to the established discount rate.

The second and most commonly used approach to outcomes that are not certain is sensitivity analysis. An initial analysis is conducted; a questionable parameter (such as discount rate) is reset to some new level; analysis is rerun. The two sets of results are compared to see how sensitive conclusions are to the parameter change. The sensitivity approach is particularly well suited to those occasions when the forester wants to evaluate the range of parameter change (such as discount rate) over which a particular alternative seems to be preferred or when the forester plays the "what if' game—what if the discount rate were 0 percent; what if 9 percent?

Decision theory provides a third approach through the concepts of decision making under risk and uncertainty. When used in this context, risk and uncertainty have specific, technical meanings. Decisions are said to be made under "risk" if an action can lead to one of several possible outcomes and the objective probability of each is known; "uncertainty" exists if objective probabilities for the outcomes are not known (Thompson 1968b). While available techniques are generally divided into two classes—those applicable to risk and those applicable to uncertainty—one technique is common to both. It involves use of outcome probabilities (objective and subjective) to calculate an "expected value" of the outcome, a weighted average of all possible outcomes (Thompson 1972).

Assume a thinning operation will cost $100 per acre today but that the future returns are not certain because yield amount and value are not known for sure. Furthermore, assume that yield will be either 0 ($y1$) or 20 ($y2$) units per acre and that value will be either $5 ($v1$) or $10 ($v2$) per unit. Outcomes range in returns from $0 (=0$u$/acre x $5/$u$) to $200 (=20$u$/acre x $10/$u$) per acre. But they are not equally likely, as shown in the probabilities below:

$$P(y1) = 0.3 \qquad P(v1) = 0.75$$
$$P(y2) = 0.7 \qquad P(v2) = 0.25$$

If the yield and value probabilities were independent, the probabilities associated with the various outcomes ($o1$ to $o4$) would be:

$$P(o1) = P(y1)P(v1) = (0.3)(0.75) = 0.23$$
$$P(o2) = P(y1)P(v2) = 0.07$$
$$P(o3) = P(y2)P(v1) = 0.53$$
$$P(o4) = P(y2)P(v2) = 0.17$$

Given these outcome probabilities, the expected value of the thinning operation is the sum of the product of each outcome's revenue and its probability:

$$EV = 0.23(0)(5) + 0.07(0)(10) + 0.53(20)(5) + 0.17(20)(10) = \$87$$

The investment analysis would use the expected value of $87 to represent the proceeds from the thinning opportunity.

ANALYTICAL TOOLS

Noncomputer-Based Tools

Two things are needed to perform an investment analysis: the discounting (or compounding) formulas and some aid to calculation. Gunter and Haney (1978) have put together a handy little tool, a decision-tree approach to identifying the correct formulas. But probably, the most generally available source of investment analysis formulas is chapter 16 in the Davis (1966) text, "Forest Management," and chapter 4 in the Leuschner (1984) text, "Introduction to Forest Resource Management."

The simplest aid to determining the compounding or discounting factors (values or multipliers) associated with the formulas is to read them from a table of values. Both the Davis and Leuschner texts have a few tables. However, for a complete set of the multiplier tables, see either those compiled by Lundgren (1971) or Thompson (1968a). It would be a rare forest economist that doesn't have one of these publications in their personal library.

For many of us, a hand-held calculator is as indispensible to investment analysis as pencil and paper. The calculator's "Y to the X power" key can be used to determine the value of most factors. Some of the more sophisticated calculators are already programmed to perform simple operations, such as present and future values, amortization, and rate of return. Some can be programmed.

Computer-Based Tools

Distributed Processing Systems—Historically, large organizations use mainframes and minicomputers to help manage day-to-day activities. Users access these computers by remote terminals. The Forest Service's Data General computer system and the Fort Collins Computer Center are examples of distributed processing systems. The major advantages of these systems are that they may be capable of handling very large problems and they can be tied to large data bases or growth and yield modeling systems.

Analysis programs (see Brooks and others 1984) come in two types—stand-alone and complementary. The MTVEST program (Zuuring and Schuster 1980) is typical of the stand-alone class of program. The user builds data files describing features of the stand management opportunity, either separately or interactively when the program is being executed. Data files are stored and can be retrieved whenever needed. A full range of analyses, features, and reports are provided, including sensitivity and marginal analysis. CHEAPO II (Horn and others 1986) is an example of a complementary investment analysis program. CHEAPO II is designed to allow users of the Prognosis Model (Stage 1973) and its associated extensions to analyze the economic aspects of management treatment projections. Two data files are needed—one is created by the Prognosis Model when it is executed and the other by the user when economic information is specified. The forester simulates growth and management of trees with the Prognosis Model and then conducts an investment analysis on the associated costs and benefits with CHEAPO II.

Microcomputers—As micro or personal computers (PC's) increase in power and capability, whatever previous advantages were possessed by larger computers will quickly disappear. Personal computers offer a level of hands-on computing capability totally unheard of with distributed processing computers. Since personal computers require active participation, users must be somewhat familiar with computer operations, terms, and concepts. The Journal of Forestry recently carried a three-part series providing just such background (Collier and Massey 1985; Cooney and Massey 1985; Massey and Cooney 1985).

Investment analysis capability of PC's seems to come in two forms—stand-alone programs (see Cooney 1985a) specifically designed to perform investment analyses and programs where investment analysis capability is a sideline or supplemental feature. The QUICK-SILVER forestry investment analysis program (Vasievich and others 1986) is a stand-alone program. It can analyze any type of forestry investment by means of a user-friendly, interactive computer program. Each analysis is based on an investment case that describes costs, revenues, and management activities. It can work with one stand or multiple stands and conduct before- and after-tax analyses.

A major type of software made popular by PC's is called the "spreadsheet." Spreadsheets are also available for distributed processing computer systems, such as the Forest Service's Data General system. The spreadsheet has been described as the computer version of the accountant's ledger sheet (Cooney 1985b) and can be applied to many problems, not just investment analyses. The spreadsheet consists of rows, columns, and cells. Data describing a cash-flow diagram can be entered into the cells. Some spreadsheet programs contain established commands that perform certain investment analysis calculations, such as present and future value or present net value. Some spreadsheets contain no data, only instructions pertaining to manipulation and analysis of data. They are called "templates" and function very much like a normal computer program, except they are easier for nonprogrammers to construct. Templates can be shared with other users.

DISCUSSION

Some final thoughts regarding investment analysis of stand management opportunities for the future forests of the Mountain West include:

—Investment analysis of stand management opportunities ought to be an active part of stand management decisions by professional foresters, not viewed as an impediment or a procedural requirement.

—Investment analysis is an attempt to assess the economic efficiency of potential management opportunities, to ensure that the economic resources entrusted to the forester are prudently used.

—Investment analysis ought to depict all technical and economic features of the management opportunity known to the forester, including a reflection of those outcomes that are uncertain or risky.

—Investment analysis ought to be tailored to each situation, tempered and conditioned by the managerial context of the decision and organization, especially recognizing decision interactions.

—Investment analysis ought to utilize the best available technology because it will free the forester of the need to perform routine tasks and allow more time for analytical design and interpretation of results.

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NET ECONOMIC BENEFITS OF RECREATION AS A FUNCTION OF TREE STAND DENSITY

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ABSTRACT

As forests progress through successional stages, suitable types of recreation follow this progression. Based on a survey of several recreation sites in Colorado, recreation use and benefits can be functionally related to tree density and tree size. A few activities such as driving off-road vehicles are optimized when there are few trees per acre. Hiking and fishing are activities that recreationists prefer to engage in within moderately stocked forests. Activities such as camping, picnicking, and backpacking are optimized when tree density is higher. Net economic value of recreation increases from less than $5 a day to more than $10 a day when the number of trees per acre triples. As tree size (measured as diameter at breast height [d.b.h.]) increases, recreation use and benefits also increase. Recreation benefits in Colorado increase from $4 per day with trees 4 inches d.b.h. to $11 per day with trees 13 inches d.b.h. The dollar benefits of recreation are more sensitive to tree density than is recreation use. The demand curves for hiking and undeveloped camping as a function of trees per acre are derived from Contingent Valuation Surveys performed in Colorado.

INTRODUCTION

During a forest's cycle from seedlings to mature trees, the forest provides many outputs. These outputs include habitat for animals, water runoff, livestock forage, and recreation opportunities. Some of these recreation opportunities utilize the products of the forests such as opportunities to view birds or harvest deer, elk, or other animals. We can trace the derived demand for different forest stocking patterns by hunters, for example, if we know how such forest stocking patterns relate to habitat quality and wildlife populations. Those combinations of land in different successional stages that provide opportunities for higher harvest success or more trophy game animals can be shown to have high economic values to hunters (Sorg and Nelson 1986; Loomis and others 1985; Donnelly and Nelson 1986; Willman 1984).

Other recreation activities such as hiking or camping directly take advantage of the site characteristics that forests in different successional stages have to offer. The purpose of this paper is to illustrate how recreation use and benefits of six recreation activities change with the number of trees per acre and tree size. With this information, the management implications of increased forest stocking and tree growth can be discussed. The reader interested in earlier studies linking forest quality and recreation should see Michaelson (1975) and Leuschner and Young (1978).

DEFINITION OF ECONOMIC VALUE

In discussions of the highest valued uses of resources, economic value is normally defined as the user's net willingness to pay. This is the definition used in textbooks on benefit-cost analysis (Sassone and Schaffer 1978; Mishan 1976; Just and others 1982) and by Federal agencies such as Bureau of Reclamation and U.S. Army Corps of Engineers for performing public investment analysis (U.S. Water Resources Council 1979, 1983). As discussed in Rosenthal and Brown (1985), price can be used as a measure of gross willingness to pay when the change in output is so small that it will not affect the market price. In the case of recreation, most forest management changes greatly affect the local supply of recreation or shift the demand curve for recreation. In either of these cases, willingness-to-pay calculations for these nonmarginal changes require using more than just one point on the demand curve (price). As Rosenthal and Brown (1985) note, use of price for small changes in marketed commodities and the area under a demand curve but above the price line (the entire net willingness to pay) is perfectly consistent with economic efficiency analysis.

CONSUMER THEORY AND FOREST QUALITY

The household production (HP) approach to consumer theory is a particularly good framework for describing how tree density and size affects recreationists' utility and benefits. With HP, consumers are viewed as combining purchased inputs such as gasoline and equipment with publicly supplied inputs such as forest land, streams, and trails to produce the characteristics or attributes of a recreation experience that provides them the most enjoyment. Thus some will choose to use these inputs to produce fishing, whereas others will produce rafting or hiking.

Given the household production framework we can specify utility as a function of these characteristics in equation 1 as:

$$U = u(E,X) \quad (1)$$
$$E = f(V,T,Q) \quad (2)$$
$$Q = g(T,Z) \quad (3)$$

where:

U = recreationist's utility
E = recreation experiences consumed
X = vector of all other non-recreation-related characteristics
V = visits to site
T = vector of tree-related characteristics (density, size, species)
Q = quality of recreation experience
Z = vector of activity-specific quality characteristics such as catch rates for fishing, success rates for hunting, or number and size of rapids for rafting.

Tree density and tree size (T), besides directly affecting the recreation experience itself, can influence the production of other desirable site characteristics affecting site quality (Q). That is, large trees are beautiful to look at, but they also produce other desirable characteristics such as shade, screening from other users, perception of a natural setting, and opportunities to view birds. For some recreation activities, too many trees can reduce satisfaction by interfering with the production of desirable characteristics; for example, dense forest may block scenic views or make fishing difficult.

Note this utility function is weakly separable between the recreation goods and all other goods (Bockstael and McConnell 1981), that is, consumers first optimize their budget between all other goods and recreation and then maximize utility within each of these bundles.

The utility function in equation 1 is maximized subject to a budget constraint. In HP, the budget constraint is really the household's cost function for producing the desired characteristics. The cost of producing these characteristics is a function of market prices for the purchased inputs and the stock of publicly provided inputs such as forest land. For some characteristics such as fishing or hunting success, the cost function is related to purchased inputs (specialized equipment, guides) and publicly provided inputs (habitat). For these type of "endogenous" characteristics, the derived demand for the publicly provided inputs can most accurately be estimated using the full household production approach. For a discussion and empirical application related to vegetation and deer hunting see Wilman (1984).

For site characteristics such as tree density and tree size, which are exogenously determined by land managers, the household production model simplifies to a framework allowing the derived demand to be estimated using the Travel Cost Method (TCM)(Bockstael and McConnell 1981) or, if properly specified, the Contingent Value Method (CVM)(Loomis 1983). When site characteristics such as tree density or size are exogenously determined by managers, recreationists can "purchase" more trees only by traveling to sites that have higher stocking rates or size.

As a forest grows, two general factors affect consumers' utility. First, the number of trees per acre over a certain size (for example, 6 inches d.b.h.) increases as the forest grows and more trees reach this size. Second, individual trees grow in size. Viewing larger trees also affects consumers' utility. As discussed previously such a growth in tree density and tree size does not necessarily result in gains to recreation because some activities benefit from more trees and others are worse off.

In this study we focus on forest stocking rates (tree density, or trees per acre) and tree size (d.b.h.). We believe that recreationists directly perceive these as desirable site characteristics. They are also an effective means for producing the other desirable site characteristics previously discussed; however, forest quality characteristics such as preferences for certain tree species or for diversity of tree species are not studied here, even though these may also be important.

METHODOLOGY

To derive a demand curve for tree density and tree size for different recreation activities the Contingent Value Method was applied. This method creates a simulated market for different tree stocking rates and tree size. Then the recreation user is allowed to "bid," or reveal his or her maximum net willingness to pay for different quantities of trees. The details of this application are discussed in the following section. Although some economists have had reservations about CVM, the method has been shown to produce reasonably accurate (plus or minus 25 to 50 percent) estimates of willingness to pay when compared to actual cash willingness to pay for hunting permits (Bishop and Heberlein 1986) and compared to the property value approach to valuing air quality (Brookshire and others 1982). The reader desiring a recent comprehensive review of the CVM methodology should see Cummings and others (1986).

The Travel Cost Method (TCM) has also been applied to this data set to estimate demand curves associated with different tree densities. The benefit estimates and sensitivity of recreation demand to trees are roughly of the same magnitude for both methods. As analysis of this data is ongoing, the interested reader is referred to Ward and others (1983).

Both TCM and CVM are recommended for use by Federal agencies in valuing outdoor recreation by an interagency committee of the Federal government (U.S. Water Resources Council 1979, 1983). Several agencies—U.S. Department of Agriculture, Soil Conservation Service; U.S. Department of the Interior, Bureau of Reclamation; and U.S. Army Corps of Engineers—use both methods.

DESCRIPTION OF SURVEY METHODS

Recreation users of six forest recreation sites in the Front Range of Colorado (435 persons) were interviewed in the summer of 1980. A stratified random sample was selected to represent the range of recreation activities, geographic distribution, recreation opportunity zones, and forest quality along the Front Range. Ponderosa pine was the common tree species that occurred between 6,000 and 8,000 ft elevation in stands averaging 160 trees (over 6 inches d.b.h.) per acre. Study sites included Red Feather Lake (120 mi northwest of Denver), Lory State Park (70 mi north of Denver), Estes Park (near Rocky Mountain National Park), Nederland area (45 mi west of Denver), Woodland Park area (70 mi southwest of Denver), and Lake Isabel area (150 mi southwest of Denver).

At the outset we wish to emphasize that the exact numerical relationships from our study will not directly transfer to other types of forests. For example, ponderosa pine (*Pinus ponderosa*) has a particularly open understory compared to blue spruce (*Picea pungens*) and other commercially valuable species. The methodology used will transfer, and very likely the pattern of results with regard to activity will also transfer.

The Contingent Value Method was applied as part of the on-site interview. The respondent was shown a set of six color pictures of ponderosa pine forest with 0 to 300 trees per acre (6 inches d.b.h. or more). The photos had basically the same topography and sky, the key difference being the number of trees in the picture (of approximately the same size, or d.b.h.). The use of pictures is recommended by the U.S. Water Resources Council (1979, 1983) to illustrate environmental quality and has been used in the Vaux and others (1984) study of the impact of forest fires on recreation values.

To start the bidding process, the respondent was asked to select the picture that most closely matched the site they were recreating at that day. The interviewer then discussed how many trees there were per acre and what that meant in terms of spacing of trees at the site. The respondent then was asked if they would pay a certain dollar amount (called a starting point) per day to recreate at the site if they knew forest quality would always be as shown in the picture chosen. If they said yes to this dollar amount, the dollar amount was raised, and they were asked the question again. The amounts were raised until the respondent indicated that they would not pay more than that dollar amount.

Next the other five pictures, which showed more or fewer trees per acre than the site at which the person was interviewed, were used in the bidding game. The interviewer asked two contingent type questions:

1. How many days would you visit this site to participate in your current activity if it always had the number of trees per acre as shown in the picture?
2. Iterative bidding to determine "What is the maximum dollar amount you would pay per day to participate in this recreational activity if the site always had the number of trees per acre as shown in the picture?"

The first question corresponds to asking how the horizontal intercept of a demand curve changed as trees per acre changed. The second question obtained the area under the demand curve associated with the number of days the respondents indicated they would visit the site. Subtracting costs per day from this area (gross willingness to pay) yields net willingness to pay for the site.

Finally, the interviewer asked additional questions about change in recreation days and maximum willingness to pay for changes in tree size.

RESULTS

Tree Density

There are two effects of the number of trees per acre on recreation benefits. The first is the effect of tree density on the number of visits recreation users will make each year. Because visits are made for a host of reasons, seeing trees being just one, recreation use is not as sensitive to tree density as are recreation benefits per day. The second effect, as illustrated in figure 1, is the net willingness to pay per day (averaging less than 6 hours) of recreation. This factor does appear to be quite sensitive to tree density. Net economic value of recreation (averaged across activities) increases from less than $5 a day to more than $10 a day when the number of trees per acre triples.

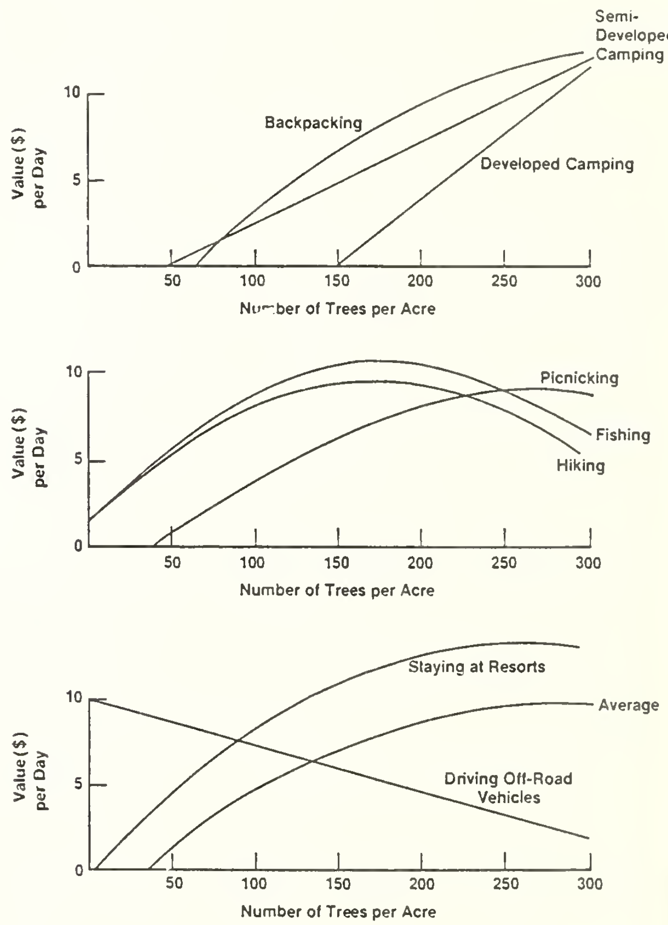

Figure 1—Consumer surplus per day of forest recreation contingent on changes in the number of trees per acre at recreation sites, Front Range, Colorado, 1980. (Average in third graph excludes off-road vehicles.)

Change in use contingent on changes in tree density can be thought of as shifting the horizontal intercept on a demand curve. Change in value per day contingent on changes in tree density can be thought of as shifting the vertical intercept of the demand curve. Combining the two effects allows us to trace out the demand effects for a given activity as the forest grows from one with few trees per acre to one with many. This is illustrated in figure 2 for hiking and figure 3 for camping at a semideveloped site.

Table 1 displays the pattern of changes in annual net willingness to pay per day as a function of tree density for six activities.

Tree Size

In addition to the effects of number of trees per acre, tree size may be of value to recreation users. To estimate this effect a contingent value question was asked of recreation users regarding their willingness to recreate (for example, number of days) and pay (for example, how many dollars) for trees one-half as large as they saw on site, the size they saw, and twice as large as the size they saw on site. From their responses recreation demand and benefits (for an average of all activities) could be related to tree size. This relationship is shown in figure 4. Annual per-visitor recreation benefits rise from $23.65 with trees 2 1/2 inches d.b.h. to $175 with trees 10 1/2 inches d.b.h. Recreation benefits in Colorado increase from $4 per day with trees 4 inches d.b.h. to $11 per day with trees 13 inches d.b.h.

From figure 4 it can be seen that tree size has a much greater effect on value of recreation (vertical shift in demand curve) than on number of days of recreation (horizontal shift). That is, recreation satisfaction (as measured by net willingness to pay) is far more sensitive than recreation participation to changes in tree size.

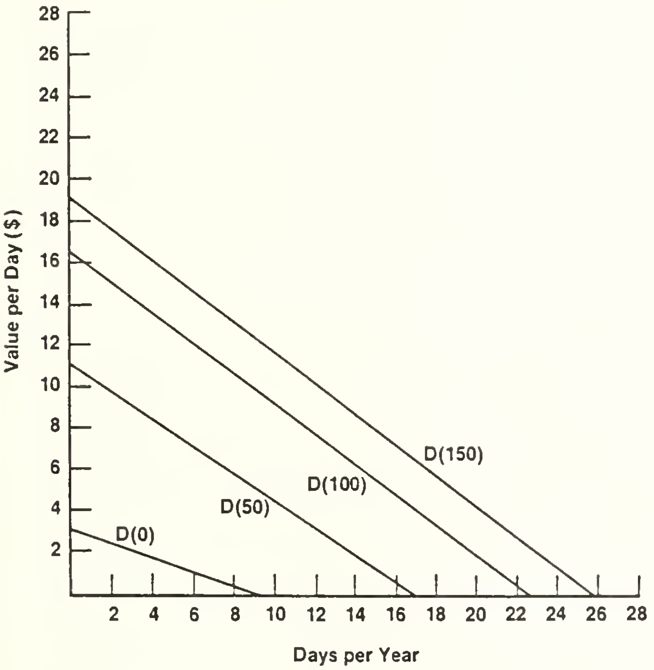

Figure 2—Hiking demand curve as a function of trees per acre. (Number in parentheses is trees per acre.)

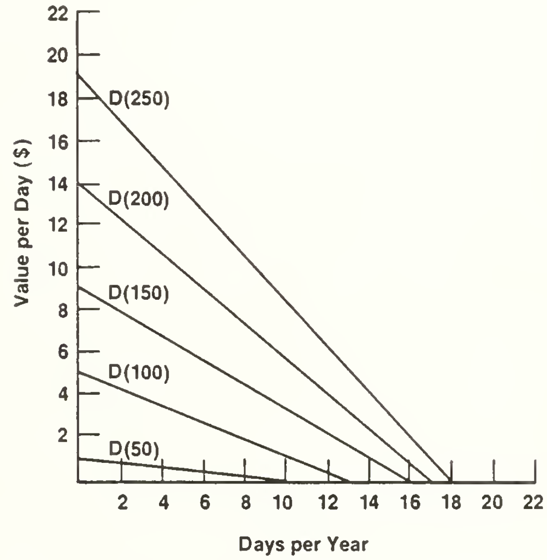

Figure 3—Undeveloped camping demand curve as a function of trees per acre. (Number in parentheses is trees per acre.)

