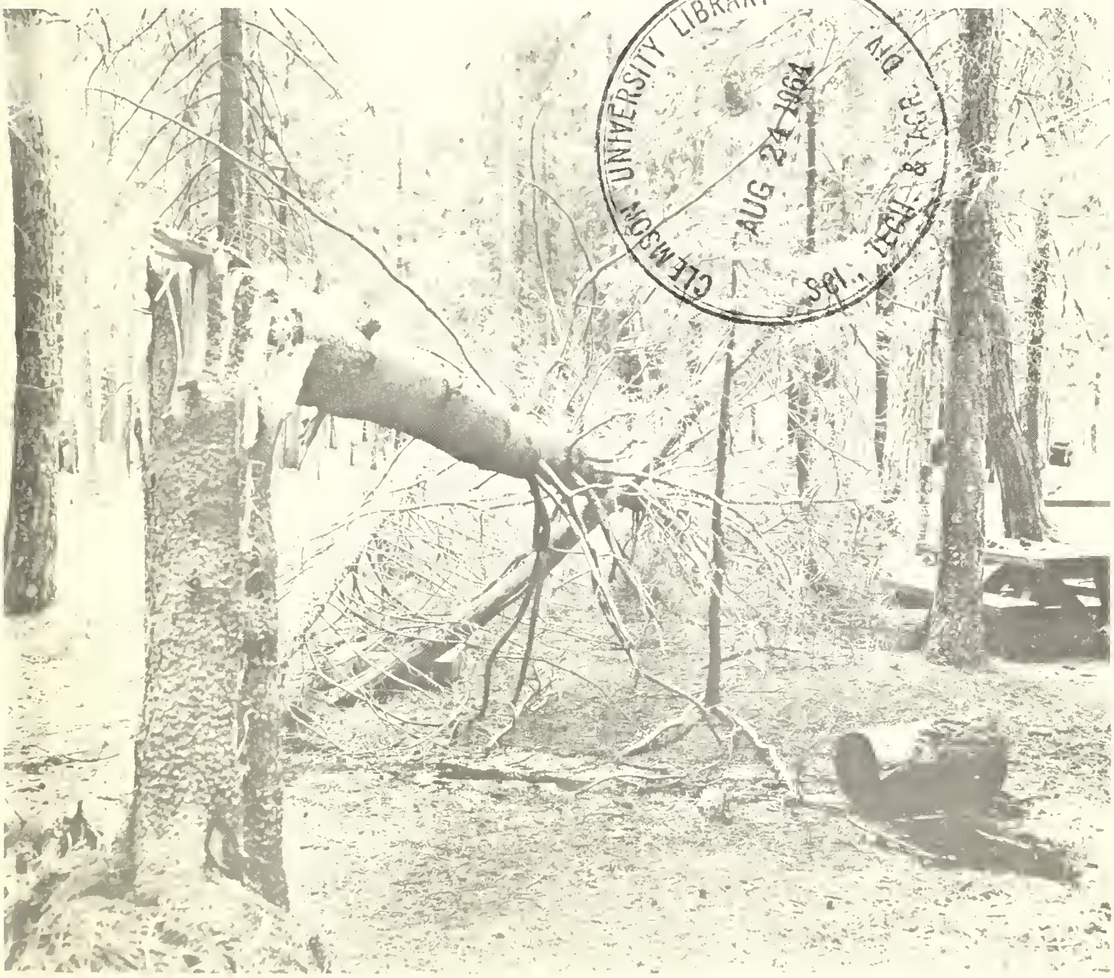
Judging Hazard from Native Trees in California Recreational Areas:

--a Guide for Professional Foresters

Willis W. Wagener



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THE AUTHOR

Willis W. Wagener is a forest pathologist. For more than 40 years, he has been studying tree diseases and their control. Dr. Wagener retired from the U.S. Forest Service in September 1962, and is now a consultant to the Pacific Southwest Forest and Range Experiment Station. He was born in northern Stanislaus County, California, was graduated from Stanford University, and earned his doctorate from the Yale University School of Forestry.

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Trees can beautify, protect, and cast a cooling shade. But they can also maim or kill if they or their parts break and fall. Failure is not likely if trees are sound, except under extraordinarily unfavorable weather conditions. Over a long life span, however, trees may suffer weakening defects that may make them unsafe. This is the potential that is of increasing concern to those in charge of forest and park recreational areas, to which people are flocking in ever-increasing numbers in California.

Defects that accompany decadence and death in trees form a part of the natural process of renewal in the virgin forest. As such, under virgin conditions, they are beneficial. But defects that seriously weaken trees in such areas take on a different significance when man enters the forests and congregates in persistent numbers at campgrounds or resort centers. They become hazards that can turn a visit or a vacation into a tragedy.

The desirability of abating tree hazards in heavily-used recreational centers is now generally recognized. But until recently, no specific information has been available on what defects are likely to render a tree unsafe or how to recognize potentially hazardous trees. This publication is a first attempt, from the best knowledge now available, at providing such information for California recreational sites. It should apply also to the reduction of tree hazards along highways and in the vicinity of homes or other structures in the woods.

This guide is intended chiefly for professional foresters charged with making safety inspections of trees in recreational areas. We assume that such men have a general background understanding of the more common tree defects that may affect safety and of the causes of defects. We further assume that they realize that any decision made regarding hazard removal is likely to have multiple effects. Some of these effects may be undesirable when measured against the intended function of the area.

The removal of a defective tree, for example, may create an opening that allows greater wind action with the increased possibility of wind damage to the remaining trees. Excessive tree removal may reduce the attractiveness of a campground to the public, thereby impairing its usefulness. It is important, therefore, that a person conducting a hazard examination should be aware of all consequences of any contemplated action. His judgment on individual trees should be based on as broad and complete a background as possible.

The Problem of Hazard

Weather

Storm Conditions

Most tree failures are associated with wind, snow, or ice, and involve some type of weakening defect. But *storm conditions may occasionally be so extreme that any forested area can temporarily be rendered unsafe by falling tops, branches, or entire trees, even if not defective.* Completely sound trees have been snapped off or uprooted during such exceptionally severe storms.

The safety of forest occupants under these conditions is assured only if they take adequate shelter or move to open ground. Lightning offers another so far uncontrollable danger in forested areas, with instantaneous hazards from electrocution or from parts flying off shattered trees.

But not all tree failures occur during windy or stormy weather. Defective trees sometimes topple when the air is still (fig. 1). These failures are more dangerous than those occurring during storms because they are likely to take place when recreational use is heavy. Thus detection of trees that can fail in the absence of wind is especially important.

In many areas, nature helps reduce hazards in

Figure 1.—This massive oak toppled at 6:10 a.m. on a windless July morning. The tree had been weakened by butt and root rot, principally from the honey fungus.

the forest by breaking down weak trees or branches during winter storms when the areas are not likely to be occupied. This is particularly true in localities subject to heavy wet snows. Thus the actual safety status for a particular location depends in part on its climatic conditions and in part on its occupancy pattern.

Safety standards need to be more strict under year-round occupancy than for occupancy only from May through September. Similarly, stricter standards are necessary for trees near valuable structures than for those away from such developments. Low elevation coastal parks and campgrounds, where snowfall is rare, can be quite different in hazard potential from those in mountain areas where snow and ice loads on trees are common annual occurrences.

Wind

Wind, acting either alone or in combination with snow or ice, causes most tree failures. In any one location the heaviest winds can be expected to come from not more than two general directions. These directions will vary somewhat, depending on the part of California involved and on the topography, but one direction is usually southerly, blowing in advance of storm centers moving down from the northwest. Severe southerly winds blow almost exclusively during late fall and winter. The other main direction for high winds is from the north to the east, depending on topography, in response to a steep air pressure gradient from the interior plateau regions of eastern California toward the coast.

Direction Orientation

With some types of defects or abnormalities, orientation as to wind directions strongly influences the likelihood of failures. The case of a ponderosa pine tree in a recreational area provides an example. Years ago, when the tree was much smaller, a wooden crossarm was spiked to the westerly side of the trunk at a height of about 15 feet. Subsequent thrifty growth of the tree caused the trunk to become flattened at that point and the crossarm to become slightly embedded. During a very severe and gusty autumn east wind the trunk broke at this point, although the wood was sound, and fell across a cabin. Failure of a tree with that much sound wood is unusual, even when the tree has a flat side. But at that location some of the strongest winds sweep in from the east and northeast. If the crossarm had been spiked in a direction parallel to these winds, such as to the south or northwest sides of the tree, the break probably would not have occurred.

The same principle applies to dead areas in mistletoe swellings, crotches of forked trees, or large open fire wounds associated with internal decay. Failure is more likely when the dead faces are toward or opposite the direction of heavy winds, or when crotches are at right angles to rather than parallel to the direction of these winds.

Orientation is likewise important when wooded parts of recreational areas adjoin large, unobstructed openings, such as provided by a meadow, lake, or cleared area. When these openings lie in a direction from which severe winds are known to blow, the border trees adjoining the openings can be expected to be subjected to unusually strong wind pressures. Defects that would not be likely to render a tree hazardous under normal stand conditions might make it unsafe in these strongly exposed situations.

Wood Strength

Liability to breakage in a tree depends in part on the mechanical strength of the wood. This strength differs in different tree species. In a standing tree, wood must resist bending and crushing under a load applied parallel to the grain. Wind pressure against a tree exerts a compressive force on the wood of the trunk on the lee side of the tree and a tension pull on that of the opposite side. The compressive wind force is in addition to that from the normal weight of the tree and sometimes, in winter, from the weight of snow or ice that may lie on the crown.

Standard Tests

Various standard tests have been developed for comparing the mechanical strength and properties of both green and dry wood. Among these are the modulus of rupture test and the test for maximum crushing strength parallel to the grain. They are the most applicable in comparing the strengths of standing trees. The modulus of rupture test gives an index to the bending strength. Table 1 compares the average modulus of rupture and maximum crushing strengths of green sound wood for a number of tree species in California. It shows that strengths differ considerably among the species. The wood of Douglas-fir, redwood, tanoak, Garry oak, and Pacific madrone is measurably stronger than that of other California species included in the table and should be less likely than the others to fail under a given stress.