Table 1—Annual recreation benefits per visitor

No. trees per acre	Camping	Pic-nicking	Back-packing	Hiking	Fishing	ORV'S
	Recreation activities[1]					
	Dollars					
0	0	0	0	14	18	214
50	2	12	0	96	106	172
100	34	59	35	187	194	110
150	76	108	90	247	253	111
200	121	141	134	251	267	81
250	163	153	161	196	231	54
300	194	141	167	102	149	21

[1] Figures indicate dollar value interviewee willing to pay.

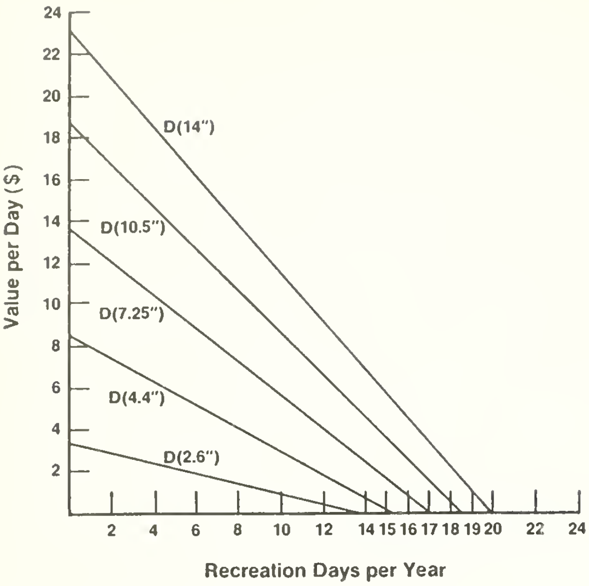

Figure 4—Recreation demand curve as a function of tree size. (Number in parentheses is tree size [d.b.h.].)

MANAGEMENT IMPLICATIONS FOR GROWING FORESTS

As tree density and tree size increase, recreation benefits go up for all recreation activities except driving off-road vehicles. Managers interested in optimizing multiple forest uses, including recreation, may have new justification for initial intensive forest management rather than sole reliance on natural revegetation. Specifically, management actions that increase the trees per acre and size of trees can be justified not only on timber production grounds but also on recreation benefits. The sooner trees reach larger sizes, the greater the net present value of recreation is at the site. Later in the forest growth cycle, thinning may be justified not only on timber production grounds but on enhancing recreation benefits of fishing or hiking. If, however, camping or picnicking are the dominant recreation activities, foresters would have to count reduced recreation values as a cost of thinning. As these results illustrate, we can integrate recreation management considerations into timber stand management to optimize the joint benefits of both uses.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Art Zack)—Most people recreate on weekends and forego the wage they could earn in a part-time job, or recreate on a paid vacation when their time must be worth what they are being paid. Are these values figured into an opportunity value of recreation?

A.—When recreation benefits are calculated from a demand curve estimated using actual travel behavior, the opportunity cost of travel time is considered by most economists as part of the "price" paid for recreation. When we ask people to directly state their willingness to pay, it is assumed that the people themselves will account for the value of their time in the answer they give us.

Q.(from Richard Babcock)—How do you verify that what people say they would pay (when they know they don't have to pay) is what they would pay when it comes time to buy the ticket?

Q.(from Anonymous)—Given the drive by some segments of society to privatize public lands, would you comment on our ability to actualize "willingness to pay" for noncommodity uses? Would individuals really be willing to pay before the resource is gone (used for commodity)?

Q.(from Richard Krebill)—Bidding to determine values is interesting, but isn't it quite confounded when the bidders know they don't really have to pay?

Q.(from B. Quinn)—You have developed demand curves based on what people you interviewed have told you. Have you field tested these curves to see whether people really put their money where their mouths are?

A.(This is a composite answer to the preceding four questions.)—My results are based on visitors' answers to hypothetical questions about their willingness to pay. Many people are, of course, skeptical about whether visitors would actually pay or behave the way they have responded. To verify or validate responses to hypothetical questions two approaches are used. The first is to run a parallel cash market for the same resource and compare the answers. In Wisconsin, two studies have been conducted comparing stated willingness to pay and actual cash payments for two resources: (1) goose hunting and (2) deer hunting. The goose hunting study found stated willingness to pay ($21) was substantially less than actual cash ($63). The complete citation to this study is given in this paper's references under Bishop and Heberlein. The more recent work by these two researchers on deer hunting showed actual cash values ($29) to be about 25 percent lower than stated willingness to pay ($38).

The second approach to validation of statements about willingness to pay is to estimate a demand curve for recreation using actual travel behavior of individuals. This Travel Cost Method has been applied to the same data set presented in this paper. The results indicate that for a 10-30 percent change in tree density, total benefits estimated by the bidding process are within 10-20 percent of total benefits estimated by actual travel behavior.

In general we see that visitors do provide reasonably accurate statements about their actual willingness to pay. Since hunters in private-land States such as Texas appear willing to pay several hundred dollars for the opportunity to hunt, I would suspect that people in the Intermountain West would also pay, if they had to!

Q.(from Anonymous)—If one-fourth to one-third of the people recreating—hunting, fishing,—are employed by the forest products industry, would they be willing to pay the same amount if they understood producing that commodity meant loss of their job—more elk, less timber harvest, and loss of a sawmill?

A.—Visitors' willingness to pay is related (though not strongly) to their income. If provision of esthetically pleasing forests reduces the timber a few visitors' produce in their jobs, then there would be an effect on their willingness to pay. The real question from society's view as a whole, is if the gain to people as consumers of forest scenery at a particular site exceeds the loss to producers and consumers of wood products from having to purchase timber from other areas. As John Krutilla of Resources for the Future demonstrated a decade ago, there may be more substitute locations for extraction of commodities than substitute sources of amenity resources.

FUTURE FORESTS—A SUMMARY PERSPECTIVE AND CHALLENGE

Robert D. Pfister
Carl E. Fiedler

ABSTRACT

This paper attempts to capture the spirit of the papers presented at the Future Forests for the Mountain West symposium by highlighting the various concepts presented. Informed stand culture (incorporating an expanded multiple-use concept that includes range, recreation, wildlife, water, and timber needs) will be required to manage future forests. The role of silviculture is changing in recognition of the fact that forestry can no longer be identified solely with timber management.

INTRODUCTION

The art and science of forestry began in Europe about two centuries ago in response to an impending wood famine. It was in this form (wood cropping) that the forestry profession came to the United States in the early 1900's. It was not until the mid-1900's, however, that the single-resource focus on wood production gave way to a broader view of forestry. Baker (1950) quoted a definition of forestry as "the scientific management of forests for the continuous production of goods and services." He went on to say, "Forestry is more than the utilization of such products as the wild and unmanaged forest may furnish, for it assumes that there is skillful planning to assure certain and continuous production, and . . . to do this in America means that silviculture must be developed in such a way as to get the maximum of effectiveness coupled with low costs." The forestry enterprise cannot overemphasize the importance of informed stand culture if it is to meet Baker's broad challenge—to maintain a balance between short- and long-term production and costs—all of this in the face of an uncertain future.

How do we deal with that uncertain future? First of all, let's recognize that it isn't unique to forestry—it is present in all of our everyday actions. In 1964, Blair Hutchison made the following statement in reference to the large, unutilized lodgepole pine resource at that time:

> Where one goes from here depends on whether he considers uncertainty an excuse for doing nothing, or a reason for doing something. When I weigh this factor and consider what we are doing in space exploration, atomic development, and other areas of uncertain reward, it seems to me our timber growing efforts are picayune.

He concludes with a perspective we must consider:

> The benefits of most of the management needed will be realized a century or more hence. I challenge anyone to predict demand or capacity to meet demand that far in the future. Some of you have heard me say that anyone who feels particularly competent in that regard should imagine himself back in 1864 trying to anticipate the situation today . . . . We are growing timber for a future we cannot foresee. Our public economics, as it relates to lodgepole pine, must therefore be of a variety that takes account of total value and provides adequate latitude for vision (Hutchison 1965).

Professionals really can't use an uncertain future as an excuse for doing nothing. Considering the dramatic increase in lodgepole pine utilization by bugs, it appears that the mountain pine beetle, rather than the forest manager, has been willing to take action in the face of uncertainty! And because of this, we as managers have often been left with only one option—to react to crises—rather than being able to prevent them by selecting from a variety of management options. It has been said, "The future is what you make it!" This applies not only in our own lives, but collectively, in the profession of forestry as well.

What do we do in the face of an uncertain future? It is tempting to fantasize that we have the authority and power to take a Lee Iacocca approach. The first thing he did with Chrysler was to get rid of all the naysayers—the ones who were always saying what could not be done, what should not be done, or what was done wrong. Even if we don't have the power to take such direct action, we can still learn from the example at Chrysler. We may have to listen to what the naysayers are saying, but we certainly don't have to let them set the agenda.

As Governor Schwinden challenged us on the opening day of the symposium, foresters must be willing to get more involved in the public arena—both for the good of the resource and the profession. In fact, this symposium was cosponsored by three professional organizations that felt it was important to provide their members with the information needed to develop responsible, professional positions on future forest issues.

What can we do as individuals? We can take a course or read a book on assertiveness training. We can exercise our rights as individuals to make decisions, take actions, and accept responsibility for those actions. In other words, we have the right and obligation to function as true professionals within the context of our current positions. We have more power than we realize if we have a strong professional commitment and develop the skills to use it for the good of our profession. Some things will be controlled by others, but many aspects will depend on us. Everything we do in the rest of our careers will either positively or negatively affect each acre for which we have direct or indirect management responsibility.

What do we want the future forests to be? That question boomerangs right back to every one of us. One approach we might use is to reflect on all the stands that we have inherited from past generations. Are we satisfied with what we have inherited? Are the stands in the condition we desire as managers? Would we pat the forester on the back who was responsible for those past decisions? Would we have done the same thing if we were the manager 20 or 30 years ago? We must be careful here, since it is easy to have 20-20 hindsight. We must remember that we are evaluating their actions against today's changing needs and values.

We can also personalize this approach and do a little futuring. We can get in our time capsules and punch in October 2, 2006, and take a field trip back to the stands for which we were responsible in 1986. Are we proud, or would we like another chance? Even if we can't take that trip "Back to the Future," we can try it mentally once in a while to remind ourselves of the importance of the stand management decisions we make today.

An interesting "Back to the Future" example concerning silviculture was provided by Wellner in a 1964 address to the Society of American Foresters. Was he a futurist? Below are some excerpts from his paper on the "Impact of Multiple Use on Silviculture in the Northern and Intermountain Regions" (Wellner 1965):

> Passage of the Multiple-Use Act in 1960 and the subsequent development of multiple-use plans on the National Forests have given impetus to coordination of forest uses. As a result, some silvicultural practices have been modified to make timber growing more in keeping with other uses. The big impact of multiple-use on silviculture. . . is still ahead of us . . . . I believe that the next 10 years will witness marked changes in silviculture to provide practices that will accomplish objectives of all uses. . . .
>
> I believe also, that timber growing costs at times will be increased by these impacts, but the opposite could be true if the other uses carried their full share of costs . . . . instead of depending, as they often do, on timber management to pay their way for them.
>
> Whether forests of the Northern Rocky Mountain and Intermountain regions are managed for timber, water, recreation, food for wildlife and domestic livestock, or a combination of these products, they will require definite, purposeful management. A blending of uses requires very skillful adaptation and coordination of silvicultural practices. The resulting silviculture may be very intensive or it may be quite simple. But we cannot sit back and let nature be the silviculturist.

It appears to us, 22 years later, that Wellner was a very capable futurist. A comparison of Wellner's 1964 predictions for the future of silviculture with a recent projection for the next 30 years (Long and others 1986) reveals several common themes:

- The emphasis will be on identifying and using cost-effective silvicultural practices.
- Increasingly, land managers will rely on natural regeneration.
- Silviculture for nontimber resources, such as water yields and recreational values, will receive increased attention.
- Control of stocking will be practiced more often to shorten rotations and improve stand health.
- New approaches to uneven-aged management will increase the use of single-tree and group-selection systems.
- Integrating various points of view will produce more focused land management objectives and better silvicultural systems.

If the profession of forestry maintains a long-term commitment to provide vigorous, healthy, and productive forests in perpetuity, then predictions of the future should be reasonably consistent from decade to decade. Deviations from this professional commitment would certainly be detectable if the futuring is strongly influenced by outside perspectives or by changes within the profession itself. For better or worse, we must continually remind the public that forests are unique and require a long-term view that the silviculturist and manager provide. Forests are not like agricultural crops that can be planted one year and not the next, depending on prices and demand.

Another earlier paper has some bearing on several topics discussed in this symposium. Wikstrom and Wellner (1961)—an economist and a silviculturist—teamed up to examine the opportunities to thin and prune in the Northern Rocky Mountains. They looked at inventory, impact of crowding, impact of limb persistence, costs, volumes, and values. They estimated that the composite effect of thinning and pruning could increase value yields from 400 to 2,600 percent (depending on species) for well-stocked stands on medium sites. On the other hand, discounting future values against costs over a long time period resulted in low rates of return (less than 4 percent for all species). The interpretation of these analyses, as well as the potential for applying a variety of stand management treatments, therefore depends on the objectives and the outlook of the respective landowner (public, corporate, or individual).

Regardless of ownership, intensive management questions concerning thinning, fertilization, genetic improvement, and pruning are not static or dead issues. Comprehensive reevaluation of alternatives will be needed periodically. Today we can use new information and techniques presented at this symposium, such as the effects of thinning and pruning on growth, new yield projection methods, and updated inventory data to provide revised estimates of the volume and value yields of our future forests. It would seem appropriate to conduct more Wikstrom-Wellner kinds of analyses and interpretations for specific areas of interest as foundations for future management decisions. Such analyses should be broad enough to take into account both direct and indirect benefits, and decisions based on them should provide management latitude in the future. In the case of thinning, for example, not all benefits of treatment are 50 years in the future. Far less obvious, but possibly more important, are the currently undervalued benefits of preventing mountain pine beetle or spruce budworm from seriously damaging or destroying the immature stands that collectively comprise our future forests.

The importance of questions dealing with stand management is strongly influenced by perspective. Most professionals work for public agencies or large companies, and therefore are buffered somewhat from the urgency, costs, and effects of stand management actions. Individual landowners, however, must face these issues directly. For one of us, these questions became very real after acquiring a 40-acre tract of second-growth forest. The stand consisted of ponderosa pine infested with mountain pine beetle, Douglas-fir infested with western spruce budworm, and a few declining aspen clones. To do nothing in this stand was clearly an unacceptable alternative. Several years were required to define objectives and select appropriate management treatments. Considerations included present and future income opportunities, treatment costs, existing insect, disease and fire hazard problems, and potential esthetic, wildlife, and recreational values. Stand improvement measures are now under way, and work continues toward meeting objectives. Some immediate income has been foregone to increase future values. The point of all this is—if every forest manager, regardless of employer, takes a personal "pride of ownership" approach to stand management, this perspective should be reflected in the quality of future forests.

We have talked about multiple-use forestry—in the past and for the future. Wellner said it was coming. It may already be here, at least in the Rocky Mountains—even though we may not realize it yet. Silviculture can no longer be identified solely with timber management objectives. Instead, we must recognize that forestry involves the production of an ever-increasing array of goods and services, and therein exists the dilemma—predicting the balance between what people need and what they want. Furthermore, in our generation of luxury consumers, the distinction between needs and wants is often obscure.

Silviculture for the future may need a new perspective. We may have to reexamine our view of multiple use in a way that as recently as the 1960's was widely disregarded: practicing multiple use on a single piece of ground. This approach may provide the best opportunity to maintain timber production in the long run. Without this approach, more and more public lands may be classified in ways that preclude active forest management.

Designing future stands to produce optimal mixes of goods and services appears to have great potential on the millions of acres of moderately productive land in the Mountain West. For example, agro-forestry (timber production and controlled grazing) may be especially appropriate for managing forest-rangeland transition areas. Balancing wildlife habitat objectives with timber production may be preferred for managing large remote areas under public ownership. Hydro-forestry is already being practiced in the high elevation forests of the Central and Southern Rockies to increase water yields and modify runoff, and its importance will likely increase throughout the West in the future. Management aimed primarily at achieving esthetic and recreational objectives has considerable potential for private woodlots and certain areas under public ownership. In fact, some private nonindustrial landowners are practicing innovative multiple-use management techniques that few in the profession have yet considered seriously.

Larry Tombaugh, Chairman of the Department of Forestry at Michigan State University, issued a challenge in his keynote address to the American Forestry Association in 1985 (Tombaugh 1985):

> The challenge of the next several decades . . . will be to . . . instill a sense of obligation concerning the land and forests in the hearts and the minds of all Americans. If done right, this initiative could be the second Golden Age of Conservation . . . . First, we will need an unprecedented degree of cooperation among all sectors of the forest resource community if we are truly to change the way that individuals think about and treat land and forests . . . Secondly, we must work together to expand the number of people involved with forest resources who are truly leaders—who know how to translate ideas into effective actions and programs. My personal belief is that our most scarce resource is not water or forests or clean air. It is leadership . . . until all of us can work to get it [conservation] back on the national agenda . . . the full potential of our forest resources in meeting a variety of needs will not be met . . . . We cannot afford to fail.

It is difficult to imagine what one person can do alone in the face of this challenge. However, the collective efforts of informed, forward-looking professionals can have a strong positive influence on our future forests and the future of forestry itself. The future, to a large degree, is in our hands. But first we must have a vision of what that future should be. McDougal (this proceedings) outlined his vision of the future forest—a hope—a goal. We share that vision. But it is probably a vision that will not be realized unless we work together to make it happen. The knowledge shared here is a first step. It provides a starting point for directing the development of today's immature stands into tomorrow's forests.

SUMMARY

The objective of this paper has been to capture the spirit and highlight the essence of the Future Forests Sympo-

sium. Our scope was not restricted to timber management alone, but instead included total forest management for the purpose of providing a full range of multiple-use and protection benefits.

All phases of stand culture in the Mountain West have been covered in the preceding papers. These papers provide a wealth of technical information to back up the management decisions of forward-looking foresters. However, the results of the application of this knowledge will not be known for many years. Will there be a change? We believe there should be. Will it be for the better? We hope it will be. However, that hope is based on the belief that our profession will reassert its leadership role in stand management. If our profession is not positive and forward-looking as well as scientifically sound, then it is something less than it should be. We must recognize and accept the challenge that the management and productivity of future forests lie in our hands—the responsibility cannot be shifted elsewhere. If we do not actively take on and meet this challenge—individually and collectively—then forestry may be timeworn rather than the time-honored profession we believe it to be.

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POSTER PAPERS

Synopses of 14 Posters Shown at the Symposium

INFLUENCE OF THE FOREST ENVIRONMENT ON PHOTOSYNTHESIS AND TOTAL NONSTRUCTURAL CARBOHYDRATES OF PINEGRASS AND ELK SEDGE

Don Bedunah, Sheryl Vogel, Jan Krueger

Many forested areas in western Montana supply an important forage resource for livestock and wildlife; yet we know very little about the physiology of the undergrowth forage plants that inhabit these sites. Pinegrass (*Calamagrostis rubescens* Buckl.) and elk sedge (*Carex geyeri* Boott) are important forage plants in many of the drier Douglas-fir habitat types and can become an important forage resource after timber harvesting or stand improvement practices. Photosynthetic rates and adequate carbohydrate reserves are major factors in the maintenance of healthy and productive perennial plants. The proper frequency, intensity, and season of forage use will depend on the physiological condition of the plants. Therefore, until data are available on the influence of the forest environment on basic physiological functions of western Montana's important forage species, there can be no adequate guidelines for the management of this resource. In addition, basic physiological information on understory species is important to understand the competitive influence of these species on tree seedling growth and to determine possible ways to manipulate these species.

In 1983, 1984, and 1985, we studied the influence of forest canopy cover and forest site on net photosynthesis, leaf water potential, predawn leaf water potential, and total nonstructural carbohydrate levels of pinegrass and elk sedge. Study sites were a *Pseudotsuga menziesii* / *Symphoricarpos albus* and a *Pseudotsuga menziesii* / *Vaccinium caespitosum* habitat type located in the University of Montana's Lubrecht Experimental Forest, Missoula County, MT.

Net photosynthesis in pinegrass (fig. 1) and elk sedge was highest in the clearcut, lowest in the unthinned forest, and intermediate in a 6-m^2 (20-ft^2) thinning in both habitat types when averaged over all dates. Complete and partial canopy removal increased the photosynthetically active radiation (PAR) that reached the understory and reduced water stress for part of the growing season. Increased net photosynthesis was related to higher PAR until water stress became the limiting factor. Increased photosynthesis in August can be attributed to 7.5 cm (3 inch) rainfall. In 1984 we measured net photosynthesis of pinegrass and elk sedge in a denser thinning (4.3 m^2 [14 ft^2]) and found no increase in net photosynthesis compared to the unthinned area. With the increase in net photosynthesis, we would therefore expect an increase in production of pinegrass and elk sedge in the clearcut and the 6-m^2 thinning. The ability of pinegrass and elk sedge to fix carbon at low leaf water potentials would make them very competitive with tree seedlings.

Total nonstructural carbohydrates (TNC) were measured in pinegrass rhizomes and elk sedge root crowns (stem bases) and roots. The TNC levels of pinegrass rhizomes exhibited a U-shaped curve with reduced levels during growth initiation in the spring and increased levels after growth cessation in late summer (fig. 2). Elk sedge, an evergreen, did not have a stage of development associated with any large changes in TNC levels of roots or root crowns. Significant site-by-date interactions were caused by 2 to 3 week delays in the development of pinegrass and elk sedge plants growing in the forested sites; this suggests that grazing practices (such as season of use and use intensity) should be established for individual species within a particular site. For example, grazing could be allowed to begin earlier in open pinegrass and elk sedge stands than in stands under a forest canopy.

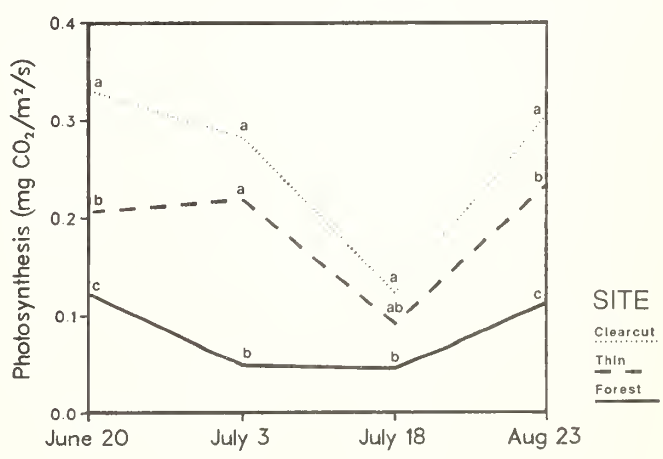

Figure 1—The influences of forest stand manipulation (clearcut, thinning to 20-ft^2 spacing, and undisturbed forest) on mean pinegrass photosynthesis (mg CO_2/m^2/s) in a Douglas-fir/snowberry habitat type in western Montana. Means with a similar letter are not significantly different at the 0.05 level of probability.

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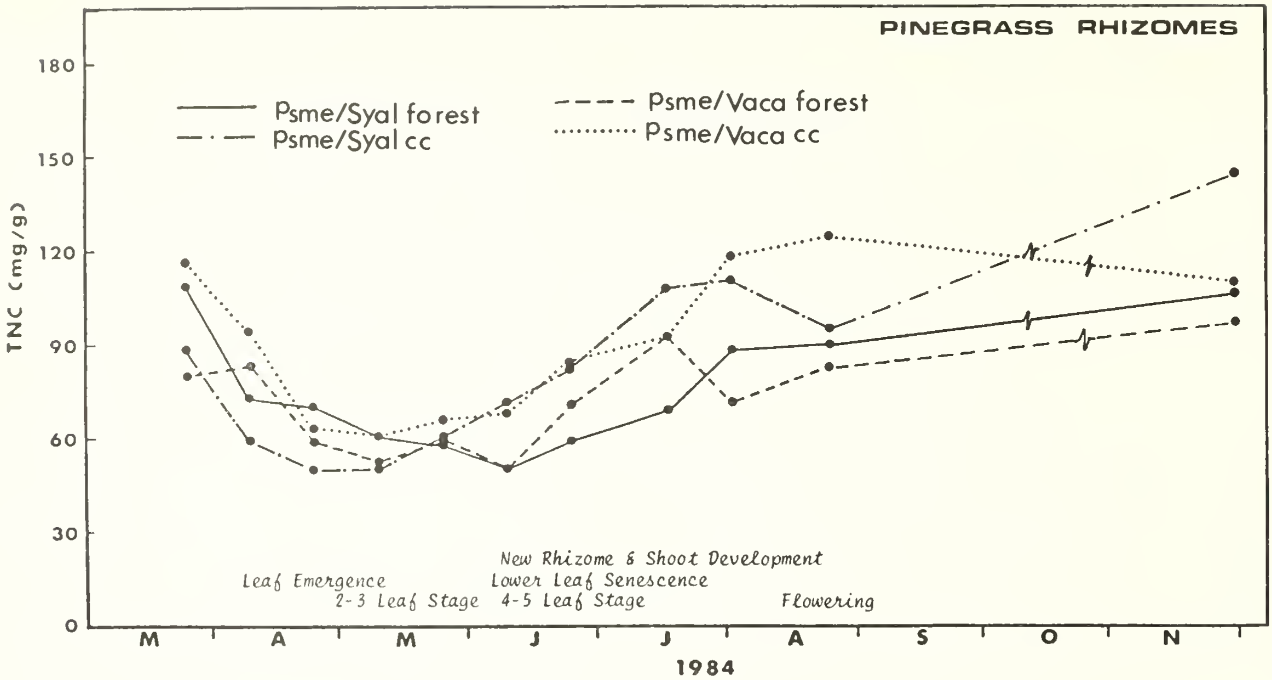

Figure 2—The influence of site on total nonstructural carbohydrates (mg/g) in pinegrass rhizomes in 1984. Phenological stages of development are also included. The sites were a Douglas-fir/snowberry habitat type (PSME/SYAL) clearcut and adjacent forest and a Douglas-fir/dwarf huckleberry habitat type (PSME/VACA) clearcut and adjacent forest.

On May 24 and June 23, 1984, we clipped pinegrass and elk sedge plants in the clearcuts and unthinned forests to 5-cm (2-in) or 10-cm (4-in) stubble heights to simulate severe and moderate defoliation. In elk sedge clipped to 5-cm stubble heights, TNC levels in roots and crowns were lower than those in controls on all collection dates. The 10-cm late June clipping reduced TNC levels in both roots and root crowns of elk sedge. Pinegrass rhizome TNC levels in the 5-cm clipping were lower than in controls 2 weeks after clipping in late May and late June. After 4 weeks, the TNC levels of the 5-cm clipped plants were no different than those in the controls. The 10-cm clipping reduced pinegrass rhizome TNC levels compared to the control 2 weeks after clipping in late June, but the 10-cm clipping treatment was similar to controls 4 weeks after treatment.

These data support the recommendations of other researchers that pinegrass be grazed early before growth slows down before summer dormancy, which also corresponds to the time when pinegrass is palatable to livestock. Heavy grazing during the periods when water stress reduces pinegrass growth and the plants are entering summer dormancy appears to be quite detrimental to pinegrass.

PRUNING YOUNG-GROWTH DOUGLAS-FIR IN THE PACIFIC NORTHWEST

James M. Cahill and Roger Fight

During the last four decades of Douglas-fir management there has been much discussion about pruning, but little action. Old-growth trees have traditionally met the demand for high-quality wood products, but stands of young-growth Douglas-fir will provide little usable clear wood. Pruning is one way to produce clear wood in intensively managed young-growth forests.

A decision to prune young-growth timber is based on the assumption that the difference in value between select and structural grades of sawn and peeled products will offset the cost of pruning. Historically, clear wood products have been worth two to three times the value of structural wood products. The future value of clear wood products manufactured from young-growth will depend on a number of factors including: (1) demand for clear wood (2) the scarcity of high-quality, old-growth logs, and (3) market acceptance of clear wood manufactured from young-growth as a substitute for the old-growth clears.

A recent product recovery study (at Voight Creek in 1985) showed that clear wood products can be recovered from pruned Douglas-fir. The recovery of high-grade lumber and veneer increased as the thickness of clear shell increased.

The computer model "PRUNESIM" uses the product recovery information from the Voight Creek Study along with growth and yield data and product price assumptions to estimate the present value resulting from pruning. This model can be used to estimate, for a variety of sites, harvest schedules, product prices, and interest rates—the cost per acre that can be profitably invested in pruning.

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LODGEPOLE PINE MANAGEMENT IN THE WALLOWA-WHITMAN NATIONAL FOREST: TWENTY YEARS OF STOCKING LEVEL CONTROL IN IMMATURE STANDS

Ernest B. Collard

Lodgepole pine occupies about 195,000 acres in the Wallowa-Whitman National Forest, which is about 20 percent of the total forested area. About 40,000 of these acres are in young seedling and sapling stands. The remaining acres are mature pole and small sawlog stands that were subjected to a mountain pine beetle epidemic from 1963 to the early 1980's.

The immature stands to be managed today are a result of a major mountain pine beetle salvage program over the last 2 decades and wildfires that have burned about 20,000 acres every 10 to 15 years. These stands have seeded in naturally at very high densities ranging from 3,000 to 25,000 trees per acre.

Thinning trials were initiated in the early 1960's on wildfire areas to develop recommended stocking levels to produce future sawlog products. One major study, conducted by Pacific Northwest Research Station personnel in the Beatty Creek area of the La Grande Ranger District, has formed the basis for management recommendations for our immature stands. Plots remeasured in 1986 have confirmed our recommended spacing of about 12 by 12 ft (table 1).

The Wallowa-Whitman National Forest has developed a reforestation stocking guide, managed yield tables for forest planning, and a proposed stocking chart based on

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Table 1—Beatty Creek initial spacing study in lodgepole pine.1986 remeasurement data on trees 5 inches d.b.h. and over

Plot no.	Spacing	DBH	TPA	BA/A	BAG	CF DG	CF VOL	CF VG	VG%	HT	Total TPA[1]
6A	6 x 6	5.0	1,490	180	15.7	0.21	1,528	163	10.7	22	2,790
7B	9 x 9	5.9	611	120	9.2	0.23	1,163	104	8.9	25	911
8B	12 x 12	6.9	477	120	12.1	0.34	1,756	200	11.4	38	1,077
9B	15 x 15	7.2	311	100	9.3	0.34	1,364	142	10.4	35	631
10B	18 x 18	7.0	315	75	8.5	0.37	1,102	140	12.7	38	2,565
Unthinned		1.7	7,500	1	-	-	-	-	-	-	10,500

[1]Includes seedlings.

the Beatty Creek study and observations in thinned immature stands throughout the Forest.

Management recommendations today specify using a clearcut regeneration system, natural seeding as the reforestation method, stocking level control by precommercial thinning to 12-ft spacings before average stand diameter reaches 1 inch (between 10 and 20 years of age), and a final harvest between 50 and 60 years of age.

GROWTH PHENOLOGY IN THINNED AND UNTHINNED LODGEPOLE PINE

Carl Fiedler

Little is known about the timing of response and allocation of increment following thinning in lodgepole pine (*Pinus contorta*). Do trees require several years to expand crowns and root systems before increasing diameter growth? Is the increased breast height diameter increment often observed after thinning due to growth response, or simple reallocation of growth lower on the bole?

A uniform, 50-year-old lodgepole pine stand at the University of Montana's Lubrecht Experimental Forest was selected to study these thinning/growth relationships. The stand is located on a gentle north-facing slope at 4,000 ft elevation, and is classified as a Douglas-fir/dwarf huckleberry (*Pseudotsuga menziesii*/*Vaccinium caespitosum*) habitat type. The stand is divided into three treatment units:

1. Thinned to 10-ft average spacing at age 20; rethinned to 14-ft spacing at age 50 (fall 1983)
2. Thinned to 14-ft average spacing at age 50 (fall 1983)
3. Unthinned control (7.5-ft average spacing)

These treatments are being measured to determine thinning effects on initiation, seasonal allocation, and cessation of diameter and height growth. Sample trees within each treatment are measured weekly for height, weekly for radial growth at five locations along the bole, and annually for diameter at 4-ft intervals along the bole. These measurements allow separation of thinning response into that portion due to increased increment and that due to reallocation of increment. Interim results follow.

PHENOLOGY

The initiation and cessation of height growth do not appear to be related to treatment over the range of densities being measured in this study. Height growth starts in mid- to late April and stops by mid- to late June in all treatments.

Radial growth starts in the latter half of April to early May in all treatments, but it continues from 1 to 5 weeks longer in the thinned treatments than in the control. Differences in length of growing season between the control and the thinned treatments appear to be greater in dry years than wet. Within an individual tree, radial growth continues about 1 week longer in the crown than at breast height.

AMOUNT AND ALLOCATION OF INCREMENT

Sample trees in the thinned treatments showed significant diameter growth response the first year after thinning (1984). Increased diameter increment in the thinned

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treatments occurred not only at breast height, but also along the full length of the bole. To date, diameter growth response has been greatest in the treatment thinned to 14-ft spacing at age 50. Diameter increment in the treatment thinned twice (age 20 and 50) shows only a moderate increase over growth in the control.

Measurements are continuing to be taken to determine both the longevity of treatment response and the changes in allocation of increment over time. Knowledge gained about seasonal growth characteristics may also be useful for developing hypotheses of mountain pine beetle-lodgepole pine relationships.

FULL-TREE THINNING UTILIZATION

Hank Goetz and Frank Maus

Thinning, a practice that concentrates growth on fewer trees, can significantly increase the productivity of forest land. In conventional thinning, the felled trees are either left to decompose slowly on the forest floor or piled for eventual burning. In either instance, while the slash is on the ground, the stand is vulnerable to damage from fire and insects and is of little value for grazing and recreation. To overcome many of the problems associated with conventional thinning, Lubrecht Experimental Forest personnel worked with adjoining private landowners and government agencies to develop full-tree thinning and utilization techniques suitable for both gentle and steep terrain. Goetz (this proceedings) briefly describes the full-tree thinning system.

The purpose of the poster session was to enable symposium participants to examine more closely the methods, machinery, and results of our operations. The presentation included: (1) posters depicting the grapple-equipped farm tractor and the Bitterroot Miniyarder, (2) specifications and fabrication plans for the tractor and yarder, (3) slides showing all phases of the operations and the variety of material produced, and (4) copies of reports that describe in detail the operations on both gentle and steep terrain.

PRODUCTIVITY OF FULL-TREE THINNING SYSTEMS

Table 1 lists the combined production rates from stump to landing for eight representative full-tree thinning units. The values for each unit represent the number of stems or cubic feet that were felled and bunched, skidded or yarded, and forwarded to the landing per person per working hour. A working hour is the time during which the crew or machine was engaged in harvest-related activity. It includes operational time, equipment downtime, and time spent in associated activity such as changing yarding corridors; it does not include unit layout, travel, lunch breaks, or record keeping activity.

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Units 1-4 are on terrain with slopes less than 20 percent; the slopes range from 25 to 50 percent on Units 5-8. Average stem sizes in cubic feet are for those trees removed from the stand. From 665 to 2,500 stems per acre were removed, depending on the unit. The thinned stands have an average residual spacing of 14 by 14 ft, or 220 trees per acre.

Felling and bunching were done manually on all units. A three-person crew, consisting of one sawyer and two stackers, was used on gentle terrain. The crew was reduced to two people on Units 5-8. The material was skidded directly from the woods to the landing on the first three units. On Units 4-6, the trees were prebunched with the indicated winch and forwarded to the landing with the farm tractor. The farm tractor was also used to move the trees from the Miniyarder to the landing. Although we did not attempt to statistically identify causes of variation between units, some general observations should be noted: (1) productivity increased on Units

Table 1—Combined production rates—stump to landing

Unit	Skidder/ yarder	Average stem size in cubic feet	Stems per person per hour	Cubic feet per person per hour
1	Tractor	0.8	45	36
2	Tractor	1.4	33	46
3	Tractor	3.0	18	54
4	Kolpe winch	1.2	25	31
5	Kolpe winch	0.7	17	12
6	Tractor winch	1.4	13	19
7	Miniyarder	0.9	20	18
8	Miniyarder	8.0	6	46

1-3 as the size of the average tree increased; (2) prebunching with the Kolpe winch on gentle terrain (Unit 4) was not as effective as direct skidding from the woods; (3) with similar-sized trees, productivity was 2 to 3 times greater on gentle terrain than it was on steep terrain; and (4) the difference in production rates between the plots thinned with the Miniyarder is a result primarily of the difference in tree size. We also used the Miniyarder on a small lodgepole pine clearcut where the average tree contained 7.6 ft^3. The production rates per-person per-hour were eight trees or 58 ft^3. Detailed productivity and cost data for all units are available from the authors.

CONCLUSIONS

Based on the Lubrecht studies, a number of conclusions can be drawn regarding full-tree thinning systems, the machinery used, and expected production rates. The successful application of small-scale systems requires compromise and cooperation between the silviculturist, marking crew, and logger. For example, sale layout must consider the special requirements and limitations of the machinery involved—a form of corridor cutting may be most efficient in many cases.

The various skidding and yarding machines all functioned well and had a minimum of downtime. With small equipment, it is important for the operators to develop harvesting techniques based on finesse rather than horsepower. The simplicity of operation and ease of maintenance enhance their suitability for landowners and part-time contractors.

Production rates will vary with the size of timber, size of crew, terrain, silvicultural prescription, and type of machinery used. However, the most important factors are the determination, innovation, initiative, and flexibility of the crew.

STAND PROGNOSIS MODEL: A TOOL FOR WILDLIFE HABITAT MANAGEMENT

Richard L. Kracht and Jerome T. Light, Jr.

The Stand Prognosis Model with the Cover extension can be used to develop silvicultural prescriptions for treatment of forest vegetation to meet wildlife habitat objectives. The Prognosis Model quickly displays stand structure at various intervals and the effects of alternative treatments.

USES OF PROGNOSIS MODEL IN MANAGEMENT OF WILDLIFE COVER

Comparison between stands:

- Which stands provide cover (hiding, thermal, or both) now?
- Which stands have the ability to produce cover and when?
- How do different stands react to various management activities?

Comparison of alternative treatments within a stand:

- To meet different management objectives.
- To provide differences in timing:
  - — earliest hiding cover
  - — earliest thermal cover
  - — longest hiding cover
  - — longest thermal cover
- Will a "No Action" alternative produce the desired management objectives?

PROCEDURES FOR USING PROGNOSIS

Define Cover Objectives

Development of definitions adapted to the local area for hiding and thermal cover, in numeric terms, are key to using this process. For example, the following definitions have been developed through the Gallatin National Forest, planning process:

Hiding Cover—Any stand where the vegetation (the sum of the stem diameters and the foliage) is capable of hiding 90 percent of an adult elk from view at a distance equal to or less than 200 ft (this is 190 ft per acre or more of stems and foliage).

Thermal Cover—Any stand of coniferous trees where the average stand height is equal to or greater than 40 ft, and the average canopy closure is equal to or greater than 70 percent.

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Run Prognosis Model

Statistically adequate data must be available in a format that can be accessed by the Prognosis Model program. Of importance is the correct measurement of crown ratios and growth. Once your data are in an acceptable format, then process them through the Prognosis Model making sure to invoke the Cover extension. By using the keywords, various treatment alternatives and corresponding stand structures can be displayed.

Interpret Model Output

The following procedure will allow you to interpret the model output and compare it with your definitions of wildlife cover.

Hiding Cover—Use the Crown Cover Statistics table. Read the Area attribute in the 0.0-9.9-ft Stand Height Class column (this is ft^2 of foliage per acre for Version 5.0); divide it by 10 (you want lineal feet rather than ft^2). Take 50 percent (foliage is 50 percent effective, Gallatin National Forest definition) of this number and use it in the next step.

Then use the Crown and Shrub Summary table. Read the Sum of Stem Diameters attribute (which is in feet); add this to the number you calculated in the first step. If it is equal to or greater than 190 ft per acre, the stand qualifies as Hiding Cover (Gallatin National Forest definition).

Thermal Cover —Use the Crown and Shrub Summary table. Read direct the Average Stand Height and the Percent Canopy Closure attributes. If the stand is 40 ft or more in height and has 70 percent or greater canopy closure, then it qualifies as thermal cover (Gallatin National Forest definition).

This procedure will need to be repeated for each cycle of output for which you are interested in determining the wildlife cover values.

GROWTH TRENDS IN NATURAL STANDS OF PONDEROSA PINE

Fred C. Martin

Detailed growth records were reconstructed for six "ideal" ponderosa pine stands in western Montana using stem analysis and increment core measurements.

These stands were "ideal" in the sense that they were relatively pure ponderosa pine, natural, even-aged, and undisturbed with extremely uniform tree spacing and little or no past mortality.

Within each stand three different levels of density, 100 CCF, 150 CCF, and 200 CCF, were sampled with replication using 1/10th-acre plots. Each stand was considered homogenous in terms of site quality, as verified by soil and vegetation analysis. All differences between plots within a stand were assumed to result solely from long-term density differences. The 200 CCF, or high-density category, is equivalent to "normal" stocking. Site indexes for the six stands ranged from 50 to over 100 on a 50-year base.

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GROWTH TRENDS OF STANDS

The graphs (figs. 1, 2, and 3) of cubic foot volume growth suggest that volume production is greater for the lower densities on low-site-quality (SQ) plots, is about equal across all density levels on medium-quality sites, and is greater for higher densities on the better sites. Examination of the periodic increment curves suggests that all of the stands are approximately at culmination of periodic annual increment (CPAI). As expected, volume increment is greatest on high quality sites and declines predictably with decreases in SQ.

The most striking feature of both the volume and basal area increment curves (ft^2) is the dip in periodic growth about 50 years ago. This dip corresponds with the "dust bowl" drought of the 30's. The higher site does not show this dip, probably due to its younger age.

The height increment curves (ft) show two significant features. First, height growth does not appear to have been substantially influenced by the 1930's drought. Second, height increment culminates later on better sites and maintains a flatter trajectory than on poorer sites.

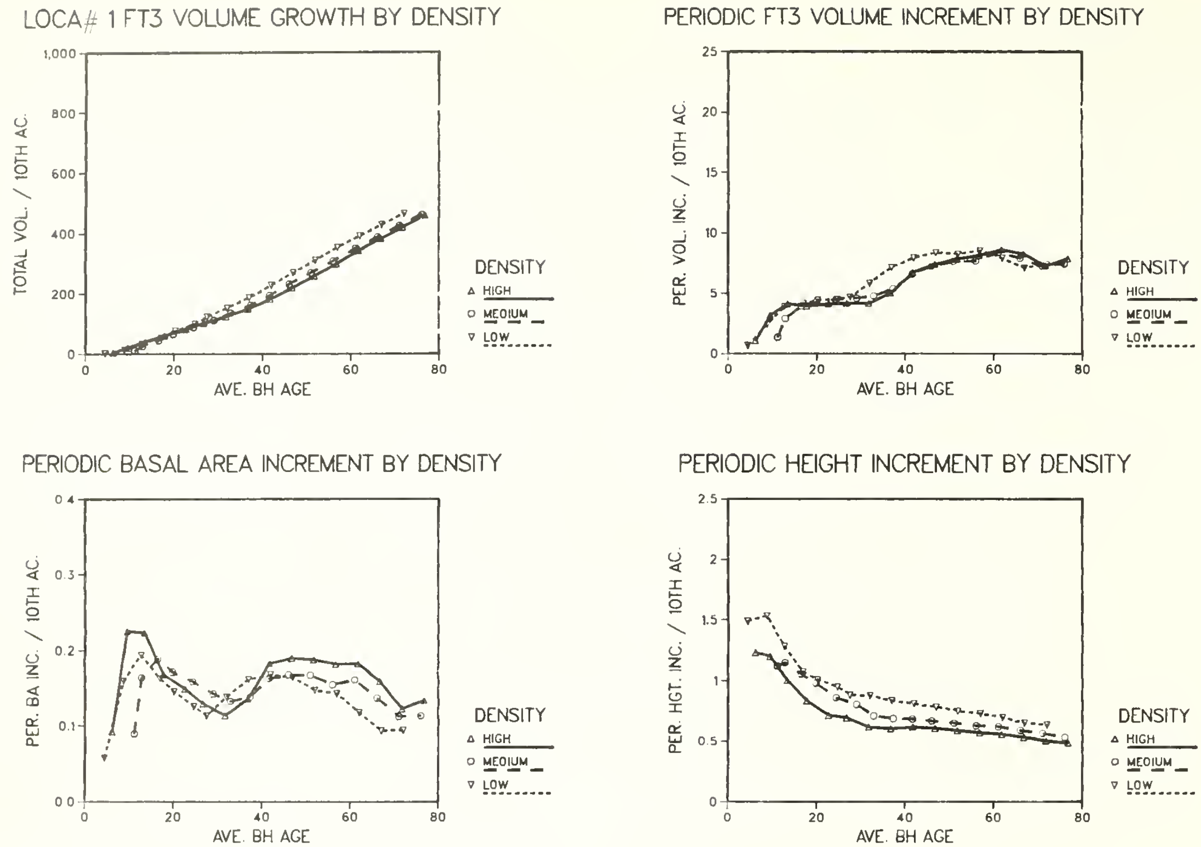

Figure 1—Growth trends under low-site-quality conditions.

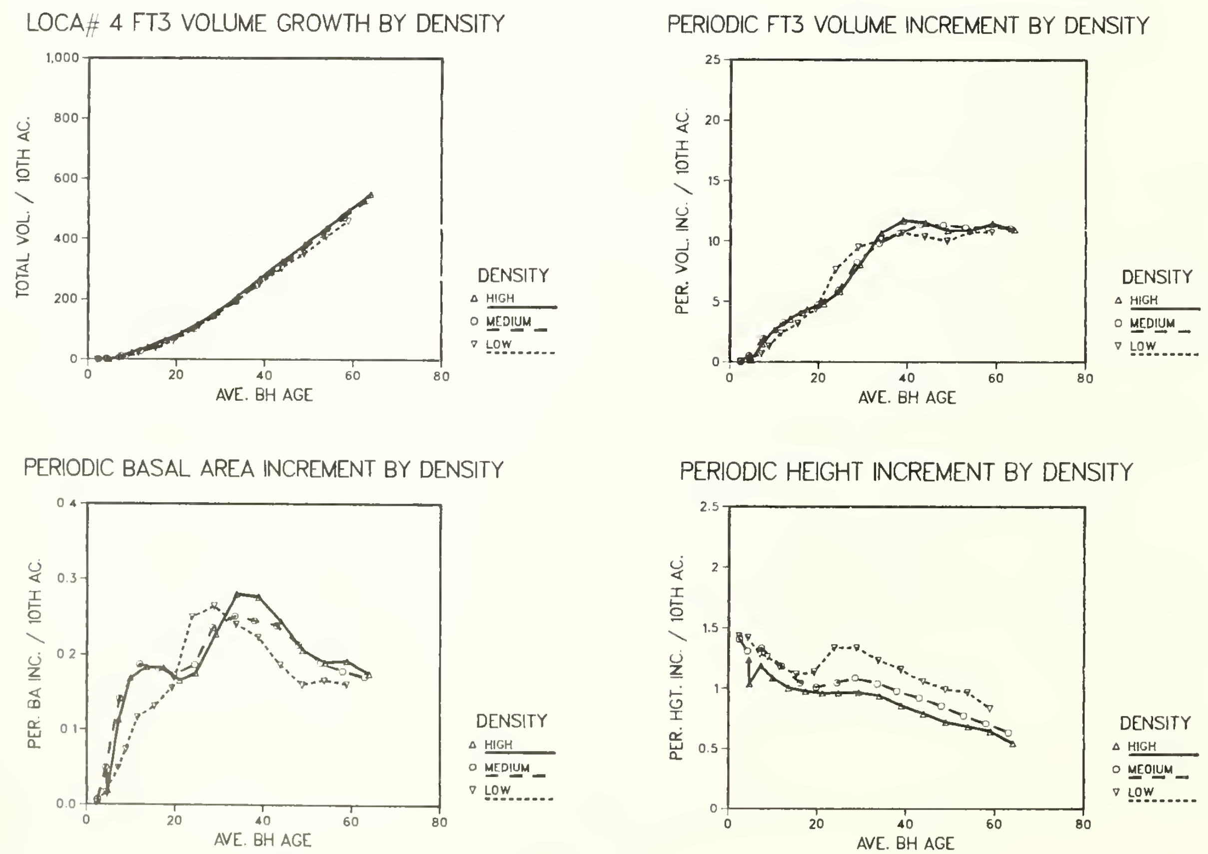

Figure 2—Growth trends under medium-site-quality conditions.