In considering forest hazards, however, we are more concerned over the loss in strength of wood from rot, usually internal, than over the comparative strengths of sound trees. In advanced cases, some heart rots may cause the heartwood to collapse, leaving a central hollow in a tree; or the decayed portion may not collapse but no longer provides any appreciable mechanical support to the affected parts of the trunk.

The Forest Products Laboratory of the U. S. Forest Service has found that both bending and compressive strengths affected the strength of a solid wood cylinder, but at different ratios (fig. 2). Application to a live hollow tree can be only approximate, because the thickness of the wall of sound wood around a hollow from decay is seldom uniform, either horizontally or vertically. Both bending and compressive strengths contribute to the resistance of a hollow tree to failure. The combined weakening effect of a hollow or of a rot column that no longer provides any appreciable mechanical support is roughly similar to the cubes of the diameters of the wood of the trunk and that of the hollow at the height of reference (fig. 3).

Expressed simply, a hollow tube represents a relatively high degree of strength as compared to that of a solid cylinder—a relationship often used in fabrication and construction in which weight is a factor. Thus a tree trunk with a hollow measuring half the total wood diameter is reduced in

Table 1.--Average modulus of rupture and average maximum crushing strength parallel to the grain of green wood of some California conifer and hardwood species

Species	Modulus of rupture[1]	Maximum crushing strength parallel to the grain[1]
	P.s.i.	P.s.i.
Conifers:		
Douglas-fir (coast form)	7,600	3,800
Redwood	7,500	4,200
California red fir	6,000	2,850
White fir	5,700	2,710
Lodgepole pine	5,500	2,610
Sugar pine	5,100	2,530
Ponderosa pine	5,000	2,400
Hardwoods:		
Tanoak	10,700	4,850
Garry oak	7,700	3,570
Pacific madrone	7,600	3,320
Bigleaf maple	7,400	3,240
Red alder	6,500	2,960
California black oak	6,200	2,800
Black cottonwood	4,800	2,160

[1] Data from U.S. Forest Products Laboratory, chiefly from Wood Handbook, U.S. Dept. Agr. Handb. 72, 528 pp., 1955, and in part from unpublished test results.

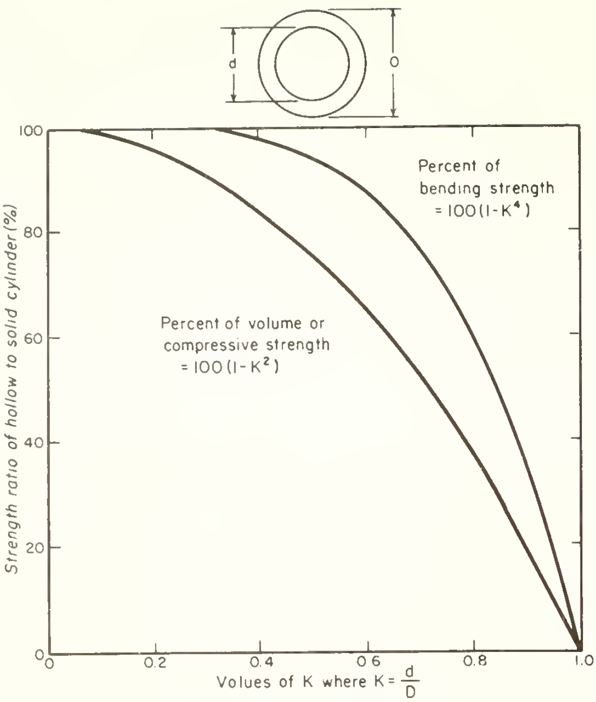

Figure 2.—Strength values in a hollow compared to a solid structural wood member of circular cross section. Compressive strength decreases as the square, and bending strength as the fourth power of the difference between the outer diameter and the diameter of the inner hollow in the wood member.

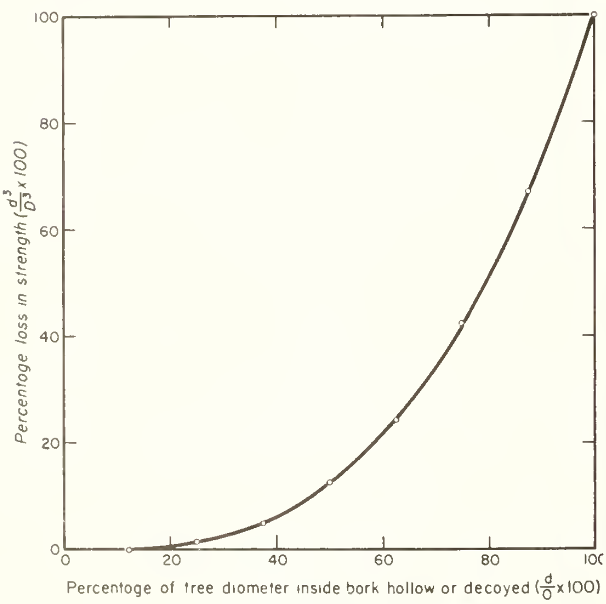

Figure 3.—Approximate percentage loss in strength in tree trunks with advanced center heart rot, or hollow from heart rot, compared with the strength of sound trees.

strength by only about 12.5 percent (fig. 4), if the hollow is centered and the width of the surrounding wall of wood is uniform. The application of the formula of cubed diameters to individual trees is described elsewhere.

Under side stress, a tree resembles a cantilever in that anchorage lies at the bottom only. In conifers and to a lesser extent in hardwoods the form of the trunk is such that resistance to side strain is distributed more or less uniformly along it. But observational and test evidence indicates that most failures of sound conifers, other than failures from snowbreak in the absence of wind, occur in the lower trunk. In defective trees, the zone of greatest weakness created by the defect usually determines the place of failure.

Breakage Source

Sound trunks or trunks with a complete ring of sound wood around the periphery break chiefly

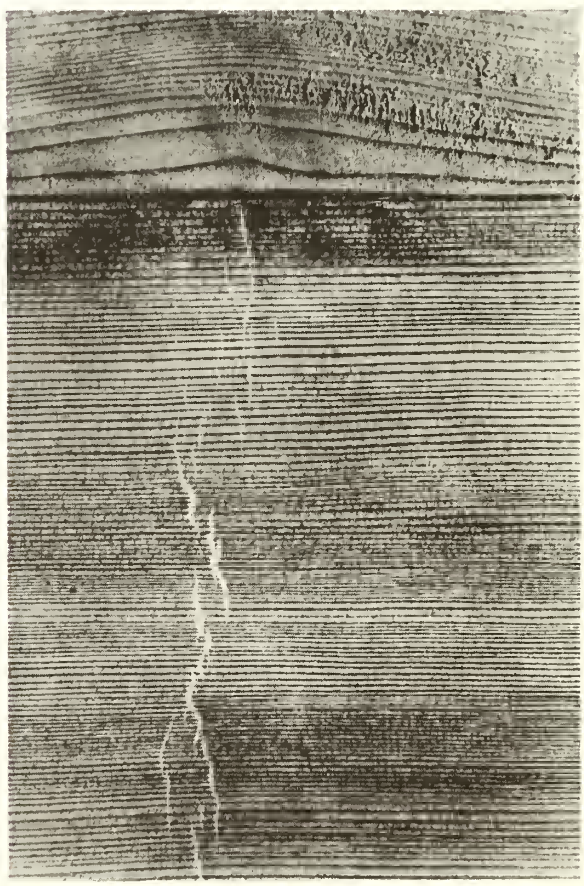

Figure 4.—Compression failure in wood. The whitish lines consist of crushed wood cells resulting from excessive pressure parallel to the grain.

from compression defects formed in the wood on the lee side of the tree during heavy winds. These defects consist of zones of crushed wood cells (fig. 4), usually extending diagonally across grain from the outside of the trunk toward the center on the side of the tree subjected to the compression force. A trunk may not actually break at the time the compression defect is created. One case is reported in which compression damage occurred in a tree trunk on three occasions over a period of 13 years. But an actual break did not develop until the fourteenth year, from a lighter wind than those producing the compression defects, but in the opposite direction.

Time and Tree Type Differences

Time Factor

Some defects in forest trees are produced almost instantaneously and render the tree potentially hazardous as soon as they occur. An example is a split through the crotch of a fork in a forked tree. But with most defects that may ultimately render a tree hazardous, the transition from a safe to a potentially unsafe condition is a very gradual one, and no sharp line of demarcation exists between the two.

Decays do not spread at any one speed in the trunk and the wood does not break down into advanced rot at a uniform rate. The rate differs not only for different decay fungi but for different climatic conditions, different host species, and different individual trees within the species. The occurrence of geographical races of the same fungus has also been demonstrated. These races differ in their rate of development at the same temperatures. In general, the rate of advance of a rot fungus in a tree is slow, requiring many years for the resulting rot to become extensive.

Because of these many differences, attempts to predict the rate of decay, such as to judge that within 10 years a tree not considered hazardous now will be weakened enough to become hazardous, are likely to be so inaccurate as to be useless. An inspector should base his judgment of a tree on its present condition, not on what he thinks the condition will be X years from now.

Hardwoods v. Conifers

In general, hardwoods undergo more stresses than conifers because of the differences in form between the two groups. Most hardwoods have a spreading habit that results in a rounded crown. Most of them are strongly influenced by light, leading to pronounced lopsidedness in crowns where the surroundings are not fully open. More strength is needed to resist storm effects by trees with spreading and irregular crowns of this sort than by conifers with crowns arranged around a central trunk. This is particularly true when the crown is weighted by snow or ice. The relatively high mechanical strength of most hardwoods (table 1) compensates in part for the need.

Heart rots in hardwood trunks commonly extend into the main branches, whereas in conifers such extension is much less frequent. This characteristic in hardwoods, together with the difference from conifers in crown shape, results in most hardwood failures taking place in branches or in crotches where branches join the main trunk, rather than in the trunks themselves (if butt failures are left out of consideration). Hardwoods are much more prone than conifers to damage in the crowns from snow and ice. Basically this means that leverage is one of the most important elements affecting the safety of hardwoods. The effect of leverage is likely to vary from limb to limb and tree to tree.