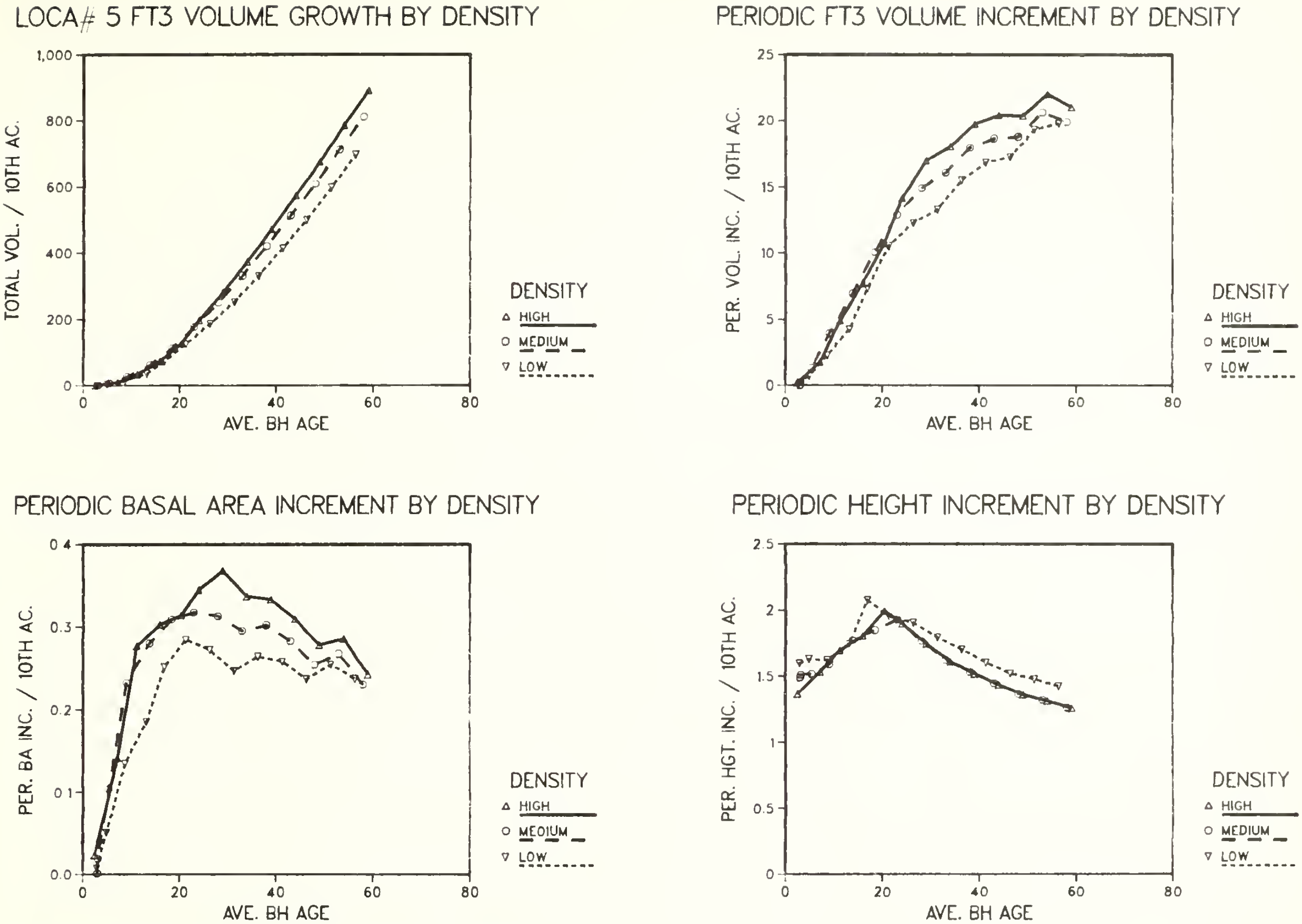

Figure 3—Growth trends under high-site-quality conditions.

GROWTH TRENDS OF THE LARGER TREES

Growth trends for the 100 largest diameter trees per acre essentially reflect the same trends as the total plot. That is, volume growth is better at low density on poor sites, with density effects decreasing with increasing SQ. The 1930's drought appears to have affected the larger trees less than the stand as a whole. Height growth also appears to be significantly influenced by density only on the poorer sites.

SNOW AND SOIL MOISTURE DYNAMICS UNDER VARIOUS LODGEPOLE PINE STAND DENSITIES

D. F. Potts

There have been numerous studies of the relationships between lodgepole pine and snow accumulation and lodgepole pine and soil moisture, but few have looked at the closely related hydrologic phenomena at the same time. In addition, most reported studies have been conducted in mid- to high-elevation zones in well-defined continental climatic regimes. Unfortunately, much of the lodgepole pine in the Mountain West is located at lower semi-arid elevations, areas that receive definite maritime climatic influence during winter—substantial cloudiness, high humidity, frequent rain-on-snow events, and high-density snow. Understanding the dynamic relationships

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between managed lodgepole pine and the hydrometeorological environment may help us optimize wood, water, and even forage production in these locations.

A systematic grid snowcourse (262 measurement points at 12- by 12-m spacings) was established across a low-elevation (1,200-m), 50-year-old lodgepole pine stand in western Montana. The 3.85-ha stand was divided into five equal-size treatment subunits—a clearcut, a control (1,750 stems/ha), and thinnings at 3- by 3-m, 4.5- by 4.5-m, and 6- by 6-m spacings. A total of 45 aluminum soil moisture access tubes (nine tubes per treatment) were systematically placed through the stand.

During the winter of 1984-1985, snow depths were measured at each systematic grid point at roughly 2-week intervals. A smaller random sample of snow water equivalent was obtained in each treatment subunit. Soil moisture measurements were made with a Troxler Model 3222 depth-moisture probe. Complete soil moisture data sets were obtained on October 6 and November 6 (before snow accumulation) and on February 22 and April 15 (roughly the beginning and end of snowmelt). We were unable to obtain complete mid-winter data sets because of the unreliable performance of the moisture probe at temperatures much below freezing. Soil moisture measurements reported here were made at a 30-cm depth.

Figure 1 shows mean snow depth in the control, clearcut, and intermediate thinning treatments through the winter. Mean snow densities for the various treatments on any sampling day were not significantly different; therefore, the snow depths indicated in the figure are proportional to snow water equivalents. Figure 2 shows the relative variability in snow accumulation, as measured by the coefficient of variation, for the same treatments and time period. Figure 3 shows changes in soil moisture content, by treatment, during the recharge period.

As has been observed in other snow studies, snow accumulation in the lodgepole pine stand was inversely

Figure 1—Mean snow depth by treatment.

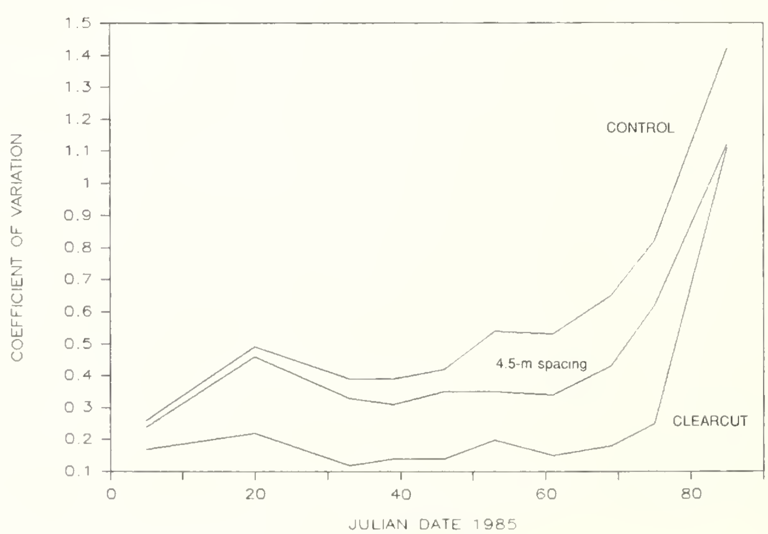

Figure 2—Relative variability of snow accumulation.

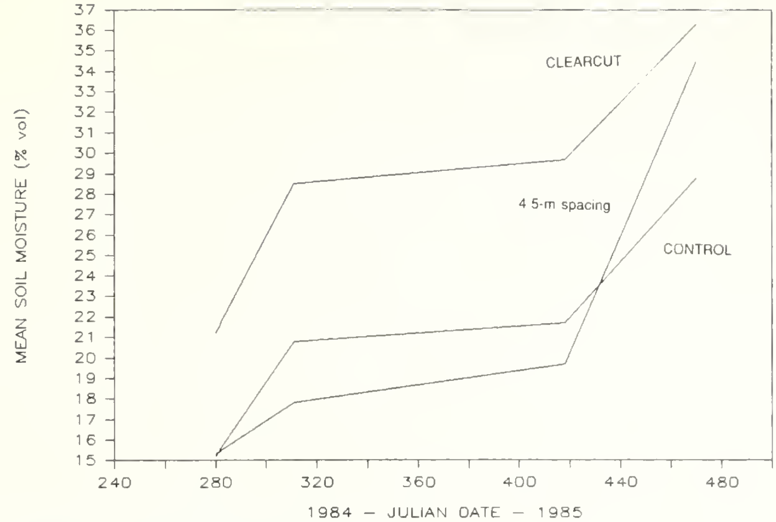

Figure 3—Mean soil moisture by treatment.

proportional to basal area. Relative variability in snow accumulation increased with surface roughness (the number of tree stems per acre) and slowly increased through the winter until rapid snowmelt occurred in March. The "imprint" of the early winter snowpack remained in place through numerous accumulation and ablation episodes during the winter.

Underneath complete canopy, snow depth continually decreased after day 40, and the presence of canopy seemed in general to accelerate rather than delay the timing of snowmelt. It seems likely that the initial differential snow accumulation observed in early winter was the result of differential longwave and convective melt energy sources during buildup rather than snow redistribution and interception loss. This conclusion is supported by the observed progression of soil moisture recharge. Although it is not entirely clear why measured recharge in the intermediate thinning lagged behind that in the control (although it did finish intermediate, as expected), the control and the clearcut curves were nearly parallel all winter. The treatments began recharge with a difference in average soil moisture content of 6 percent by volume and completed recharge with a difference of 7.5 percent by volume. Spatial variation in soil moisture was almost eliminated within treatments. The clearcut was uniformly at field-moisture holding capacity by April. Normal spring rains would fully recharge the control and provide surplus water for runoff from the clearcut and the other treatments.

CONTROLLING TREE MORTALITY RESULTING FROM PRESCRIBED UNDERBURNING

Elizabeth D. Reinhardt and Kevin C. Ryan

Prescribed fire may be an element of intermediate stand treatments. It is used to thin stands, to alter species composition, to manipulate understory plant communities, and for fuel treatment following a thinning or sanitation cut. To use prescribed fire effectively, managers need to predict and control the resulting tree mortality. Knowledge of fire-caused tree mortality allows the silviculturist to decide whether fire is an appropriate treatment, and it allows the fire manager to design successful fire prescriptions.

We hypothesize that tree mortality is primarily determined by two kinds of damage: cambial damage and crown damage (fig. 1). Cambial damage is assumed to be a function of bark thickness. A single, species-independent model was produced:

$$P = 1/(1 + \exp(-1.466 + 4.862 * B - 1.156 * B^2 - 0.000535 * C^2))$$

where P = probability of mortality, B = bark thickness in inches, and C = percent of crown volume scorched.

This model is based on data collected from 2,356 trees from 43 prescribed fires in Montana, Idaho, Washington, and Oregon. Seven species are represented in the data: lodgepole pine, Engelmann spruce, subalpine fir, western redcedar, western hemlock, western larch, and Douglas-

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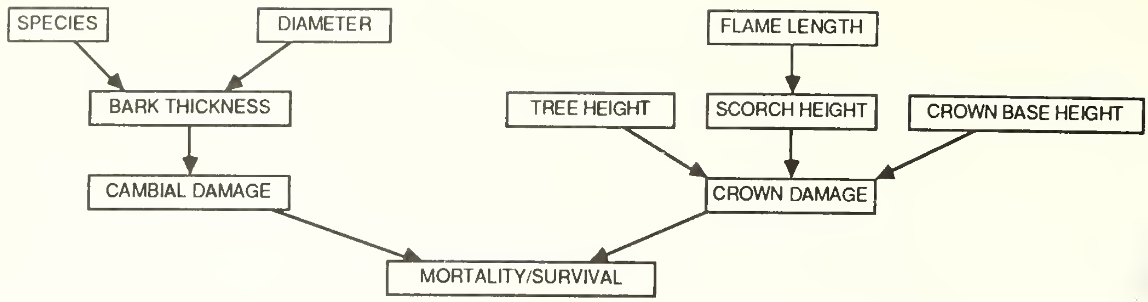

Figure 1—A conceptual model of tree mortality.

fir. Model performance is good, resulting in correct predictions for 85 percent of the trees.

To make the model more useful for prescription development, the independent variables are broken down further. Bark thickness is represented as a function of species and diameter. Percent of crown volume scorched is functionally represented by scorch height, tree height, and crown ratio, assuming a parabolic crown shape and a uniform scorch height. Van Wagner's crown scorch height model is used to relate scorch height and flame length.

This formulation allows us to predict mortality from species, diameter, height, crown ratio, and flame length. The first four of these variables are known to a silviculturist or fire manager, the fifth is set in the prescription process. A graphic representation of these relationships allows the manager to determine the flame length that results in a target mortality for a selected component of the stand, or to predict mortality of selected components of the stand at a given flame length (fig. 2,3).

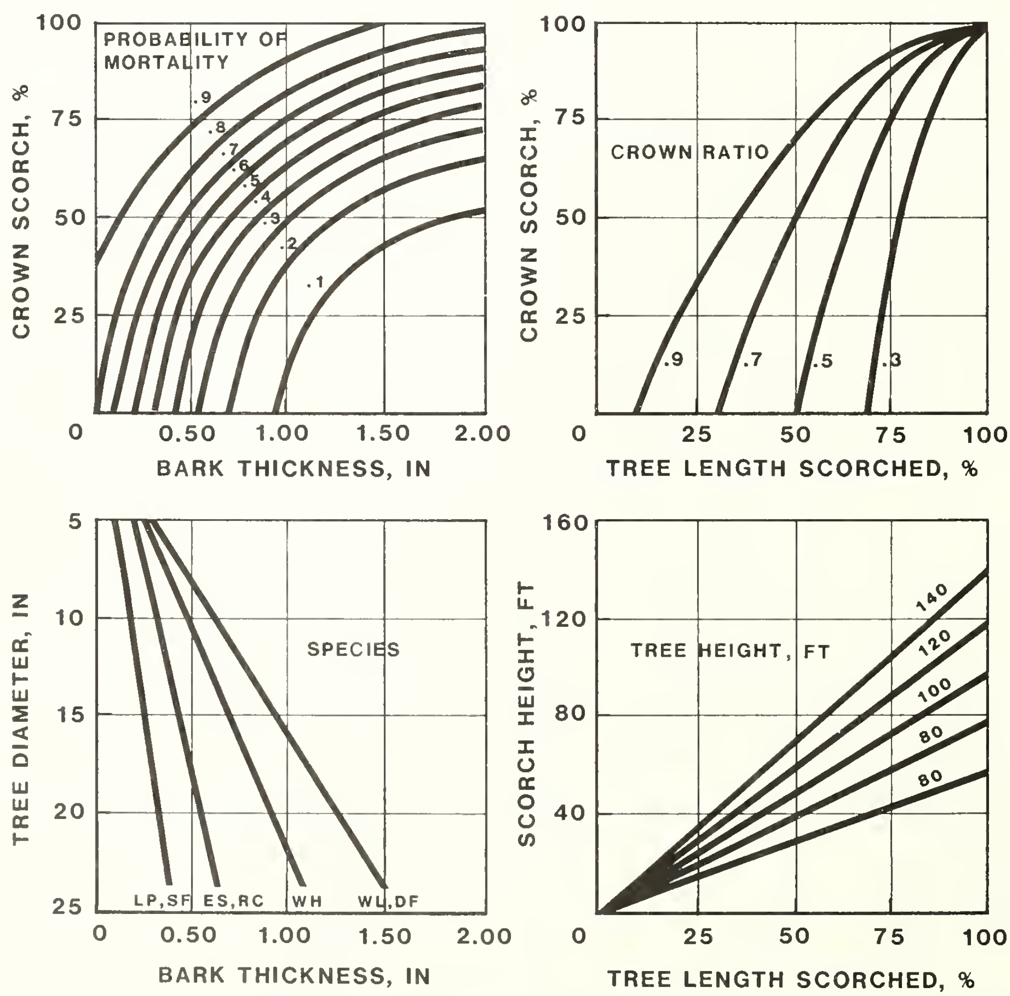

Figure 2—The relation of tree mortality to species, size, and scorch height.

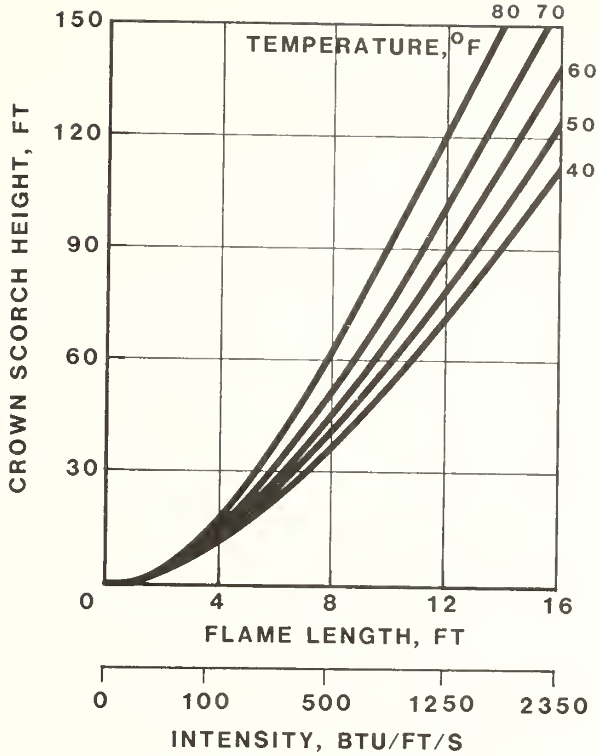

Figure 3—Van Wagner's model for relating flame length to scorch height.

WIND AND SNOW DAMAGE IN THINNED LODGEPOLE PINE

Jack A. Schmidt

Lodgepole pine is a seral species that commonly regenerates after intense fires. Replacement stands are typically pure or nearly pure, even-aged, single-storied, and overly dense. Individual trees exhibit relatively rapid juvenile height growth resulting in tall, slender stems. Being an intolerant species, lodgepole pine readily self-prunes in dense stands, resulting in short crowns. Root development is variable and dependent on soil characteristics. During seedling and sapling development the taproot is dominant, but gradually becomes less significant as trees mature. Lateral roots provide the major support after lodgepole pine reaches pole size.

These physical characteristics, in combination with thinning densely stocked stands, forecast potential stand damage problems due to wind and snow. The potential for significant damage and mortality of residual stands must be considered when prescribing thinning or other partial cutting practices. This paper reports initial type and extent of wind and snow damage to lodgepole pine thinned to various levels of basal area within 15 small-stem stands in western Montana.

METHODS

These evaluations of wind and snow damage and mortality were made in study areas that had been thinned to meet utilization, growth response, and other research objectives. Each of 15 locations of the study was subdivided into three treatments: control with no thinning (average 1.6 acres), 33 percent basal area (BA) reduction (average 1.9 acres), and 66 percent BA reduction (average 1.8 acres). This assessment, made 1 to 3 years after thinning in the different study areas, focused on wind and snow damage due to their potentially devastating effect within a unit soon after thinning. The four specific types of damage measured included: severely leaning trees, uprooted and down trees, snowbent trees, and trees with broken stems (illustrated in fig. 1). Stands varied in age (52 to 122 years), in site index (55 to 94), and in stand density (1,175 to 7,200 stems/acre).

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Figure 1—Types of damaged trees.

The damage inventory procedure involved a systematic examination of each treatment subunit. All trees within each treatment subunit were observed for damage. Damaged and down trees were marked to aid subsequent remeasurement, and the location of the measured trees was plotted on a field map of the treatment subunit. Observations and measurements on each damaged or down tree included: type or category of damage, tree d.b.h., degree of lean or bend, and magnetic azimuth of lean or direction of fall for prostrate trees.

RESULTS

Level of thinning influenced the amount of damage that occurred. In total, the 33 percent BA reduction treatment resulted in very little damage—less than 1 percent—and the 66 percent reduction treatment in a slightly greater amount (table 1). Although the total damage averaged a little over 3 percent in the 66 percent removal stands, there was substantial variation between locations.

The type of damage observed varied considerably between locations with some locations experiencing primarily snowbend and some uprooted and down. However, when all areas were summarized together, the four different types of damage occurred at about the same rate. As shown in the following tabulation, leaning, snowbend, and uprooting each accounted for approximately 30 percent of total observed damage, with breakage making up the balance.

Type of damage	Percent of damaged stems
Uprooted and down	30
Snowbend	30
Leaning	27
Broken stem	13

As expected, tree diameter was strongly related to susceptibility to certain kinds of damage. As shown in the following tabulation, larger trees were generally more susceptible to wind damage (lean, windthrow); smaller trees were more susceptible to damage in which snow loading was a major factor (breakage, snowbend).

Type of damage	Average D.b.h.
	Inches
Uprooted and down	4.8
Leaning	4.6
Broken stem	3.3
Snowbend	2.7

These data from 15 locations and 3 treatments illustrate the amount and type of damage for 1 to 3 years following thinning. This is a relatively short time period to judge what the long-term damage picture will be. To date, it appears that those locations and treatments that sustained little damage in the first year continue to remain essentially free of damage. Units with appreciable early damage appear to continue accruing additional damage in succeeding years.

Table 1—Percent of residual stems damaged within each treatment—an average of all locations

Treatment	Type of damage: Leaning	Uprooted	Snowbend	Broken	Total damaged
	Percent				
Control	<0.01	<0.01	0.02	0.02	0.04
33% BA reduction	0.24	0.09	0.06	0.36	0.75
66% BA reduction	0.87	1.34	0.48	0.55	3.24

INFLUENCE OF SITE ON GROWTH OF REGENERATION IN NORTHWEST MONTANA

Raymond C. Shearer

A series of 10-acre clearcuts in the western larch cover type of northwest Montana were prescribed burned from May through October in 1967 and 1968. The objective was to determine how these fires could meet site preparation, hazard reduction, and other management goals. Previous publications describe how various intensities of fires affect early tree regeneration and vegetation succession, watershed values, small mammals, and atmospheric resources. This summary shows the influence of (1) aspect and (2) phase of the *Abies lasiocarpa / Clintonia uniflora* (ABLA/CLUN) habitat type on growth of naturally regenerated western larch, Douglas-fir, Engelmann spruce, subalpine fir, and lodgepole pine; and of planted larch, Douglas-fir, and spruce.