Rots and Hazard

The single most important process contributing to hazards in the forest is the destruction of wood by wood-rotting fungi. Many such fungi are found in California, but only a relatively few are of primary importance in affecting the safety of trees. No attempt has been made in this paper to provide pictures of individual rots because the specific characteristics are not likely to be too obvious in the woods. By the time a heart rot has reached a stage of materially affecting the strength of the trunk, the breakdown in the wood has often proceeded so far that much of the individual character of the rot has been lost. Within large open wounds, secondary or successional fungi often invade and tend to obliterate some of the distinguishing characteristics of the primary rot. For these reasons the decays as actually seen in advanced cases in defective trees may not closely resemble the pictures of the respective rots shown in textbooks. But most rots fall into two general types that are readily distinguishable from each other: (a) white rots and (b) brown rots. The ability to recognize these types is helpful in diagnosis.

Types and Classes of Rot

Type Differences

The two types of rot arise from differences in the nature of the decay process in each. In white rots, which may actually range in color from whitish to reddish or brown, all wood constituents are attacked, resulting in soft and flaky or stringy decay (fig. 5). Brown rots, on the other hand, are caused by fungi that remove the cellulose of the wood but leave the lignin. The resulting rot may be from light to very dark brown. Friable in texture, it reduces to a powder when rolled between the fingers, and breaks up from shrinkage cracks into rectangular chunks (fig. 6). This type of decay is sometimes popularly known as "dry rot," although the affected wood is actually quite moist during the decaying process.

Growth Environment Differences

Rots also divide roughly into two classes, not readily separable visually, based on different activity potentials in trees and thus differing in their capacity to render a tree hazardous.

The first class is from fungi adapted to growth in dead branches or exposed sapwood: locations where the oxygen supply is ample. They are essentially saprophytes and are more common on hardwood trees than on conifers. Most of them can extend from a decaying branch into the heartwood of a larger live branch or trunk to which the decaying branch is attached, but they seldom progress far in the live member. If the opening through which the fungus extended is later healed over, cutting off the oxygen supply from the outside, the decay process is restricted and eventually the causal fungus may die. Fungi of this class seldom result in extensive decay within the tree unless the trunk has numerous openings.

The other class arises from the true heart-rot fungi which are adapted to growth in a limited oxygen supply if necessary. They can progress in

Figure 5.—A typical white rot from the yellow cap fungus in the heartwood of California red fir.

Figure 6.—A typical brown cubical rot from the sulfur fungus in the heartwood of California red fir.

heartwood for indefinite distances, regardless of openings. Most cases of extensive heart rot in trees develop from these true heart-rot fungi.

No easy way is known for distinguishing between these two classes of rot fungi in the field. In general, the first class is made up of fungi that rot dead limbs and exposed saywood; the second class consists of fungi that develop only in heartwood. But a few fungi are in an intermediate class. For the person in the woods, the important thing is to understand that these two general classes exist and that a rotten limb often does not indicate extensive internal rot.

Most heart rots tend to develop in a particular part of a tree, such as the trunk or butt. These differences in location often arise from differences in the common places of entry of the causal fungus: fungi that normally enter through branch stubs on the trunk develop as trunk rots; those that enter through basal wounds, such as fire wounds, develop as butt rots or rots of the lower trunk. This does not mean that trunk rots do not occasionally extend down into the butts of trees or vice-versa but that, in general, they center in the particular part of the tree where establishment first occurred. The location within the tree thus becomes a convenient basis for reference to the important decays that may influence tree safety.

Trunk Rots in Conifers

Only a few trunk rots are likely to influence the safety of coniferous trees in recreational areas in California, although a number of others may occasionally do so. None of the trunk rots is as important in rendering trees potentially dangerous as root and butt rots.

Hosts listed below are for California only and only for tree species that may be found on recreational areas.

Brown Stringy Rot

Hosts.—White and California red firs.

Causal fungus.—Indian paint fungus *Echinodontium tinctorium.*

Indicators.—Perennial conks (one to six or more) on trunk, issuing under dead branch stubs or at knots (fig. 7).

Conks.—Rough and blackish on top; grayish and toothed or spiny underneath; a light brick or rusty red interior; 3 to 12 inches wide.

Place of infection.—Chiefly through knots and branch stubs.

Rot.—Late stages stringy; rusty brown, although basically classed as white rot.

Figure 7.—Conks of the Indian paint fungus on a white fir trunk. (National Park Service photo.)

This rot causes occasional failures in old firs, almost exclusively during severe winter storms. The size and distribution of the conks gives a rough index of the stage and extent of the rot within the tree. Conks less than half a foot across are ordinarily young and indicate that the rot at that point has probably not yet reached an advanced stringy stage unless the affected tree is small and suppressed. Larger conks indicate that the fungus has long been established in the tree and that the rot is in the late stringy stage, extending for many feet above and below the conk. Extensive decay is also indicated by conks widely spaced along the same trunk, such as more than 10-feet separation in vertical distance between upper and lower conks.

The decay is restricted to the heartwood and in some instances may not affect the entire cross section of the heartwood column. The degree of weakening depends much upon the width of the saywood, which in turn is governed chiefly by the rate of diameter growth of the tree.

Mottled Rot

Hosts.—White and California red firs. (Also occurs on several hardwood species but not common on these in California.)

Causal fungus.—Yellow cap fungus *Pholiota adiposa.*

Indicators.—Annual conks.

Conks.—Mushroomlike, yellow, with gills on the under surface; soft, short-lived; appears in clusters through bark crevices or at edges of open wounds after fall rains.

Place of infection. — Chiefly through open wounds or dead areas, such as fire wounds and the exposed wood of dwarfmistletoe cankers.

Rot.—Late stages whitish, mottled with brown; narrow, irregular channels or pits in the decayed parts.

Mottled rot that has become established through open basal fire wounds (fig. 5) may extend up in affected trunks for as much as 50 to 60 feet. That developing in the dead parts of open dwarfmistletoe cankers is usually localized in the cankered part of the trunk swelling. Except for locations where exposed dead sapwood is present, the decay is confined to the heartwood. In old infections the rot may collapse, leaving a hollow butt.

The weakening effect on a tree trunk thus depends on the thickness of the zone of live sapwood outside the decayed heartwood and the relation of this width to the total radius of the trunk at the level of maximum rot development.

Brown Cubical Rot

Hosts.—California red fir and hardwoods, such as oaks and eucalyptus.

Causal fungus.—The sulfur fungus *Polyporus sulphureus.*

Indicators.—Conks appearing from openings in the trunk, usually near the tree base. The conks are annual in that they last for only one season, but do not develop every year.

Conks.—Clusters of thin, shelf-like fruiting structures, soft when fresh, bright orange on top and bright sulfur-yellow underneath; becomes hard and brittle upon aging, changing to a chalky or grayish white. Broken remnants of this stage may persist on the trunk for some months. Size variable, but usually 8 inches or more wide.

Place of infection.—Chiefly through open trunk wounds or dead branch stubs.

Rot.—A brown cubical heart rot, usually centering near the base of affected trees (fig. 6).

Failures of California red firs from brown cubical rot appear to be relatively rare. When they do occur, the failures are usually during severe winter storms. The cubical rot in large open basal wounds, such as those from fire, often indicates the presence of decay in the heartwood of affected trees.

The following two trunk rots are included here because they are so common in their chief host species in California that questions may arise concerning their effect on tree safety. Both are pocket rots of the heartwood from fungi that do not invade the wood uniformly, but leave a framework between pockets that continues to provide partial support to the trunk. For this reason, failures in trunks in which these rots are present are rare, except under extreme storm conditions. Their presence should thus not be regarded as rendering a tree unsafe.

Red Ring Rot ("White Speck")

Hosts.—Chiefly Douglas-fir; occasional in sugar pine, ponderosa pine, white fir, incense-cedar, and several other conifers in California.

Causal fungus.—Ring scale fungus *Fomes pini.*

Indicators.—Perennial conks; swollen knots; sometimes by the presence of cupped bark plates in such species as ponderosa pine and white fir.

Conks.—Numerous, shelflike; scattered along affected trunks, appearing mostly at knots but in white fir directly on the bark. Hard and woody; upper surface rough dull grayish or brownish

Figure 8.—Hollowness in the stump and in a main branch of a black oak, decayed by a white-rot fungus. Note the greater degree of hollowness in the branch, as compared with that in the trunk at stump height. (National Park Service photo.)

black, concentrically furrowed, under surface brown or grayish brown, pore mouths irregular in outline. Varies from 1 to nearly 12 inches wide, mostly not more than 6 inches wide.

Place of infection.—Mostly through branch stubs or open knots.

Rot.—In advanced stage, consisting of numerous small white pockets separated by firmer wood walls; pockets either occurring uniformly across the affected wood or confined to concentric zones or bands. Decay confined mostly to heartwood, although sapwood may be affected by the fungus in the vicinity of punk knots, or adjacent to heartwood where the decay is well advanced.

Pocket Dry Rot

Host.—Incense-cedar.

Causal fungus.—*Polyporus amarus.*

Indicators.—Conks or shot-hole cups, the latter marking in the bark the location of former conks. The shot-hole cups show numerous worm holes in the bark, with part of the bark often chipped away by woodpeckers searching for larvae in the wormholes.

Conks.—Soft, fleshy, bracket or bell-shaped, tan on top and bright sulfur-yellow underneath; becomes tough and brown on aging, and eventually hard and dry; 4 to 12 inches wide. Produced only in occasional years and on only occasional infected trees.

Place of infection.—Large open wounds in which heartwood is exposed.

Rot.—Pockets of dark brown cubical rot in the heartwood, the pocket separated by essentially sound wood. Pockets variable in size and shape, mostly 6 to 12 inches long, but many shorter, mostly not over 1½ inches wide.

Trunk Rots in Hardwoods

A rather long list of decay fungi has been found in hardwoods in California, but only a few are sufficiently common or cause a decay extensive enough to warrant mention here. Because of the difference in tree form in the hardwoods as compared to conifers, most trunk rots in hardwoods also extend into the main branches, where they may cause greater weakening than in the main trunk (fig. 8).

The oaks are among the most common hardwoods within recreational areas in California and, if old, they are also among the most defective. Two of the three decays listed below are found chiefly in oaks.

White Pocket Rot ("Piped" Rot)

Hosts. — Oaks, particularly California black oak.

Causal fungus.—*Polyporus dryophilus.*

Indicators.—Conks or their remains; rot of the fungus showing through trunk or main lateral openings.