The study location is in the Miller and Martin Creek drainages near Olney, MT (48° 31' N. latitude, 114° 43' W. longitude) in the Tally Lake Ranger District, Flathead National Forest. Species composition of the 200- to 250-year-old harvested stand in percentages was: western larch 26, Douglas-fir 31, Engelmann spruce 31, subalpine fir 6, and lodgepole pine 6. Elevations range from 4,200 to 5,000 ft. Clearcuts range from stream bottom to ridgetop on slopes that average 24 percent (range 9 to 35). Cool, moist conditions occur; precipitation averages 25 inches annually. Three phases of the ABLA/CLUN habitat type occur: (1) *Xerophyllum tenax* (XETE) on drier south- and west-facing slopes; (2) *Menziesia ferruginea* (MEFE) on the cooler, middle and upper north- and east-facing slopes; and (3) *Clintonia uniflora* (CLUN) on west-, east-, and north-facing slopes on the remaining sites.

NATURAL REGENERATION

The 1984 data were taken from an average of 50 (range 32 to 89) 1/300-acre (145.2 ft^2) circular plots evenly spaced throughout each of 40 units. Phase of the ABLA/CLUN type (CLUN, XETE, or MEFE) and azimuth (N = 320 to 40°, E = 50 to 130°, S = 140 to 220°, W = 230 to 310°) were recorded for each plot. The tallest tree of each species on each plot, regardless of age, was measured to provide the data base. Total height, 1980-84 leader growth, and diameter at 4.5 ft were analyzed by analysis of variance to determine the significance of phase or aspect.

The developing stands in the 40 units are a mix of at least five conifer species, similar in composition to the nearby seed source. Most natural regeneration in the units resulted from the moderate 1967 and abundant 1971 and 1980 seed crops. Only the clearcuts burned in 1967 have trees dating from seed produced that year. Some regeneration resulted from the poorer seed crops that dispersed in other years. As a result of the range in age, each species (especially larch and lodgepole pine) has a wide size range throughout most units. Age was not determined for the trees measured in this study.

Growth of conifers was influenced significantly by phase of the ABLA/CLUN habitat type and by aspect 16 to 17 years following the burning treatments (tables 1 and 2). Growth of western larch was better in the CLUN phase than in either the XETE or MEFE phase; Douglas-fir and Engelmann spruce grew better in the CLUN and MEFE phases than in the XETE phase; lodgepole pine responded better in the XETE and CLUN phases than in the MEFE

Table 1—Influence of phase of ABLA/CLUN h.t. on average height (feet), average 1980-84 terminal leader growth (feet), and average diameter at 4.5 ft (inches) and range of tallest natural western larch, Douglas-fir, Engelmann spruce, subalpine fir, and lodgepole pine regeneration on 0.003-acre plots, Miller Creek, 1984[1]

Phase	Total trees	Height	1980-84 leader	D.b.h.
		Western larch		
XETE	818	8.0a (0.9-26.8)	4.7a (0.5-14.0)	0.73b (0-4.4)
CLUN	519	9.6b (0.7-26.0)	5.5b (0.4-17.2)	0.94c (0-4.2)
MEFE	347	7.3a (1.0-25.9)	4.7a (0.3-13.7)	0.59a (0-3.6)
		Douglas-fir		
XETE	674	3.2a (0.5-12.2)	2.3a (0-9.9)	0.12a (0-1.9)
CLUN	356	4.2b (0.5-20.9)	2.8b (0.3-8.6)	0.19b (0-3.5)
MEFE	275	3.6b (0.5-13.2)	2.6b (0.4-7.7)	0.16b (0-1.9)
		Engelmann spruce		
XETE	436	2.5a (0.5-11.0)	1.7a (0-8.3)	0.06a (0-1.5)
CLUN	342	3.6b (0.5-11.5)	2.2b (0.4-6.2)	0.14b (0-1.6)
MEFE	376	3.5b (0.5-13.8)	2.3b (0.4-7.9)	0.12b (0-2.1)
		Subalpine fir		
XETE	360	2.0a (0.5-19.8)	1.4a (0-8.6)	0.04a (0-3.3)
CLUN	237	2.2a (0.5-6.2)	1.5a (0.5-4.3)	0.01a (0-0.4)
MEFE	279	2.2a (0.5-7.1)	1.7b (0.3-5.1)	0.01a (0-0.5)
		Lodgepole pine		
XETE	171	12.9b (0.6-23.9)	6.5b (0.7-11.6)	2.03b (0-4.6)
CLUN	53	12.0b (1.7-23.8)	6.5b (0.9-12.2)	1.77b (0-4.2)
MEFE	31	6.6a (1.0-16.0)	4.6a (1.0-8.7)	0.83a (0-2.9)

[1]Averages not sharing a postscript letter in each group within the columns differ significantly (P = 5 percent).

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Table 2—Influence of aspect on average total height (feet), average 1980-84 terminal leader growth (feet), and average diameter at 4.5 ft (inches) and range of tallest natural western larch, Douglas-fir, Engelmann spruce, subalpine fir, and lodgepole pine regeneration on 1/300-acre plots, Miller Creek, 1984[1]

Aspect	Total trees	Height	1980-84 leader	D.b.h.
		Western larch		
North	439	7.4a (1.0-25.9)	4.7a (0.4-13.7)	0.61a (0-3.6)
East	387	10.2c (1.0-26.8)	5.7b (0.3-17.2)	1.06c (0-4.4)
South	480	7.8a (0.7-26.2)	4.6a (0.4-12.2)	0.70a (0-4.1)
West	444	9.0b (1.0-24.4)	5.2b (0.4-14.0)	0.80b (0-3.8)
		Douglas-fir		
North	364	3.9b (0.5-16.5)	2.8b (0.3-8.7)	0.19bc (0-2.0)
East	257	4.1b (0.5-13.6)	2.8b (0.4-7.2)	0.21c (0-1.8)
South	432	3.0a (0.5-20.9)	2.1a (0-9.9)	0.09a (0-3.5)
West	292	3.5ab (0.5-13.6)	2.4a (0.4-7.2)	0.13ab (0-1.9)
		Engelmann spruce		
North	435	3.4bc (0.5-13.8)	2.2b (0.4-7.9)	0.11b (0-1.8)
East	266	3.6c (0.5-13.2)	2.3b (0-7.3)	0.13b (0-2.1)
South	266	2.5a (0.5-11.0)	1.6a (0.4-8.3)	0.06a (0-1.5)
West	216	3.0b (0.5-10.6)	1.9a (0.4-6.2)	0.10ab (0-1.2)
		Subalpine fir		
North	321	2.0a (0.5-10.2)	1.5b (0.4-4.8)	0.01a (0-1.1)
East	178	2.7b (0.5-19.8)	1.9c (0-8.6)	0.03a (0-3.3)
South	209	1.8a (0.5-6.4)	1.2a (0.3-5.0)	0.01a (0-0.4)
West	178	2.2a (0.5-11.3)	1.5b (0.4-4.7)	0.05a (0-2.6)
		Lodgepole pine		
North	30	7.1a (1.0-18.8)	4.3a (0.9-9.1)	1.04a (0-3.8)
East	56	12.1b (1.6-23.8)	6.9b (1.3-12.2)	1.80b (0-4.2)
South	131	13.2b (0.7-23.9)	6.6b (0.7-11.6)	2.16b (0-4.6)
West	69	11.4b (0.6-22.3)	5.9b (0.6-11.0)	1.61a (0-4.0)

[1]Averages not sharing a postscript letter in each group within the columns differ significantly (P = 5 percent).

phase; and subalpine fir growth was about the same for all three phases (table 1).

Significantly better growth of western larch occurred on east-facing slopes, followed by west-facing slopes, and was least on north- and south-facing aspects. Growth of Douglas-fir, Engelmann spruce, and subalpine fir also was better on east aspects than on the other aspects (table 2). Growth of lodgepole pine was more favorable on south-, east-, and west-facing slopes than on north-facing slopes (table 2).

PLANTATIONS

The 1984 plantation data were obtained by measuring all surviving trees planted 11 to 14 years earlier, either as 1-0 western larch or as 2-0 Douglas-fir and Engelmann spruce bare root stock. Initially, 50 seedlings of each species were planted in openings drilled by 4-inch power augers on each of 13 designated study areas. Phase of the habitat type and azimuth were recorded for each row of seedlings. Analysis of variance determined if phase or aspect influenced growth of the plantations.

Growth of the plantations was influenced by phase (table 3) and aspect (table 4). Larch usually grew better in the CLUN phase than in the MEFE phase and trees on both of these phases grew better than in the XETE phase. Douglas-fir growth was best in the CLUN and MEFE phases and poorest in the XETE phase for all 4 years of planting. Growth of spruce was usually better in the MEFE phase than in the CLUN or XETE phase. The best

Table 3—Influence of phase of ABLA/CLUN h.t. on average total height (feet), average 1980-84 terminal leader growth (feet), and average diameter at 4.5 ft (inches) and range of western larch, Douglas-fir, and Engelmann spruce by year of planting, Miller Creek, 1984[1]

Year planted	Phase	Total trees	Height (ft)	5-year leader (ft)	D.b.h. (inches)
			Western larch		
1970	XETE	66	11.9a (4.9-18.0)	5.6a (2.1-10.4)	1.4a (0.1-2.7)
	CLUN	99	15.7c (4.0-23.0)	7.6b (2.2-12.6)	2.0c (0-3.4)
	MEFE	120	13.6b (5.5-20.1)	8.0b (2.6-16.4)	1.7b (0.2-4.0)
1971	XETE	55	11.1a (3.5-18.6)	5.5a (1.9-9.2)	1.3a (0-2.5)
	CLUN	139	14.3b (1.7-21.5)	7.1b (1.0-12.7)	1.8b (0-3.2)
	MEFE	179	13.6b (1.3-20.2)	7.6b (0.5-12.5)	1.7b (0-5.2)
1972	XETE	83	11.3a (5.3-19.3)	6.2a (2.1-12.3)	1.3a (0.1-3.1)
	CLUN	147	14.0b (3.0-20.0)	7.3b (1.6-12.2)	1.7b (0-2.8)
	MEFE	140	12.2a (2.7-20.0)	7.0b (0.8-11.5)	1.4a (0-2.8)
1973	XETE	52	9.5a (2.7-14.5)	5.8a (1.8-9.4)	1.0a (0-1.9)
	CLUN	98	11.9b (0.5-18.0)	6.8b (0.4-12.4)	1.3b (0-2.3)
	MEFE	198	10.4a (1.8-18.8)	6.4ab (0.8-11.4)	1.1ab (0-2.5)
			Douglas-fir		
1970	XETE	103	8.6a (2.4-14.3)	4.7a (1.7-7.5)	1.0a (0-2.4)
	CLUN	131	10.1b (2.0-15.4)	5.5b (1.7-10.0)	1.3b (0-2.4)
	MEFE	170	10.0b (1.2-20.0)	5.7b (0.7-10.6)	1.3b (0-3.2)
1971	XETE	142	7.8a (2.8-15.3)	4.4a (1.2-7.9)	0.8a (0-2.3)
	CLUN	167	9.1b (2.1-16.1)	5.0b (0.6-9.0)	1.0b (0-2.4)
	MEFE	236	9.6b (1.2-16.3)	5.6c (0.8-9.4)	1.2c (0-2.3)
1972	XETE	100	6.1a (1.7-11.2)	3.6a (1.0-7.0)	0.4a (0-1.2)
	CLUN	158	7.5b (1.9-12.9)	4.3b (0.7-8.2)	0.7b (0-1.8)
	MEFE	237	7.4b (0.7-15.2)	4.5b (0.3-10.0)	0.8b (0-2.0)
1973	XETE	56	5.4a (1.4-10.2)	3.2a (0.1-6.2)	0.3a (0-1.3)
	CLUN	107	6.3ab (0.5-12.3)	3.8b (0.3-7.9)	0.4ab (0-1.6)
	MEFE	211	6.3b (0.5-11.3)	4.1b (0-7.7)	0.5b (0-1.8)
			Engelmann spruce		
1970	XETE	108	5.5a (1.8-9.0)	2.6a (0.7-5.0)	0.4a (0-1.1)
	CLUN	153	5.8a (0.4-13.9)	2.7a (0.6-6.5)	0.5a (0-2.3)
	MEFE	233	6.8b (1.6-14.4)	3.7b (0.5-7.9)	0.8b (0-2.2)
1971	XETE	60	4.5a (1.7-7.3)	2.4a (0.5-4.1)	0.17a (0-1.0)
	CLUN	114	4.4ab (1.4-10.2)	2.3a (0.8-5.5)	0.16ab (0-1.2)
	MEFE	212	4.9b (0.8-11.2)	2.8b (0.4-5.5)	0.27b (0-1.4)
1972	XETE	54	3.9a (1.9-6.8)	2.2a (0.8-4.6)	0.10a (0-0.5)
	CLUN	94	4.0a (1.4-8.8)	2.2a (0.5-5.2)	0.13ab (0-1.1)
	MEFE	127	4.4a (1.7-8.8)	2.7b (1.1-5.3)	0.21b (0-1.1)
1973	XETE	34	3.7ab (2.3-5.8)	2.2ab (1.2-3.4)	0.04a (0-0.4)
	CLUN	76	3.1a (1.0-6.1)	1.8a (0.5-4.1)	0.04a (0-0.8)
	MEFE	100	4.1b (0.9-8.3)	2.6b (0.5-4.7)	0.16b (0-1.1)

[1]Averages not sharing a postscript letter in each group within the columns differ significantly (P = 5 percent).

Table 4—Influence of aspect on average total height (feet), average 1980-84 terminal leader growth (feet), and average diameter at 4.5 ft (inches) and range of western larch, Douglas-fir, and Engelmann spruce by year of planting, Miller Creek, 1984[1]

Year planted	Aspect	Total trees	Height (ft)	5-year leader (ft)	D.b.h. (inches)
			Western larch		
1970	NORTH	74	13.7a (5.5-22.1)	7.4ab (2.9-12.1)	1.8a (0.2-3.3)
	EAST	111	15.0a (4.0-23.0)	8.2a (2.2-16.4)	1.9a (0-4.0)
	SOUTH	34	11.2b (4.9-18.0)	4.8c (2.1-8.2)	1.1b (0.1-2.7)
	WEST	66	13.9a (6.2-20.8)	7.0b (2.6-11.4)	1.8a (0.4-3.2)
1971	NORTH	192	13.7b (1.3-21.5)	7.4a (0.5-12.5)	1.7b (0-5.2)
	EAST	136	12.7b (1.7-21.0)	6.9b (1.0-12.7)	1.5c (0-3.0)
	SOUTH	—	—	—	—
	WEST	45	15.3a (10.0-19.3)	6.5b (4.1-9.4)	2.0a (1.0-3.1)
1972	NORTH	182	12.7a (2.7-20.0)	6.7bc (0.8-10.4)	1.5a (0-3.1)
	EAST	86	13.1a (4.2-19.0)	7.8a (2.1-12.2)	1.5a (0-2.8)
	SOUTH	19	10.0b (5.3-17.1)	5.4c (2.1-12.3)	1.0b (0.1-2.4)
	WEST	83	13.0a (6.2-18.6)	6.9ab (2.5-11.0)	1.6a (0.5-2.6)
1973	NORTH	162	11.0a (1.8-18.8)	6.6a (0.8-11.4)	1.2a (0-2.5)
	EAST	115	10.7a (0.5-18.0)	6.4a (0.4-12.4)	1.1a (0-2.3)
	SOUTH	—	—	—	—
	WEST	71	10.3a (2.7-16.1)	5.9a (1.8-9.4)	1.1a (0-2.1)
			Douglas-fir		
1970	NORTH	105	10.7a (3.5-20.0)	5.9a (1.8-10.6)	1.4a (0-3.2)
	EAST	131	9.4b (1.2-15.5)	5.4ab (0.8-10.0)	1.1ab (0-2.5)
	SOUTH	42	9.2b (5.5-13.5)	5.1ab (2.7-7.5)	1.1a (0.1-2.0)
	WEST	126	9.3b (1.2-17.8)	5.0b (0.7-8.7)	1.1ab (0-2.7)
1971	NORTH	275	9.5a (1.2-16.3)	5.5a (0.8-9.4)	1.1a (0-2.2)
	EAST	164	8.2b (2.1-16.1)	4.6b (0.6-9.4)	0.9b (0-2.3)
	SOUTH	—	—	—	—
	WEST	106	8.7b (2.8-15.3)	4.8b (1.2-7.9)	1.0ab (0-2.4)
1972	NORTH	262	7.5a (0.7-15.2)	4.5a (0.3-10.0)	0.7a (0-1.9)
	EAST	122	7.2a (1.9-12.4)	4.1ab (0.7-7.8)	0.7a (0-2.0)
	SOUTH	32	5.3b (1.7-8.2)	3.0c (1.0-5.0)	0.2c (0-0.8)
	WEST	79	6.7ab (3.0-9.9)	3.9bc (1.8-6.0)	0.5b (0-1.2)
1973	NORTH	88	6.5a (0.7-11.2)	4.2a (0.4-7.7)	0.5a (0-1.8)
	EAST	138	5.9ab (0.5-12.3)	3.6b (0-7.9)	0.4b (0-1.6)
	SOUTH	—	—	—	—
	WEST	48	5.5b (1.4-10.2)	3.3b (0-6.2)	0.3b (0-1.3)
			Engelmann spruce		
1970	NORTH	169	7.1a (2.9-14.4)	3.7a (0.7-7.9)	0.8a (0-2.2)
	EAST	168	5.7b (0.4-13.9)	2.9b (0.5-6.6)	0.5b (0-2.3)
	SOUTH	37	5.4b (2.4-8.0)	2.7b (0.9-4.3)	0.4b (0-1.0)
	WEST	120	5.9b (1.6-11.7)	2.9b (0.8-7.4)	0.5b (0-1.4)
1971	NORTH	207	5.0a (0.8-11.2)	2.7a (0.4-5.5)	0.28a (0-1.4)
	EAST	127	4.3b (1.6-9.5)	2.4b (0.8-5.1)	0.15b (0-1.2)
	SOUTH	—	—	—	—
	WEST	52	4.5ab (1.7-7.3)	2.3b (0.5-4.1)	0.21ab (0-1.0)
1972	NORTH	133	4.2a (1.7-8.8)	2.5a (1.1-5.2)	0.17a (0-1.1)
	EAST	71	4.3a (1.4-8.8)	2.7a (0.5-5.3)	0.22a (0-1.1)
	SOUTH	15	3.0b (1.9-5.3)	1.6b (0.8-3.0)	0.02a (0-0.3)
	WEST	56	4.2ab (2.3-7.1)	2.3ab (1.2-4.0)	0.12a (0-0.8)
1973	NORTH	103	4.0a (0.9-8.3)	2.5a (0.5-4.7)	0.15a (0-1.1)
	EAST	61	3.2b (1.0-6.7)	1.9b (0.5-4.5)	0.06b (0-0.8)
	SOUTH	—	—	—	—
	WEST	46	3.5ab (1.6-5.8)	2.1b (1.2-3.4)	0.03b (0-0.4)

[1]Averages not sharing a postscript letter in each group within the columns differ significantly (P = 5 percent).

growth of larch occurred on the east-, west-, and north-facing slopes—the poorest performance was on south-facing slopes. Growth of (planted in 1971) larch, though, was better on the west than on the north and east aspects. Douglas-fir growth was better within the 1970, 1971, and 1973 plantations on the north-facing slopes than on the contrasting aspects. Spruce planted in 1970 on north-facing slopes had better growth than on the other aspects. Although growth of spruce planted in 1971, 1972, and 1973 on the north aspects was as good as or better than on the other aspects, the differences were usually not as great.

All plantations of larch were significantly taller than those of Douglas-fir; plantations of Douglas-fir were significantly taller than those of spruce. Total height in 1984 is shown by year of planting for each species in table 5.

Table 5—Total height (in feet) of these species planted in four different years

Species	Year of planting 1970	1971	1972	1973
Western Larch	13.9	13.5	13.1	11.0
Douglas-fir	9.7	9.0	7.2	6.2
Engelmann spruce	6.2	4.7	4.2	3.7

CONE PRODUCTION AND STAND DENSITY IN YOUNG WESTERN LARCH

Raymond C. Shearer and Wyman C. Schmidt

Young, managed stands of western larch are replacing the virgin forests that have dominated the Northern Rockies. Research began in 1985 to study the influence of stand density (spacing) on the frequency and amount of seed cone production on 30- and 32-year-old larch in western Montana. Four stands were used: two on moderately productive sites (Site Index 59 at 50 years) in the Coram Experimental Forest near West Glacier; one on a poorer site (SI 52) at Cottonwood Lakes near Seeley Lake, about 85 mi south of Coram; and one on a better site (SI 69) at Pinkham Creek near Eureka, about 62 mi northwest of Coram. In 1961, four 1-acre plots at each of the four sites were thinned to average spacings of 6.5, 8, 11, and 15 ft. In addition, at each Coram site a 20-ft average spacing and an unthinned control (~2-ft average spacing) were installed. The crowns of 10 taller trees in each treatment and control were examined for 1985 seed cones and for open seed cones that were still attached from previous years.

Although seed cone production began several years ago on many sample trees (table 1, old cones), most stands had few trees with any developing cones in May 1985 (table 1, new cones). The number of trees with old cones was about the same at each location. But in 1985, more trees produced cones on the better sites at Coram and Pinkham than on the less productive Cottonwood site. About 19 percent of the sample trees produced cones in 1985, ranging from 1 and 2.5 percent in the unthinned and 6.5-ft spacing plots, to 30 and 50 percent in the 15- and 20-ft spacing plots.

The average number of cones per tree in 1985 increased as the average spacing increased (table 2). No cones were found on any of the unthinned plot trees. Only one of the 40 sample trees in the 6.5-ft spacing produced cones (it had 18), for an average of 0.4 per sample tree. The number of cones per tree averaged 9.5 in the 20-ft spacing—23 times greater than in the 6.5-ft spacing. The maximum number of cones produced on a tree in 1985 was 65 on a tree in the 15-ft spacing.

Table 1—Percent of trees with old and new cones, May 1985. Sample size: 19 trees per location and spacing

Location	Spacing (ft) 20	15	11	8	6.5	Unthinned
			Old cones			
Coram-1	60	50	30	20	10	0
Coram-2	90	80	60	30	0	0
Cottonwood	[1]—	40	50	30	0	[1]—
Pinkham	[1]—	50	30	20	20	[1]—
			New cones			
Coram-1	40	60	10	10	0	0
Coram-2	60	0	30	30	0	0
Cottonwood	[1]—	20	10	0	0	[1]—
Pinkham	[1]—	40	20	30	10	[1]—

[1]No plot established.

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Table 2—Number and standard deviation (±) of new seed cones per tree, May 1985. Sample size: 10 trees per location and spacing

Location	Spacing (ft) 20	15	11	8	6.5	Unthinned
Coram-1	6±9	10±21	2±8	1±2	0	0
Coram-1	13±18	0	6±10	4±8	0	0
Cottonwood	[1]—	<1±1	1±4	0	0	[1]—
Pinkham	[1]—	8±17	<1±1	1±2	2±6	[1]—
Average	10±14	5±14	2±6	1±6	<1±3	

[1]No plot established.

All seed cones were produced on ascending branches or on the 1981 to 1984 terminal leaders, except within the 20-ft average spacing plots at Coram. There, half the trees produced cones on both ascending and horizontal branches. Most seed cones were produced within the upper third of the crown. Of the trees with cones, 76 percent had cones only in the upper third of the crown, 19 percent had cones in the upper two-thirds of the crown, and 5 percent produced cones in 1985 only in the central third of the crown.

This study will continue 5 to 10 years with cone counts taken annually in May and late August to determine cone survival. Seeds extracted from mature cones will be x-rayed and germinated to determine seed quantity and quality.

THE STAND MANAGEMENT COOPERATIVE

T. A. Snellgrove and H. N. Chappell

The Stand Management Cooperative is a research and development organization created to provide a continuing source of high-quality data on the long-term effects of silvicultural treatments and treatment regimes on stand and tree development and wood quality. The program will build a link—now largely missing—between silvicultural and yield research on the one hand, and wood quality and utilization research on the other. Emphasis is on forest plantations and management practices of the future. Results will include improved guidelines for stand treatment leading to better management decisions.