Conks. — Light brown, darkening somewhat with age, usually hoof-shaped, up to 6 inches wide; issuing at knots or open wounds. A hard gritty core persists for many weeks after the balance of the conk has eroded away.

Place of infection.—Mostly through broken branches or open wounds.

Rot.—Consisting of long, narrow white pockets in the heartwood, running together longitudinally. The rot may ultimately collapse partially, creating irregular hollows within affected heartwood. Confined to the heartwood, usually of the upper trunk and main branches.

Figures on the prevalence of specific decays in the oaks of California are not available, but dryophilus rot is undoubtedly one of the most common, particularly in mountain and foothill areas. Breakage of trunks or main branches because of its presence ocurs almost exclusively during severe windstorms or, more commonly, from the weight of clinging snow in snowstorms.

Brown Cubical Rot

This rot is described in the section on trunk rots in conifers.

In oaks, this decay is almost always confined to the lower trunk because the fungus becomes established chiefly through basal fire wounds. But it may occasionally center higher up in the trunk. The rot is confined to the heartwood, but usually involves the entire heartwood cross section. The presence of the rot is usually detectable within open basal wounds.

White Trunk Rot

Hosts.—Aspen and willow in California.

Causal fungus.—False tinder fungus *Fomes igniarius.*

Indicators. — Perennial conks on affected trunks.

Conks.—Common on affected trees; from one to many per tree, emerging at knots and branch stubs; hoof-shaped, 2 to 8 inches wide; upper surface grayish black to black, rough and cracked; under surface brown with small circular pores; interior is rusty brown, showing many layers of tubes.

Place of infection.—Branch stubs, knots, and open wounds on trunks.

Rot.—A soft whitish rot in the advanced stage, rather uniform in texture with fine black zone lines running irregularly throughout. Not collapsing or forming hollows, confined to heartwood.

This rot is quite common in aspen in California, but spotty in occurrence. It may be prevalent locally in some stands but absent in others. It rarely causes failure in affected trees, in part because the rot never collapses to form hollows within affected trunks and in part because the proportion of heartwood to sapwood is usually not as large in aspen as in mature trees of many other native tree species.

Root and Butt Rots

California has several diseases in this category that may materially affect tree safety. One of them, caused by the fungus *Armillaria mellea,* ranks among the most important sources of tree hazard.

Shoestring Root Rot

Hosts.—Among forest trees chiefly oaks and white and California red firs.

Causal fungus.—Honey fungus or oak root fungus *Armillaria mellea.*

Indicators. — Flattened black rhizomorphs ("shoestrings") over bark below ground level or between bark and wood in dead areas. Conks (fruitbodies) when present.

Conks.—Mushroomlike, appearing in clusters at the ground line around the base of infected trees after fall rains or in the spring. Color varies from honey yellow to dark smoky gray. Soft and fleshy, short-lived; under surface with radiating gills rather than pores.

Place of infection.—Through basal wounds or by way of roots.

Rot.—In the advanced stage, whitish, soft and spongy; often becoming somewhat stringy in white and California red firs; traversed by irregularly distributed black zone lines in most cases.

The causal fungus of this rot can decay physiologically dead wood, such as heartwood, and also can kill live wood. It is often associated with the roots and butts of decadent oaks. It is an important killer of planted trees and shrubs in orchards and gardens on ground formerly occupied by oaks or other susceptible native vegetation. But in California forests, although it may occasionally kill young conifers in the vicinity of affected oaks, its chief role is to cause butt and root rot in oaks and true firs. Affected trees may eventually fail at the base, either during strong winds or under perfectly calm, still conditions (fig. 1). Several accidents or near-accidents in campgrounds or similar heavily-used recreational areas have been traceable to the destruction of wood in roots and tree bases by this fungus.

In infected bark, small, thin white mycelial plaques are formed within the bark layers when the fungus is active. In hardwood bark, the mycelium of these plaques has a fan-shaped pattern, but in conifers the pattern is usually straight and parallel. Concurrent with formation of the plaques, a felt of white mycelium develops between the bark and wood at the butt of infected trees.

A unique feature of the fungus is the formation, in well established cases, of flattened blackish fungus structures known as rhizomorphs. Their appearance suggests black shoestrings, hence the common name of "shoestring fungus." They usually appear either over the outside of the bark below ground level, or form between wood and bark if patches of bark have been killed and have separated from the wood. No other native butt and root rot fungus in the West produces such structures. Accordingly, if found, they provide positive evidence of the presence of the Armillaria fungus.

The fungus destroys the basal heartwood of affected trees, but usually does not extend up in the trunk in the heartwood for more than 10 feet. A hollow is often formed in the butt from collapse of the decayed wood there. The basal sapwood near ground level may also be invaded and killed, along with the overlying bark, but not uniformly. Thus, killing of sapwood may be in progress along one part of the circumference of the tree near ground level but not along other parts. A tree often may fail at the base before it is dead, except for California live oak and Engelmann oak, in which direct killing by the fungus is not unusual. Both oaks and firs weakened at the base by the fungus may fall in the absence of wind, either in the evening or early morning hours after a moderately warm, dry day.