Gaps in our knowledge exist about effects of treatments in forest plantations in terms of long-term growth data, interactions of treatments, and effects on wood properties. The program in stand management will involve major efforts in plot installation and treatment, data collection and management, and data analyses. Primary emphasis in initial program phases will be on defining quantitative effects of silvicultural treatments on volume production, tree dimensions, wood quality, and stand dynamics. In future years the program will also provide analyses and interpretations of the data including improved stand simulators, yield estimates, and stand treatment guidelines. Work will concentrate on forests west of the Cascade crest in Oregon and Washington and in coastal British Columbia. Initial emphasis will be on Douglas-fir.

The Stand Management Cooperative involves forest industry, public land-managing and research agencies, and universities. Currently, 23 organizations participate in the cooperative, including five universities. The program is headquartered at the University of Washington.

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EVALUATION OF ALTERNATIVE FIRE HAZARD REDUCTION TECHNIQUES IN HIGH-HAZARD, HIGH-VALUE, AND HIGH-USE FORESTS

Ronald H. Wakimoto, Robert D. Pfister, Konstandinos Kalabokidis

Forested areas heavily used by recreationists have severely restricted options for management treatments to reduce fire hazard and capture the productivity potential of the site. A high proportion of these sites occur in the ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga mensiesii*) forests of Montana—an environment having a long fire season. Therefore, treatments are needed to minimize fire hazards while optimizing the multiple benefits of recreation, wildlife, timber, and water production.

The objective of this study was to determine the relative cost and effectiveness of alternative slash disposal treatments aimed at reducing fire incidence (ignition), rate of spread (control), intensity (damage), and resistance to control (difficulty of fireline construction). Six treatments were tested:

1. Bulldozer pile and burn
2. Lop and scatter
3. Removal of pieces over 3 inches (7.6 cm) in diameter by farm tractor
4. Firewood removal and leave material less than 3 inches diameter
5. Firewood removal and lop material less than 3 inches diameter
6. Firewood removal and hand pile and burn material less than 3 inches diameter.

The treatments were applied to a 48-acre study area along Highway 200 on Montana Division of Forestry land adjacent to the University of Montana's Lubrecht Experimental Forest. The stand was second-growth ponderosa pine, Douglas-fir, western larch (*Larix occidentalis*), and lodgepole pine (*Pinus contorta*), that had been logged by individual tree selection a year before the application of the treatments. An intensive fuel inventory, using the planar intersect technique for inventorying downed woody material, was conducted at the site before the application of the treatments. Detailed cost records were kept during the application of the treatments and a second fuel inventory was conducted after the treatments were completed.

Small diameter fuel (0-3 inches) reduction was statistically significant at the 5 percent level for all treatments, except for "lop and scatter" and "firewood removal." However, fuel bed depth reduction was significant for all treatments.

Using the fire behavior prediction computer system BEHAVE, the fire behavior potential of the fuels before and after each treatment was calculated. Two sets of typical environmental conditions (spring and mid-summer) were used for the comparisons. The results are shown in figure 1 where the solid lines represent mid-summer conditions and the dotted lines represent spring conditions.

All six treatments showed significantly reduced fire potential and predicted fire behavior within the limit of manual attack methods. "Lop and scatter" produced acceptable fire behavior, but effectiveness is perhaps limited to low fuel loads (less than 10 tons/acre [22.4 metric tons/ha] of total woody fuel).

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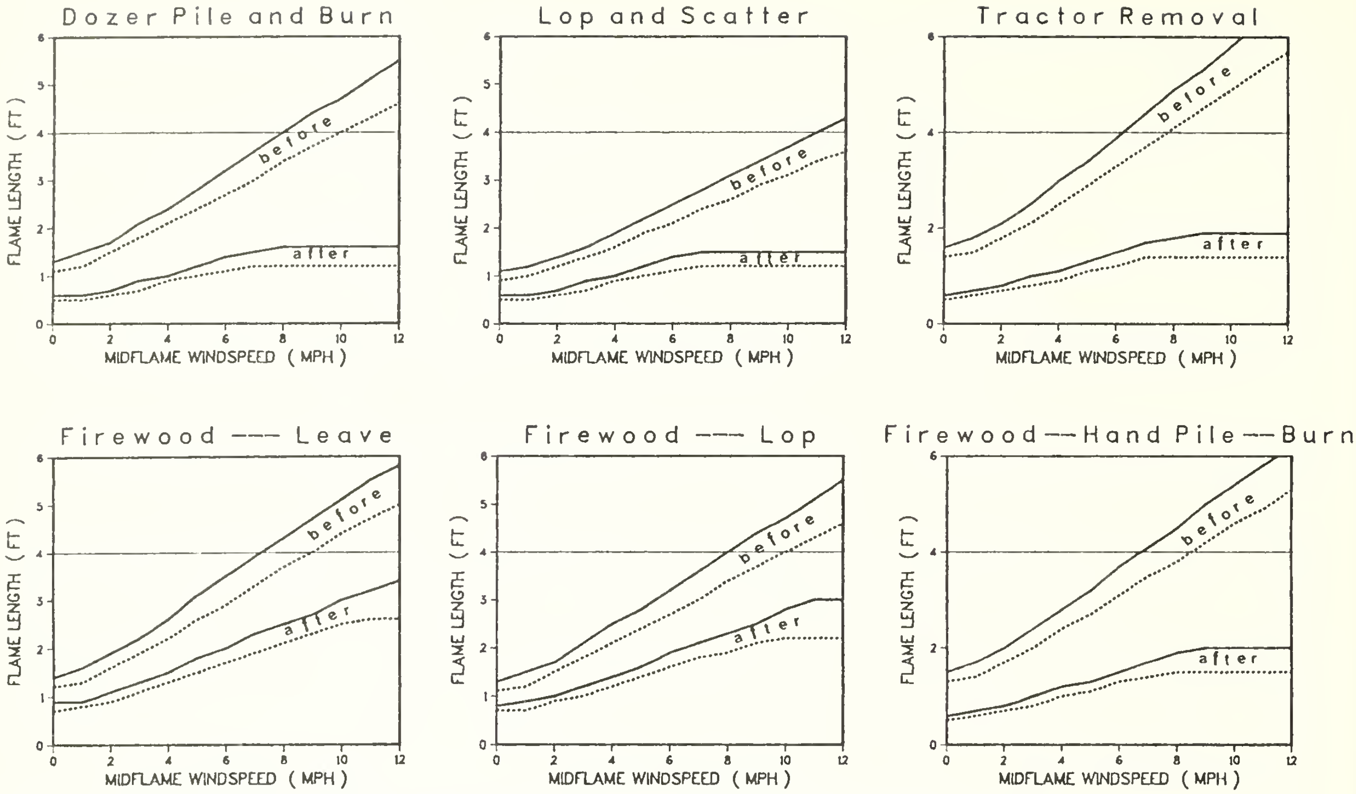

Figure 1—Relationship of flame length to midflame windspeed for six different fire hazard reduction treatments.

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Includes 57 papers and 14 poster synopses that present current technical information about young forests of the Mountain West—forests that range from the east slopes of the Cascades and Sierras to the high plains of the United States and Canada.

KEYWORDS: immature stands, inventory, timber quality, wildlife, water, forage, recreation, stand density, thinning, growth models, fertilization, genetics, insect and disease impacts, economics, lodgepole pine, ponderosa pine, Douglas-fir, western white pine, western larch, western hemlock, western redcedar, grand fir, white fir, spruce, aspen

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**Intermountain
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General Technical
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Increment-Borer Methods for Determining Fire History in Coniferous Forests

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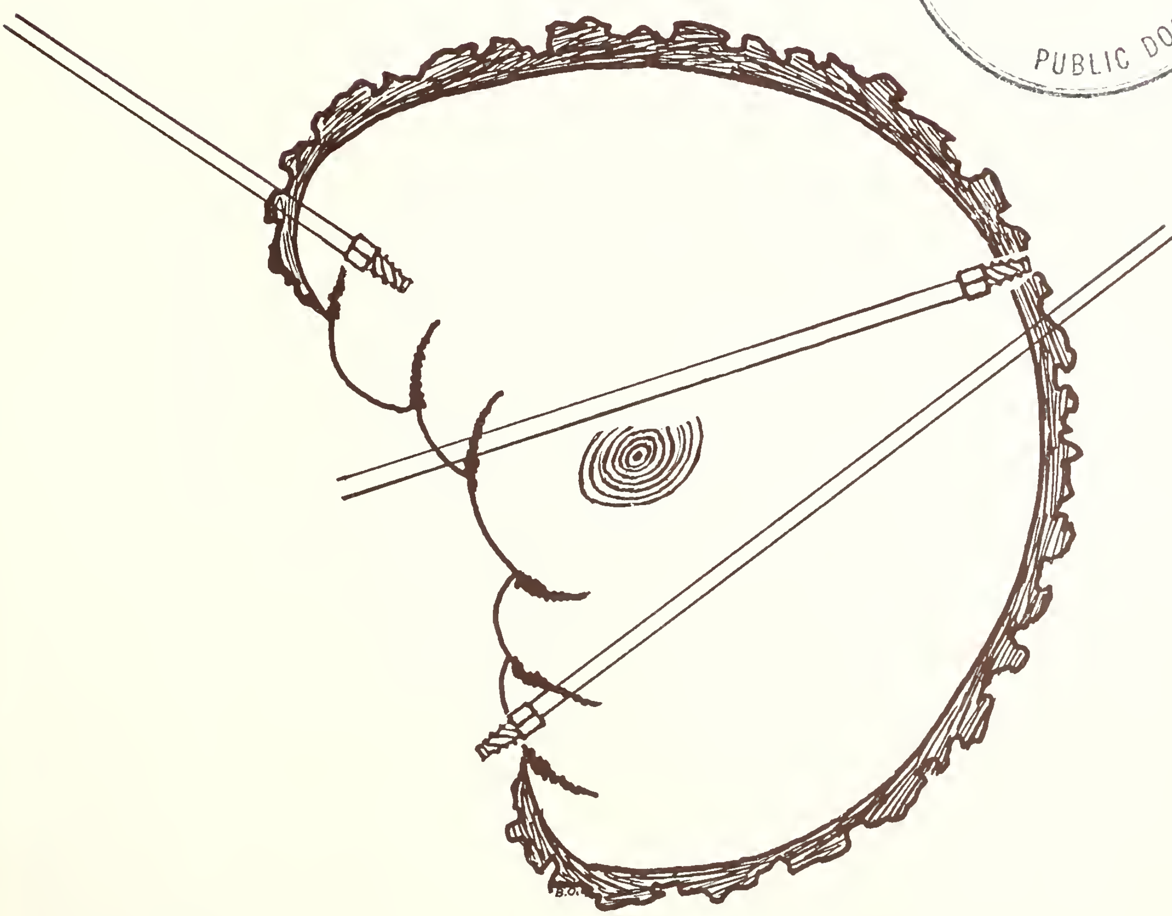
Stephen F. Arno



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RESEARCH SUMMARY

This report describes use of increment borers for interpreting fire history in coniferous forests. These methods are especially useful in wildernesses, parks, and other natural areas where fire history is needed for fire management planning, but where sawing cross-sections from fire-scarred trees is undesirable or prohibited.

The techniques presented here can be used to estimate fire years and the length of fire intervals with accuracy sufficient for many needs. Methods described include combinations of scar boring, face boring, and back boring to date individual fire scars; calculations of mean fire intervals for trees with multiple fire scars; and age-class sampling to characterize the effects of past fires on stand structure and composition.

The report discusses selection and layout of study areas and the collection and analysis of samples. The authors tell how to estimate frequency, intensity, and size of fires.

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Increment-Borer Methods for Determining Fire History in Coniferous Forests

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INTRODUCTION

Information on fire history is important for fire management planning in wildernesses, parks, and other natural areas where management goals include returning fire to a semblance of its primeval role as an initiator of vegetative succession. A few hundred publications and reports describe some aspects of fire history in different localities of Western North America. (For example, see studies listed in Martin [1982], Mastrogiuseppe and others [1983], McBride [1983], and Stokes and Dieterich [1980]). Still, many wildernesses and natural areas lack sufficient fire history information for guiding management. For example, data on frequencies, sizes, burning patterns, and effects of past fires are helpful in developing strategies for using fire to maintain or recreate desired vegetative patterns.

A commonly used technique for obtaining fire history information is by sawing cross-sections from fire-scarred trees (Arno and Sneck 1977; McBride and Laven 1976). But in natural areas such sampling may not be feasible even on a limited basis because of visual concerns, physical damage to trees, or prohibitions on the use of chain saws (motorized equipment). It is also difficult to handsaw "partial cross-sections" from large trees without causing a substantial amount of damage. Occasionally, undecayed stumps can be used to reconstruct fire history (Jacobs and others 1985; Kilgore and Taylor 1979); but most natural areas do not have enough stumps to supply this information.

To overcome these difficulties, we present methods in which increment cores are used to document fire history. These methods are based on a recent exploratory study (Barrett 1987) and on our experience in earlier fire history investigations. Several other investigators (for example, Arno 1976; Frissell 1973; Heinselmann 1973; Means in preparation; Sheppard and Lassoie 1986) have used increment cores to date single fire scars on trees and to identify tree age classes that represent postfire regeneration. No one, however, has produced a comprehensive guide to various methods that can be used for different field situations.

The relatively simple and economical techniques presented here can be used to estimate fire years and the length of fire intervals with accuracy sufficient for many needs in natural resource management and research. (Dendrochronological cross-dating of ring-width patterns on increment cores or tree cross-sections is an optional technique which can increase precision, but at additional expense [Madany and others 1982; McBride 1983; Sheppard and Lassoie 1986; Stokes and Smiley 1968]). The following increment boring procedures can be applied in most coniferous forests in North America. The procedures are intended for situations where sawing of cross-sections is undesirable or prohibited. Otherwise, analysis of cross-sections (Arno and Sneck 1977) is preferable because it is more accurate and economical.

TEST RESULTS OF INCREMENT BORING

In the exploratory study (Barrett 1987), increment cores were obtained from 49 fire-scarred trees. Fire scar years were estimated from the cores and the results were compared with estimates from sawn cross-sections. This sampling was conducted on three areas in western Montana and northern Idaho. Four tree species were sampled successfully with an increment borer: lodgepole pine (*Pinus contorta* var. *latifolia*), ponderosa pine (*P. ponderosa* var. *ponderosa*), interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), and western larch (*Larix occidentalis*). In contrast, excessive bole rot prevented increment-borer dating of fire scars on grand fir (*Abies grandis*) and on most western redcedar (*Thuja plicata*). Severe bole rot and indistinct growth rings and scar formations might also hamper increment-borer sampling of fire scars in other species. Therefore, users of this technique should first determine the feasibility of boring the species that occupy the proposed study area.

The following synopsis of study results suggests the levels of precision that can be attained. (More detail on study results is given in appendix A.) On 90 percent of the sample trees having single and double fire scars, fire years estimated from increment cores were within 3 years of those estimated from sawn cross-sections. Sheppard and Lassoie (1986) and Means (in preparation) used increment borers to date single fire scars on high-elevation lodgepole pine and coastal Douglas-fir (*P. m.* var. *menziesii*); they achieved similar levels of precision without dendrochronological cross-dating and greater precision with cross-dating.

We also sampled 11 ponderosa pine and Douglas-fir trees that each had between three and 16 well-preserved fire scars. The mean fire interval (MFI) for each tree based on increment cores was usually within 10 percent of the MFI derived from cross-sections (appendix A). MFI's were determined by (1) systematically counting the number of fire scars on the tree, (2) estimating the years of the earliest and most recent fire scars that were bored, and (3) dividing the number of years between the first and last fires by the number of fire intervals.

On sites that experienced frequent surface fires, the single-tree MFI's were often much longer than the "site MFI's" (appendix A) calculated from sawn cross-sections of several trees (Arno and Petersen 1983). As explained later, however, it is often possible to closely approximate the site MFI by boring trees that have the largest number of scars and then using the trees with the shortest MFI's to represent site fire frequency.

In forests that burned primarily in severe stand-replacing fires, there usually are few fire-scarred trees to provide a long-term record of fire history. Consequently, we also present an increment-boring technique for characterizing fire history based solely upon the tree age classes that regenerated after fires.

RECOMMENDED SAMPLING APPROACH

The methods outlined here are an extension of Arno and Sneck's (1977) methods for determining fire history from sawn cross-sections. Therefore, this paper concentrates on giving detailed instructions for increment-boring procedures and only briefly reiterates important points from the previous methodology. When possible, cross-sections should be collected because such samples can enhance dating accuracy. In wildernesses and parks, for example, impact can be minimized by cross-sectioning fire scars on stumps, snags, or trees outside but adjacent to the study area.

Selection of a sampling design is guided by study goals. If the goal is to characterize fire history throughout a large and diverse study area, obtain or prepare a map of stands or vegetation types (cover types). The map should also show major topographic differences, such as northern and southern exposures. The stand map (for example, a 7.5-minute U.S. Geological Survey topographic quadrangle) should be based on interpretation of aerial photographs.

Next, use the map to stratify the study area into stand types to ensure that an adequate number of sample sites is selected within each stratum. Transects along roads and trails and elevational contours may be useful for efficient sampling of the various strata (Arno and Sneck 1977).

It should be possible to map the approximate boundaries of past fires if a dense network of sites is selected for sampling throughout the study area (Arno 1976; Heinselmann 1973; Tande 1979). Additionally, where stand-replacing fires occurred, a stand mosaic of fire-initiated even-aged classes can often be identified on the aerial photographs. In such cases, include preliminary sketches of fire margins on the stand map. Fire margins, reflected by different textures on the photograph, can then be verified or adjusted during the field sampling.

The completed fire history maps have useful implications for fire management planning in natural areas. By combining the map with stand structure data (size- and age-classes by species), it is possible to interpret past patterns of both understory fires and stand-replacement fires relative to differences in topography and vegetation types.

FIRE-SCAR SAMPLING

Selecting Sample Trees

If fire scars are present in the sample stands, increment cores can be used to date the scars as well as any fire-induced regeneration. First, conduct a stand reconnaissance to locate the trees that have the clearest, most complete fire-scar sequences containing the greatest number of scars. These trees should also contain wood adequately sound for sampling. A thorough survey and examination of available fire scars will greatly enhance the efficiency of the time-consuming borer sampling and core analyses.

The investigator must also be careful to differentiate between fire scars and those caused by other agents such as mountain pine beetles (Gara and others 1986), root rot (Arno and Davis 1980), or animal or logging damage (Arno and Sneck 1977). Generally, exposed fire wounds ("catfaces") are triangular, and the wound begins at or below ground line. Catfaces usually have relatively uniform margins, in contrast to scars resulting from bark beetle attacks or root rot, which exhibit highly irregular edges and patterns of continuing dieback (Gara and others 1986). Fire wounds often have char on the adjacent bark or, if more than one fire has occurred, on the catface itself. These wounds tend to occur on the uphill side of trees, where heat concentrates during the burning process. On large trees, fire scars usually are centered in hollows between root buttresses rather than directly above a buttress, as is common with root-rot scars.

When possible, choose the most vigorous trees for sampling (for example, dominants or codominants with healthy crowns), because their growth rings tend to be relatively wide and these trees are less likely to have missing growth rings (Stokes and Smiley 1968). Also, species such as pines and Douglas-fir are desirable for sampling because they tend to have distinct scars and growth rings.

After the sample trees have been selected, mark their locations on a topographic map. Nearby topographic or cultural landmarks such as ridges, streams, and trails are useful in pinpointing the stand and sample tree locations (aerial photographs can also be useful). Next, carefully interpret and record the fire scar evidence associated with each tree—this includes the species, diameter, and location of the tree; approximate dimensions of the fire wound; the number of visible fire scars; extent of decay; and tree vigor (Arno and Sneck 1977).

The fire scar count is very important. Each scar is indicated by a distinct fold of healing tissue, which often can be traced along both sides of the catface. Some of the fire scars may have been overgrown (and thus obscured) by healing tissue either locally or throughout the catface. Those that are locally overgrown or locally burned off by subsequent fires can easily be overlooked and must be detected by several systematic inspections of the entire catface (fig. 1).

Here are some hints for interpreting fire-scarred trees in the field: (1) char on the exposed wood of the most recent scar is evidence that another fire subsequently burned this tree—the second fire either failed to scar the tree or its scar is overgrown; (2) char on the outer bark of an apparently unscarred tree is also clear evidence of a fire, but it

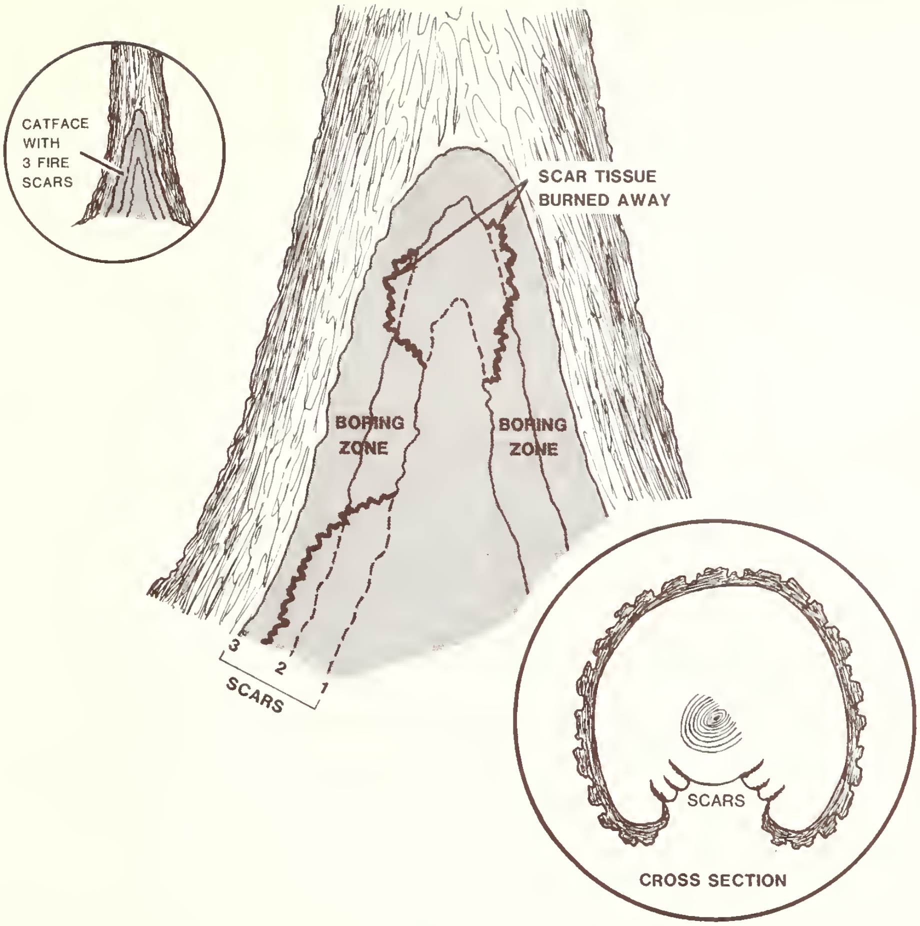


Figure 1—Catface with three fire scars, illustrating the discontinuous remains of some scars and including a cross-sectional view of the scars.

may not have inflicted a scar, so select another tree; (3) finally, a completely overgrown fire scar may be indicated by a prominent vertical bark "seam" on the trunk (fig. 4, page 7).

Preparation for Borer Sampling

A minimum of three increment borers and some spare extractors should be taken into the field because borer-clogging pitch frequently is encountered. If possible, carry borers that can penetrate the full diameter or at least to the center of the largest trees. Short borers are useful for small trees, or for boring scars located near the ground. To obtain clean, datable cores, the borer must be sharp and clean. Maeglin (1979) and Agee and Huff (1986) describe borer maintenance techniques. A dull borer is difficult to drive and will produce a rough core with spiral striations that obscure the growth rings. Periodic sharpening is necessary; the tip is dull when it cannot easily cut through a sheet of paper. A borer that is rusty or pitchy often yields twisted, soiled cores; therefore borers should be cleaned daily. A .22 caliber rifle cleaning kit works well on most borers. Between borings spray the borer and extractor with lubricant to discourage pitch buildup. Lengths of $^3/_{16}$-inch-diameter hardwood dowels are useful for unjamming borers (0.20-inch core diameter) in the field. (A checklist of field equipment is provided in appendix B.)

Before undertaking fire-scar sampling with an increment borer, it is helpful to become familiar with the patterns of fire scars and tree rings visible on sawn cross-sections of the species that will be studied. When inspecting these cross-sections, visualize the appearance of an increment core that intersects the scar area. Stumps in nearby logged areas or cross-sections gathered during other fire history studies are suitable for this purpose.

At the sample tree, the first step is to sketch a hypothetical cross-section at the height above ground where cores will be taken. That is, sketch the tree as if it were a stump viewed from above (fig. 1). Draw the positions of external scars and hypothesized internal scar patterns on this sketch (fig. 1, inset). Note the approximate distances between scars on the catface and indicate them on the sketch. Each boring pathway will then be sketched relative to the scar locations. Closeup photography can aid in documenting the external appearance of the scar but should not replace the sketches.

While boring a sample tree, record preliminary analyses of the increment cores. For instance, did the core intersect the fire scar? If not, does the core contain any suggestion of a fire injury, such as a pronounced pitch ring or sudden, marked change in growth rate? Also, make field counts to estimate the approximate year of the scar evidence on the core. Use a 10x hand lens and, if feasible, use a single-edged razor blade to carefully slice a smooth, flat surface on the core to help distinguish suppressed annual rings. As explained later, these rough estimates of scar years will be compared to estimates from other cores taken from the same tree, and also to estimates from nearby sample trees. This rough chronology of fire scar years will help guide the sampling to ensure that adequate repetitive data are obtained for each fire year. Making preliminary fire-year estimates and written interpretations in the field is critical because this information will determine when an adequate sample has been obtained from each tree.

It is also critical to carefully label and store each increment core because inadequately labeled or badly broken cores are unusable. Cores can be stored in plastic drinking straws and placed in protective boxes or map tubes. The core labeling can be done on masking tape stapled to the end of each straw. Label with pencil or water-resistant ink and always make a final confirmation that the labels agree with the field notes and sketches. Label information includes an identification code for the sample stand, tree, and core (for example, "Stand I, Tree 1, Core A").

Boring Methods

Dating of trees with single or double fire scars involves a combination of "scar boring," "face boring," and "back boring." Combinations of these and other boring techniques are used for multiple-scarred trees. In the exploratory study (Barrett 1987) single-scarred trees took a minimum of 15 minutes to sample, whereas old trees with complex, multiple-scarred catfaces required as much as 90 minutes. Sampling generally becomes more complex with increasing numbers of fire scars per tree, with increasing tree ages and diameters, and when rot or obscure growth rings are encountered.

SINGLE-SCARRED TREES

The Scar-Boring Method—This method uses a combination of "scar boring" and "back boring" and is often the most effective approach for estimating the year of the scar on large trees that have a single fire scar. The scar-boring method is generally the most useful approach if the tree's diameter exceeds the length of the increment borers, thereby preventing the use of other techniques described later, or if the tree's center is rotten (Means in preparation). First, choose the best area on the trunk for sampling—identify the section of the catface that has optimum scar development and the least-decayed wood (fig. 1). Boring low on the bole (1 to 2 feet above the ground) can help avoid locally absent areas of individual growth rings occurring higher up on the bole (Zackrisson 1980), which may be a problem on poor sites (Stokes and Smiley 1968).

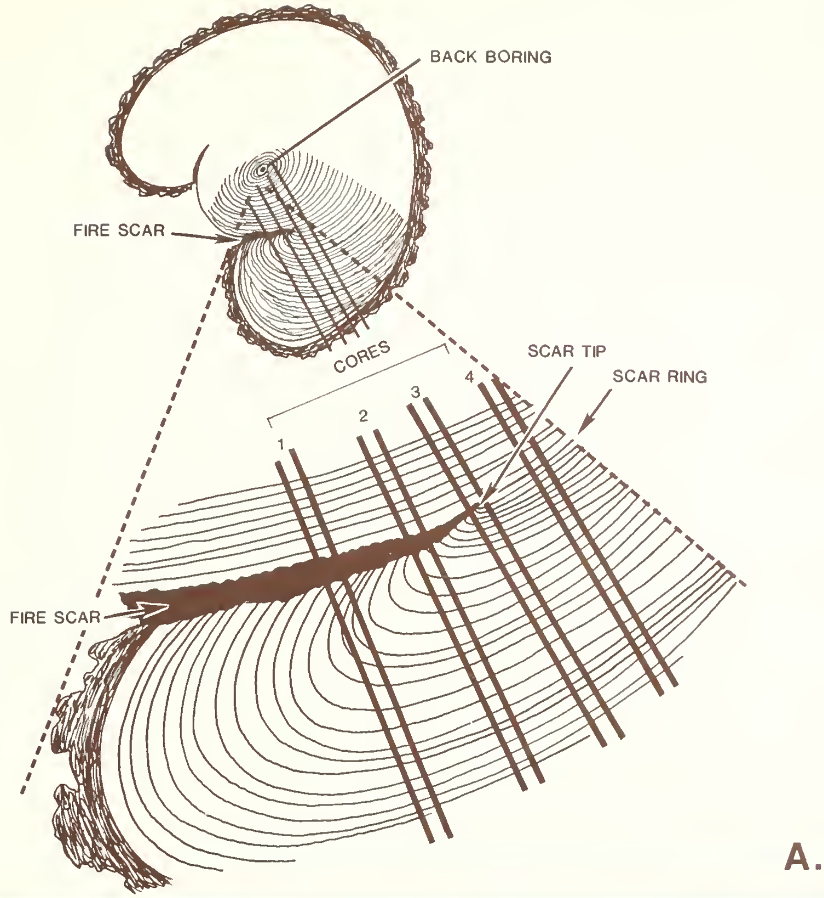
Take the first core from the back (unwounded) side of the tree, from the cambium to the pith (fig. 2). This "back boring" must intersect the pith, or its immediate vicinity, so that pith age can be determined accurately. Make an approximate count of the total age to the pith, and inspect the core to identify any sudden, major change in growth-ring widths that might have been triggered by the fire (fig. 3). If such a growth change occurs near the estimated fire year from scar boring, it can help confirm and refine the fire year estimate. Final scar year determinations will be made in the laboratory, with a microscope, but field estimates will help guide the borer sampling process.

Next, "scar boring" is carried out at the same height on the trunk as the back boring. For clarity, we will describe the process of sampling the right side of a single-scarred catface (fig. 2A). Take the first core so that it intersects the buried "scar ring"—the cambium at the time the tree was scarred (fig. 2, core 1)—2 to 4 inches to the right of the catface.

Extract the core and examine it for evidence of the scar ring. The scar ring usually is indicated by (1) a pitch deposit, (2) a change in ring-width pattern, and (3) an abrupt change in color as the first postscar rings covered the scar surface. Also, (4) the scar ring often is disjunct from the subsequent, healing rings because of an anatomical separation of the wood; thus, the increment core readily breaks at the scar ring. Growth rings immediately following the scar ring often (5) slant at an angle, rather than lie parallel, to the other rings in the core. If none of these diagnostic features is present, the borer apparently has missed the scar (in this example, the borer is too far to the right). If this is the case, another attempt should be made to intersect the scar ring by boring closer to the edge of the catface (that is, to the left). After each boring, examine, label, record, sketch, and store the core.

After the scar ring has been intersected, the next step is to make successive borings (to the right in this example), with the goal of intersecting the "scar tip" (fig. 2, core 3). In each of these successive borings, start the borer a short distance farther away from the edge of the catface and bore parallel to the previous attempts. The distance between successive borings depends upon the apparent pattern of scar healing. If the postscar growth rings are wide or if the catface is largely overgrown, make successive borings a few inches apart. Conversely, on slow-growing trees, make the borings closer together (for example, one-half inch apart). In such cases you may have to vary the boring heights slightly to avoid intersecting previous borings.

To improve accuracy in estimating the fire year, it is important to obtain a core that intersects or comes very close to the scar tip. Examine each core for evidence of the scar tip. Using the figure 2 example, if the borer pathway were still to the left of the scar tip, the scar ring would still be discernible, as described above. When the scar tip is approached, however, the scar ring usually becomes less pronounced. Although seldom intersected precisely, the scar tip itself is suggested by a faint line of pitch accompanied by a very slight crack in the core. To verify that the scar tip or the first postscar ring has been identified, take another core slightly past the scar tip (fig. 2, core 4). In this core, postfire growth rings lie parallel to the prefire rings, and there is no intervening pitch deposit or anatomical break. At this time, make a preliminary estimate of the scar year and compare it to estimates derived from the back-boring core and to estimates from other sample trees in the stand. If the full sequence of core samples described here has not been obtained or if a clear interpretation of



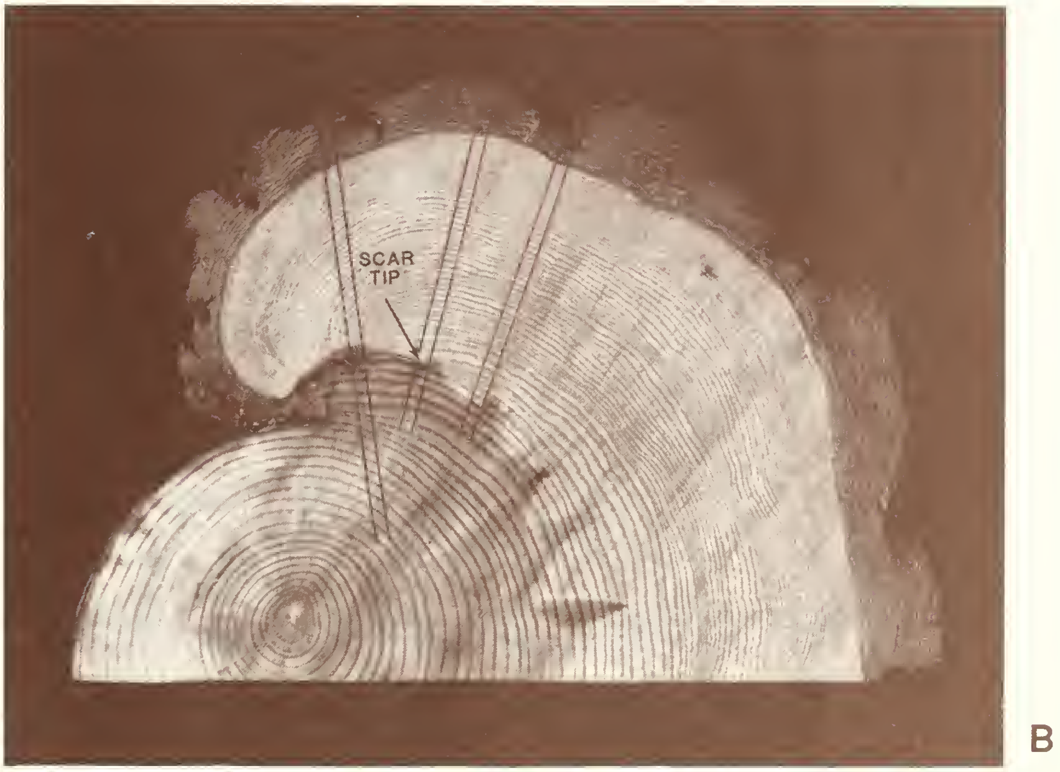


Figure 2—A. Scar-boring procedures illustrated on a hypothetical cross-section of a single-scarred tree. B. Scar boring illustrated on an actual cross-section of ponderosa pine, showing the growth patterns that would appear on cores from the outer fire scar.

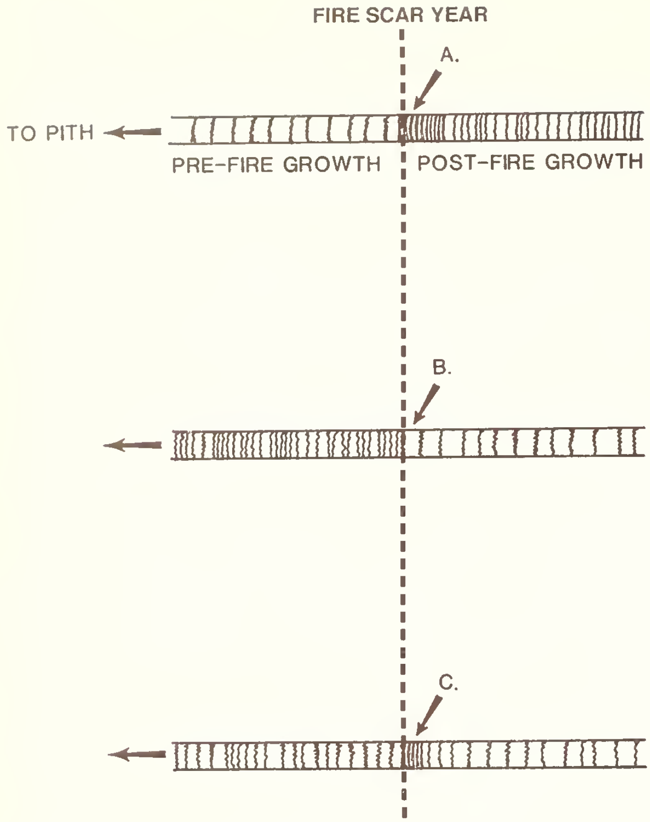


Figure 3—Annual growth-ring patterns commonly associated with fire scarring. These are simulated increment cores taken from beyond the fire scar. A. Fire damage causes marked reduction in growth, including perhaps missing rings; tree recovers slowly. B. Fire does not significantly damage tree, but kills some competitors, resulting in increased growth rate. C. Fire damage causes short-term reduction in the tree's growth, but also reduces competition, thus growth rate ultimately increases.

the scar year is not possible, select another area along the catface and repeat this sequence, or sample another tree.

As an aid to identification, the core that intersects the scar tip area often reveals an abrupt change in growth rate at the scar ring. In this case, the same growth change (fig. 3) should be visible on cores taken beyond the scar tip, and the fire year estimate can be verified from these cores. The core obtained by back boring also should be examined for such a growth change. If the tree was badly scorched by the fire, its immediate postfire growth rings are likely to be extremely narrow, locally absent, or missing entirely, especially near the edge of the fire wound. This appears as a sudden, drastic narrowing of radial growth, followed by a recovery or an increase in growth rate.

Occasionally, additional postfire rings are found in cores taken from the back of the tree or at locations past the scar tip; these represent growth rings that were locally absent near the fire scar. In the laboratory, careful shaving or fine sanding of the increment cores can help determine whether these are authentic annual rings or false rings. Under magnification, the dense summerwood portion of a false ring generally exhibits a gradual transition in both directions to lighter springwood (Stokes and Smiley 1968). In a genuine annual ring, the summerwood ceases abruptly on its outside edge and is followed by the next year's springwood.

The scar-dating procedure in the laboratory is as follows: First, mount the cores in a slotted "core board" (Arno and Sneck 1977) and shave or finely sand the cores. The cores should then be examined in the same sequence in which they were removed from the tree (fig. 2) as a cross-check of the field interpretations. First, count the annual rings in the core that extends from the cambium to the pith (from back boring) and estimate the pith year. Also note any dramatic changes in growth rate near the preliminary estimate of the scar year. Next, date back to the scar ring on the cores obtained from scar boring (cores 1 through 4 in fig. 2). The following list provides an example of evidence recorded from a sequence of cores similar to those in figure 2:

Back-boring core	—1800	estimated pith year at 4-foot sampling height; ~1911 marked growth suppression
Scar-boring core 1	—1915	pitchy scar break
Scar-boring core 2	—1912	pitchy scar break
Scar-boring core 3	—1910	faint pitch line and crack (apparent scar tip)
Scar-boring core 4	—1910	marked growth suppression but no pitch line or crack

The estimated fire year in this example would thus be 1910.

Scar boring also can be used on "seam scar" trees (Means in preparation). On such trees, a vertical bark seam—not to be confused with typical fissures in the bark—indicates that there is a completely overgrown fire scar within the tree (fig. 4). Seam-scarred trees may contain one or, occasionally, multiple buried scars; however, it is extremely difficult to sample multiple seam scars with an increment borer because the number of scars and hence the borer sampling approach cannot be determined visually. To obtain the date of a single seam scar, make a series of scar borings at increasing distances from the seam, until the scar tip is encountered (fig. 4).

The Face-Boring Method—"Face boring" can be used on a single-scarred tree that has relatively sound wood and whose diameter is less than the length of available increment borers (fig. 5). When sampling small-diameter trees, such as lodgepole pine, a single face boring, made in a few minutes, can produce an accurate estimate of the scar year. Face boring can also be used to check the results of scar boring, or it can serve as an alternative method when scar boring has proven unsuccessful because of localized rot or obscure growth rings near the scar tip.

First, examine the surface of the single-scar catface and select a location where the wood is sound and feasible to bore. If the catface is badly weathered or hardened by dried pitch, it is often possible to start the borer in the healing growth barely overlapping the edge of the catface (fig. 5).

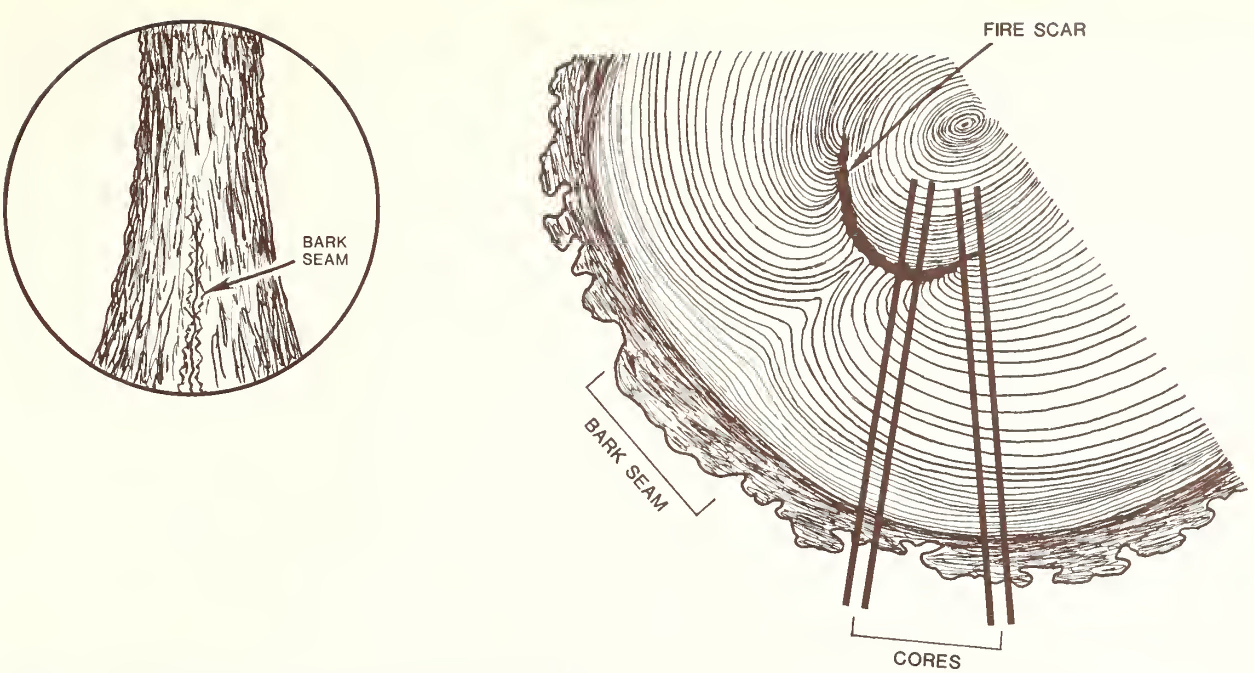


Figure 4—An external view and a cross-section of a seam scar.

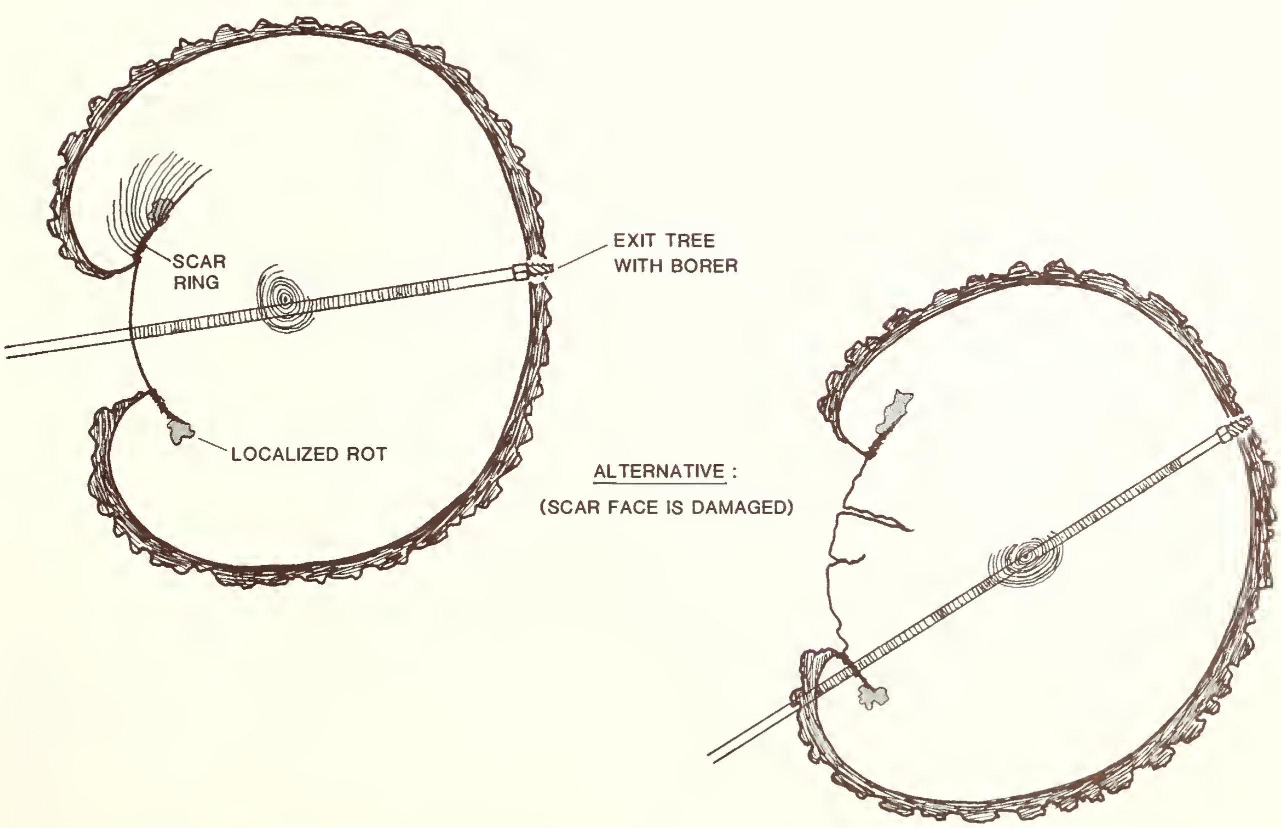


Figure 5—Face-boring procedures illustrated on a single-scarred tree.

Next, bore entirely through the bole. Obtaining the pith is not necessary for determining the scar year, although the pith date can sometimes be useful for estimating the date of tree age-class establishment, as explained later. Be careful to stop the borer as soon as the tip breaks through the bark on the opposite side. (This may be accompanied by a splintering sound.) If all of the screw threads were allowed to exit the trunk, it might be difficult to remove the borer.

It also might be possible to face-bore in reverse ("reverse face boring") by starting the borer on the back of the tree. This can be a useful method if the catface is hardened, damaged, or too deeply enclosed within the tree to bore. The approach is to bore through the tree's center and emerge on the exposed scar or in the adjacent healing tissue. Again, it is not necessary to obtain the pith.

Extract the core and inspect it to see if it contains the scar ring. If the exposed catface was penetrated, the scar ring will have a weathered surface. It may have fallen away when the borer broke through the surface. (This can be prevented by having an assistant hold a block of wood against the spot where the borer is beginning to emerge.) If the scar ring is not found on the core, search for it on the ground, below the borer tip, or bore again—this evidence is essential for estimating the fire year. If the borer emerged in the healing tissue, the scar will usually be indicated by a pitchy ring (previously described) beneath the healing growth.

A continuous core from the catface through the bole to the cambium on the back of the tree (or vice versa) allows for relatively accurate dating of the fire scar. Count the number of annual rings between the cambium and the earliest ring on the core. Subtract this number (of rings) from the date of the cambium to determine the year of the earliest ring. To estimate the scar year, count "up" from the earliest ring to date the scar ring.

If the increment borers are too short to extend through to the opposite side of the tree, a less efficient alternative is to make the face boring to intersect the pith and then a back boring from the cambium to the pith. The back boring should be made slightly below or above the face boring to avoid intersecting its pathway. Because the scar year estimate must be based on two separate cores, the pith must be obtained in both cores. On a large tree if the pith is missed slightly, the number of rings to the pith could be estimated as described by Applequist (1958) and Arno and Sneck (1977).

TREES WITH TWO OR THREE SCARS

The following methods can be used for trees with catfaces containing two or three fire scars. First, if the catface is not badly charred, date the innermost scar using one of the face-boring techniques. Then date the outermost (most recent) scar using the scar-boring approach (fig. 6A). Be careful not to bypass the tip of the outer fire scar and inadvertently sample earlier scars. If the sample tree has three large fire scars it might also be possible to date the middle scar, using either the scar-boring or reverse-face-boring methods. Examine figures 1 through 6 in the field and then experiment with the various techniques to determine which will be most useful.

If the face of the innermost scar has been too badly burned to permit face boring, reverse-face boring should be considered (fig. 6B). In this situation, start the borer on the back side of the trunk and aim through the tree to intersect the healed-over portion of the innermost fire scar. This might require several attempts, but it can be rewarding. Reverse-face boring offers good precision since the scar ring is obtained in a transect through the undamaged center of the tree.

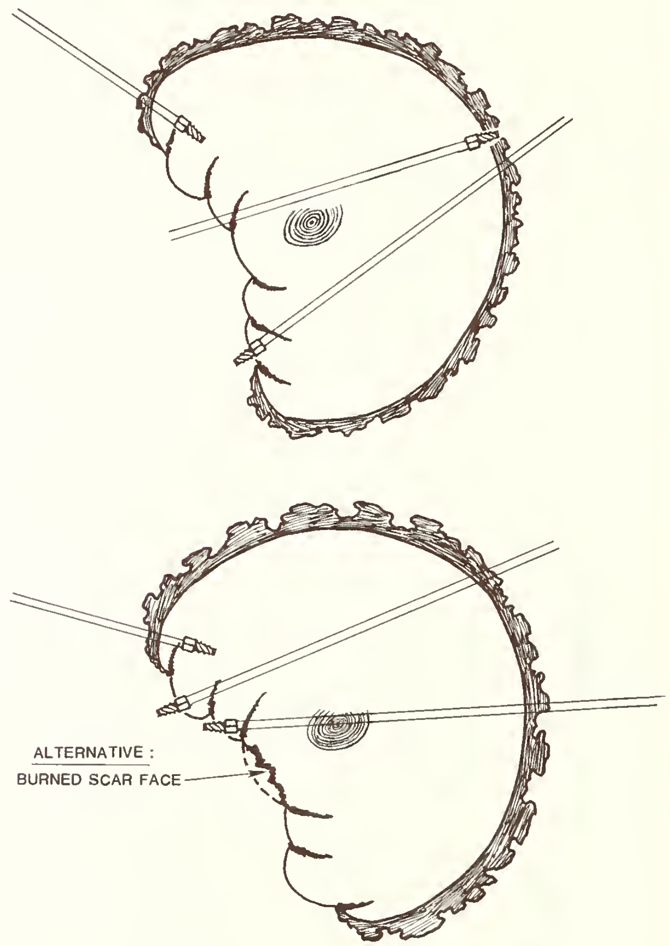


Figure 6—Cross-sections of trees with three well-formed fire scars showing scar boring of the outer scars, face boring of the inner scar in top drawing, and reverse face boring of middle scars and inner scar in bottom drawing.

MULTIPLE-SCARRED TREES—THE MEAN FIRE INTERVAL METHOD

The "mean fire interval" (MFI) method is used when a catface contains three or more fire scars, and it is not possible to date all of the scars. The goal is to date the outermost scar and one of the innermost scars and then estimate the MFI for the intervening period. The MFI equals the number of years between the first fire and the last fire, divided by the number of fire intervals, which is one less than the number of fires.

At the tree, make several counts of the number of fire scars between the outer and inner scars by closely examining the entire periphery of the catface—frequently scars have been locally burned off or overgrown (fig. 1). On old, multiple-scarred trees the earliest fires often cannot be dated because their scars have been destroyed by subsequent fires. In such cases, **the earliest scar suitable for boring** should be chosen as the start of the scar sequence for MFI calculations. As will be explained, however, in a given stand, it is important to sample sequences with the largest numbers of scars.

On trees with relatively few, well-formed scars, the outer and inner fire scars can be sampled with the scar-boring, face-boring, and reverse-face-boring techniques previously described. On old trees with many scars, "exit-scar boring" is often necessary for intersecting the targeted innermost scar (fig. 7). This technique affords less accurate dating than the other methods, but is sometimes the only alternative for determining MFI's, when sawing cross-sections is not possible. Exit-scar boring is similar to scar boring except that the borer is started on the back of the tree and aimed so that the tip exits at the targeted early fire scar deep within the catface. The location of the emergent borer tip and the borer angle allows the investigator to determine which scar was intersected.

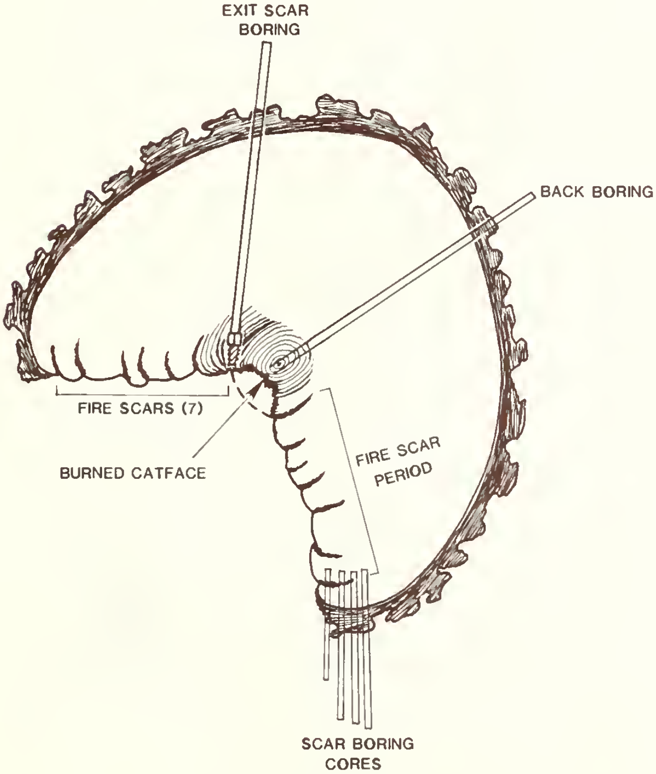


Figure 7—Cross-section of a multiple-scar tree showing possible pathways for exit-scar boring to date inner scars, and scar boring to date the outermost fire scar.

It may take a few attempts to obtain clear evidence of the early scar ring. Even on the best cores, the ring count from the cambium to the early scar probably will represent only the approximate number of years since the early fire. This is because the scar tip is rarely obtained, and locally missing rings are common in old trees that have been scorched by many fires. For characterizing fire history, however, such imprecision often is not a serious problem, because MFI's calculated from the most-scarred trees in the stand usually will be close to those calculated from sawn cross-sections (appendix A).

Along a similar vein, it is important to note that this increment-boring approach produces an estimate of the MFI from an individual tree, or "for a point on the ground" (Arno and Petersen 1983). This contrasts with a "site MFI," which is usually shorter because it is based on a correlation of fire scar records from several trees (Arno and Sneck 1977). If a thorough stand inspection reveals that the most complete scar sequence on any tree contains only a few scars, then the MFI for that tree may well represent the site MFI. But, if the site has been subjected to frequent surface fires, individual trees are unlikely to have been scarred by every fire that occurred during their lifetimes. Thus, even the most complete single-tree MFI will usually be somewhat longer than a site MFI (Arno 1976; Arno and Petersen 1983). To minimize this tendency, sample only the most frequently scarred trees, then use the shortest MFI to represent the best approximation of site MFI. (For example, note that in appendix A several trees were sampled in a grove whose composite MFI was 9 years, yet the individual-tree MFI's ranged from 11 to 21 years). Another limitation is that, unlike the fire record from a sawn cross-section, increment borer sampling cannot provide estimates of minimum and maximum fire intervals or of the distribution of interval lengths.

Age-Class Sampling

In addition to fire scars, many stands have even-aged classes of seral species that became established soon after fires. Age-class sampling is an important component of fire history studies because it helps describe the influence of past fires on forest composition and stand structure. On sites that experienced severe fires, where there are few usable fire scars, age-class sampling may be the primary method for characterizing fire history.

STANDS WITH FIRE SCARS

In forests where past fires can be dated from scars, age-class sampling should still be conducted at each sample site. For example, one goal might be to identify the approximate number of trees per acre by species, sizes, and ages that survived fires, as well as those that regenerated in the postburn environments. These age- and size-class data by species should be collected at each fire scar sample stand, as determined in the stand sampling design. The purpose is to characterize the stand structure relative to the fire history.

First, inspect the stand in the vicinity of the fire scar sample trees to visually identify all apparent age classes of seral trees. Similar tree diameters and crown conditions often are indicative of an age class. For example, one class might consist of immature trees with pointed tops and vigorous leaders; others might have mature trees with rounded tops, overmature trees with flat tops and gnarled upper branches, and senescent trees with thin foliage and gnarled branches throughout the crown (Daniel and others 1979; Keen 1936).

Next, sample a few trees in each apparent age class. Also, in order to interpret successional trends, sample understory trees. Sample size depends on the stand's structural complexity. One approach is to concentrate sampling in one or more macroplots (0.10 to 0.25 acre each) in each stand. Choose the location of plots to include the various age classes found in the stand. Within the macroplots or other sample units, tally all trees by species and by actual diameters or by diameter classes. Tree ages for the major size classes should then be obtained by increment boring.

In most forests, fire-induced age classes are made up largely of shade-intolerant species. Total ages (to the pith) of a minimum of five trees in each potentially fire-induced age class should be sampled by increment boring at 1 foot above ground line. (It is seldom feasible to bore directly at the ground line.) Large trees can be bored higher on the bole if necessary. A correction factor representing an average time necessary for the species to attain the increment boring height should then be determined. This can be done by cutting saplings at ground level and counting the number of years they required to reach the boring height. To characterize the initial height growth of a postfire age class, it may be preferable to gather this information from saplings on disturbed sites rather than in the understory of a dense stand. This factor is added to the ring count obtained from the increment core to obtain an estimate of the tree's total age.

On each sample tree, obtain the pith or its immediate vicinity. A rapid growth rate near the pith is characteristic of regeneration on an open site, and thus of postfire regeneration. Alternatively, if most trees exhibit slow initial growth they may not be fire-initiated.

The oldest trees in a fire-initiated age class provide the best indicator of the fire year, but the establishment dates of even these trees can postdate the burn by a substantial number of years. Nevertheless, age classes of very old seral trees often provide the only estimates of fire years that preceded fire scar evidence.

Enter the data on fire-induced age classes on a stand table (fig. 8) to provide a long-term picture of succession. If stands that experienced numerous surface fires were sampled with the MFI method, the dates of most fires will remain unknown. Still, age-class analysis can reveal the general effect of this pattern of fires on tree regeneration and survival. For example, analysis will indicate whether the stand exhibits several age classes of seral, disturbance-dependent trees that apparently became established in response to the frequent fires. The age-class data also will indicate which species were most abundant in association with the various kinds of fires that occurred in the past. Also, because the year of the most recent fire has been estimated, the investigator can compare current patterns of tree succession and fire occurrence to those of the past.

In stands that did not experience frequent surface fires, scar sampling can often reveal approximate fire years within the last two or three centuries. Inspect the data for any apparent relationships between each tentative age class and the fire years that were estimated for the site (fig. 8).

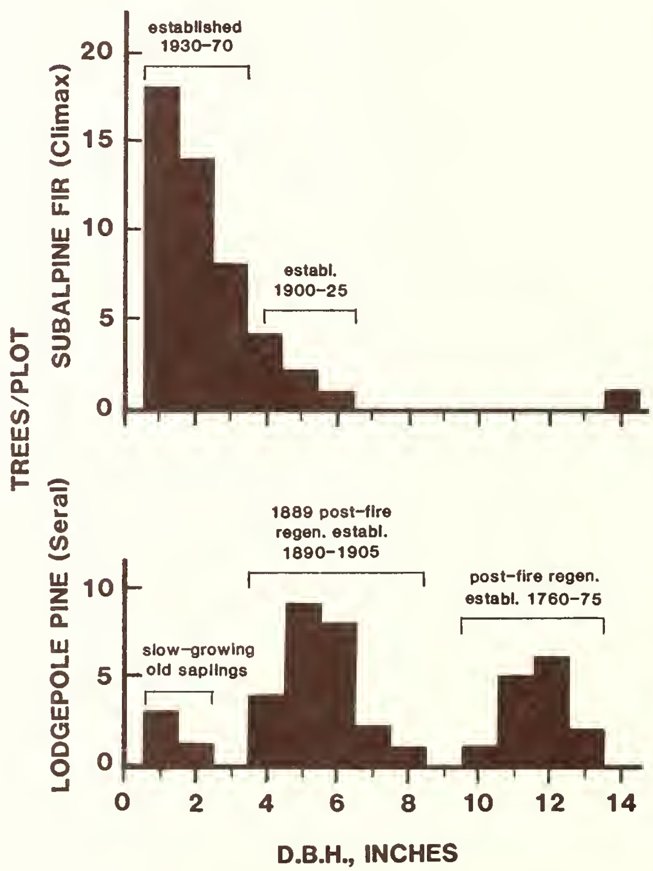


Figure 8—An example of stand table data for a macroplot, showing two fire-induced age classes of lodgepole pine. Trees that are now greater than 10 inches in diameter had survived the 1889 fire and contained fire scars. Most subalpine fir were apparently killed by the 1889 fire.

STANDS LACKING FIRE SCARS

In forests composed primarily of even-aged stands that characteristically burned in severe, stand-replacement fires (for example, Rocky Mountain lodgepole pine), fire-scarred trees may be too scarce or too old and severely decayed to warrant increment-borer scar sampling. In these situations, fire history should be characterized by developing "age-class chronologies."

The first step is to develop a stand-origin map based on interpretation of aerial photographs and examination of fire suppression records (Heinselman 1973; also see our sampling design recommendations on page 2). This map of the forest mosaic shows the pattern of even-aged stands that resulted from the most recent stand-replacing fires. Field sampling must then be done to determine the approximate stand-origin years for the mapped stand mosaic.

An additional goal here is to develop a chronology of initiation years for age classes that occupied the site before the last fire. This evidence of earlier fires is based on the pith years (year of germination) of former age classes of seral species. These often are still represented in the stand as scattered remnant trees or fire-killed snags. First, use aerial photographs and ground reconnaissance to select sample sites that have the largest number of remnant old trees and snags. At each site, in addition to the current age class, datable remnants of at least one prior age class usually can be found (Barrett 1986, 1988).

Begin sampling by estimating the earliest germination year for the current fire-initiated age class. To do this, determine ages (since germination) for a minimum of five seral (shade-intolerant) trees, making preliminary counts in the field. Establishment years of trees in the same fire-initiated age class will often vary by 15 to 25 years or more, but the earliest sampled year provides the best estimate of the fire year. Expanding the number of sample trees might improve the estimate of the fire year. Also, it is often possible to designate the precise year of a 20th century fire by examining fire atlases maintained by land management agencies.

Repeat this sampling procedure to identify any older age classes on the site. The best sample trees are usually found along the margins of the most recent burn. Trees at the burn margins also often have fire scars that can be sampled to improve the estimate of the fire year. Additionally, some trees may have survived on rocky outcrops, stream margins, or other microsites that escaped severe burning. Old snags are often difficult to bore, but it may be permissible to fell and cross-section some snags to date such age classes. Alternatively, it may be possible to locate and saw samples from snags that have fallen in recent years and are not yet badly decayed.

It is important to estimate sample-tree ages in the field in order to identify and adequately sample all age classes on the site. Where snags were created during a known fire year, their age at death can be subtracted from the fire year to obtain the estimated establishment period for this early age class. Table 1 gives an example of fire history data based largely on age-class chronologies. In instances where no datable remnants of a fire-initiated age class can be found in a very old stand, the maximum tree ages evidently represent a long fire interval (Hemstrom and Franklin 1982).

Table 1—A hypothetical example of fire history for one site based on age-class chronologies of seral trees. (In this case there are two fire intervals and the MFI is approximately 155 years)

Estimated fire year/ stand-initiation year		Evidence
1910	—	exact year listed in area fire atlas and confirmed by postfire age classes and a few fire scars
approx. 1785	—	based on origin years of seven live seral trees, ranging from ~1785 to ~1805
approx. 1600	—	based on origin years of four seral trees killed in 1910 fire, ranging from ~1600 to ~1620

Characterizing Fire Frequency—Age class chronologies provide the sole means of characterizing fire frequency for stands that lack fire-scars. When there is evidence of only the two most recent fires on a site, it is not possible to estimate mean, maximum, and minimum fire intervals. These fire history statistics can, however, be calculated for a network of sites in the same forest zone (for example, the "lower subalpine zone").

First, stratify the sample sites by forest zones. For each zone, list all the individual fire intervals that were identified on the sample sites (table 2). A "multiple-site average fire interval" can then be calculated by totaling the number of years in all the fire intervals and then

Table 2—An example of data showing approximate fire intervals among different sample sites within one forest zone. The intervals are compiled (bottom) to derive a "multiple-site average fire interval." Data are from Barrett (1986) for seral species in the "lower subalpine zone" (Pfister and others 1977) of Glacier National Park, MT

Site number	Age-class origin dates			Complete fire intervals (years)
1	~1575	~1780	1929	205, 149
2		~1780		none[1]
3	~1539	~1780	1929	241, 149
4	~1593	~1780		187
5	~1562	~1894		332
6	~1673		1926	253
7		~1720	1910	190
8	~1673		1910	237
9	~1673			none[1]
10		~1750	1919	169
				2,112 yr - 10 intervals

Multiple-site average fire interval = 211 years
Shortest interval = 149 years
Longest interval = 332 years

[1]If numerous incomplete fire intervals are obtained from sample stands, they could be included in calculations of multiple-site average fire intervals, for instance as was described by Arno and Petersen (1983).

dividing by the number of intervals (Means 1982). If there are some very long intervals (complete or incomplete) in the data, it is advisable to consider calculating a median interval rather than the mean described here (Arno and Petersen 1983; Romme 1980). Minimum and maximum intervals can also be identified among these data. If the goal is to characterize fire history for a relatively large area, it is desirable to use well-dispersed sample sites in the calculations, to avoid excessive repetition of some individual fire intervals.

Characterizing Fire Size—Age-class chronologies also can be useful for interpreting size, configuration, and continuity of past fires. (Aerial photographs of the current age-class mosaic will provide an initial impression.) In a large study area (for example, more than 50,000 acres) data from the network of well-dispersed sample sites will suggest which fires were very large. A fire would be interpreted as having been extensive and severe if age-class remnants regenerating from it were found in many different vegetation zones across diverse topography. Conversely, the age-class data from sample sites might suggest that some fires were confined by topographic barriers such as rivers or barren rocklands. Strive for good dispersion and adequate density in the distribution of sample sites, because this will generally enhance your ability to interpret such fire patterns.

CONCLUSIONS

Prior to 1900, fire was a major disturbance agent in most North American forest types. Managers of natural areas are now faced with the challenge of deciding how and when to reintroduce fire. In small areas this might involve manager-ignited prescribed fires. Conversely, in large areas more lightning fires might be allowed to burn under prescribed conditions. In some of the high-fire-frequency vegetation types, it might also be necessary to augment lightning fires with manager-ignited fires in order to prevent undesirable fuel buildups or vegetation changes. Fire history information provides managers with site-specific data on the frequencies, patterns, and general effects of past fires. This information serves as a benchmark for managers to use in maintaining and simulating the forest conditions for which natural areas were established. Use of low impact research methods will help managers determine fire history without damaging wilderness values.

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APPENDIX A: COMPARISON OF FIRE-SCAR YEAR ESTIMATES FROM INCREMENT CORES (BARRETT 1987) WITH THOSE BASED ON SAWN CROSS-SECTIONS (FROM ARNO 1976; ARNO AND PETERSEN 1983; AND UNPUBLISHED DATA)

P = *Pinus ponderosa*; F = *Pseudotsuga menziesii*; LP = *Pinus contorta*; L = *Larix occidentalis*; C = *Thuja plicata*

			Estimated year of first fire		Estimated year of last fire		Mean fire interval (yr)		
Tree No. and species	No. of increment cores	No. of external scars	From cores	Diff. from cross-section	From cores	Diff. from cross-section	From cores	From cross-section	From small stand
				Single-scarred Trees					
1-LP	6	1	1905	+1 yr	NA		NA		
2-LP	8	1	1904	0					
3-LP	7	1	1889	0					
4-LP	5	1	1886	–3					
5-LP	6	1	1891	+2					
6-LP	4	1	1889	0					
7-LP	3	1	1892	+3					
8-LP	5	1	1906	+2					
9-LP	6	1	1911	+7					
10-LP	5	1	1889	0					
12-L	5	1	1903	–1					
13-L	5	1	1806	+1					
14-L	5	1	1904	0					
15-F	5	1	1805	0					
17-F	6	1	1904	0					
18-L	4	1	1905	+1					
8-P	5	1	1922	+3					
10-P	5	1	1920	+1					
11-P	8	1	1919	0					
12-P	5	1	1919	0					
16-F	5	1	1889	0					
17-F	4	1	1889	0					
19-P	4	1	1927	–2					
20-P	7	1	1928	–1					
2-C	6	1	1914	–5					
3-C	3	1	1919	0					
5-C	3	1	1928	+4					
				Multiple-scarred Trees					
9-P	8	2	1877	–6	1919	0	NA		
18-P	8	2	1928	–1	1938	0			
21-P	6	2	1918	–1	1937	–1			
23-P	5	2	1920	+1	1929	0			
2-P	5	3	1643	0	1758	+1	58	57	10
13-F	11	3	1752	–2	1889	0	69	68	19
14-F	6	3	1836	–1	1869	–2	17	17	19
15-F	7	3	1807	+4	1889	0	41	43	19
22-P	4	3	1915	–4	1938	0	12	10	9
1-P	6	4	1815	+5	1889	0	25	26	10
5-P	8	4	1698	+2	1892	0	65	65	9
6-P	11	10	1685	–5	1886	–6	22	22	9
4-P	10	12	1658	–10	1886	–3	21	20	9
7-P	8	14	1659	–9	1916	–3	20	19	9
3-F	6	16	1731	+9	1896	+4	11	11	9

APPENDIX B: LIST OF FIELD EQUIPMENT

–"methods" booklet/photocopied scar illustrations
–tatum (tally board)
–field forms
–7.5 minute topographic maps/aerial photographs
–3 increment borers (16-inch or greater length)
–spare extractors
–plastic drinking straws
–map tubes
–masking tape for labeling cores
–pocket stapler/staples (for stapling straw ends)
–spray lubricant
–wax for borer bit
–3/16-inch hardwood dowels
–waterproof pens/pencils
–35-mm camera/film
–10x hand lens
–single-edge razor blade
–pocket knife with multiple tools (awl, screwdriver)

Barrett, Stephen W.; Arno, Stephen F. 1988. Increment-borer methods for determining fire history in coniferous forests. Gen. Tech. Rep. INT-244. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 15 p.

Describes use of increment borers for interpreting fire history in coniferous forests. These methods are intended for use in wildernesses, parks, and other natural areas where sawing cross-sections from fire-scarred trees is prohibited.

KEYWORDS: fire ecology, fire management, forest succession, natural areas, wilderness management

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)