Annosus Root and Butt Rot

Hosts.—White and California red firs; occasional in Douglas-firs. Also attacks and kills ponderosa, Jeffrey, and other pine species, but without causing a butt rot in them as it does in the firs.

Causal fungus. — The Fomes root fungus *Fomes annosus*.

Indicators. — The relatively characteristic rot showing in open basal wounds; sometimes crown deterioration evidenced by the presence of scattered dead twigs and branches when not caused by dwarfmistletoe, and by reduced foliage growth.

Conks.—Irregular in shape; in firs developing only within the hollow butts of trees badly decayed by the fungus, often at ground level or below. Perennial, whitish to light brown when fresh, tough and corky in texture, later darkening and hardening. Shreds of old decayed wood are often incorporated into the conks.

Place of infection. — Usually through open basal wounds such as fire wounds. May also enter through roots.

Rot.—In the advanced stage in firs, white, soft, and stringy, with white pits, these sometimes showing black centers; the rot often eventually collapses in the butt, forming a hollow. Chiefly confined to the heartwood, but may extend into the roots or part of them.

In some native pines of California this fungus is an active killer, especially around stumps in which it has become established. But in the true firs and Douglas-fir the fungus does not ordinarily invade or kill the butt sapwood. It often extends into part of the roots, however, and is a source of windfall in the firs. Most windfall in firs takes place during windstorms but occasionally affected firs fall on windless nights, usually following a warm dry day.

The rot may extend up through the heartwood from basal wounds for as much as 40 or 50 feet. Conks of this fungus in firs are almost always hidden within basal hollows and are thus of little help in identifying the presence of the fungus in standing trees. The fungus takes many years to weaken the base of affected trees enough to make them possible hazards.

In inspections for hazardous trees, suspect this fungus in any hollow-butted true fir in which the hollow is large, extends well below ground level, and is associated with a white soft rot. If the crown is also decadent, with scattered old and recent dead branches, the Fomes is almost sure to be present in the main roots.

Red-Brown Butt Rot

Hosts.—Douglas-fir, California red fir, various pines.

Causal fungus.—The velvet top fungus *Polyporus schweinitzii.*

Indicators. — Conks at tree butts or from ground near the butts; brown cubical rot showing in open basal wounds.

Conks.—Shelf-like when attached to the butts of trees; roundish, with depressed centers and short central stalks when arising through the soil from roots; often multiple. Reddish brown above, greenish yellow underneath when fresh, under surface turning brown when bruised; changing to a chocolate or blackish brown in age; annual, but the conks persistent after death; not destroyed by insects.

Place of infection.—Commonly through basal wounds, especially fire wounds; sometimes through roots.

Rot.—A yellow-brown to red-brown cubical rot, breaking into large chunks; these divided at intervals by thin, crust-like resin-colored fungus layers. Confined to heartwood, usually of butt and roots.

Rot from the velvet top fungus is fairly common in Douglas-fir butts in California, but basal failures from it are rare except during extremely severe storms. In California red firs and in the pines, butt failures from this rot are more common, but they almost always occur during windstorms, mainly in winter. The rot usually stops within 12 feet of ground level. Only long-standing cases in old, slow-growing trees are likely to offer any recreational hazard.

Sap Rots in Hardwoods

Hardwood tree species are much more subject than conifers to pathogenic fungi attacking bark and cambium. Commonly known as canker organisms, these fungi in California are more likely to be active in low elevation or coastal recreational sites than in mountain districts. Once they kill the bark and cambium, the dead sapwood below becomes subject to sap rots. The decay can seriously weaken affected parts because it destroys the strength of wood in the outer part of the trunk or branch where strength is most needed.

Many different fungi may be active as sap rots, depending on the tree species affected and the location. Most of them fruit during the rainy season, producing either fleshy, mushroomlike fruit-bodies that soon disappear or numerous small, thin, shelflike conks that are more persistent. The fruit-bodies either appear on the bark itself or emerge through cracks in the bark or from exposed wood where branches have been removed, whereas the conks of heart rot fungi almost invariably appear at branch stubs or at openings connecting with the heartwood. A few sap rots that may also occur on dead parts of living trees have crustlike fruit-bodies that may be produced under loose bark, in bark cracks, or as crusts over the bark surface.

Sap rot may be present without surface evidence of fruiting of the causal fungus. In such cases the condition of the bark will usually indicate that it is dead. Suspect sap rot under any areas of dead bark and investigate the condition if within reach.

Other Conditions Affecting Hazard

In addition to decays in living trees, various other defects or conditions may affect the safety of forest trees, or become a problem to the field inspector. The more common of these are described below.

Snags

Snags vary greatly in their stability, depending chiefly on the species of tree that they represent and on the climatic conditions of the area. But eventually all snags fall; when this may happen is unpredictable, except in broad terms. The shedding of dead branches or the breaking off of portions of the top or trunk of snags from weakening by decay is also common, especially in pine snags or those from the true firs.

Most snags fall or break off during winter storms, but this cannot be guaranteed. Moreover, at these times the direction of fall is uncontrolled, and damage may result to surrounding trees or installations. Deaths, injuries, and considerable aggregate damage to vehicles and structures have been reported from the falling of snags or their parts. On this basis it appears wise to regard all snags as potentially dangerous and to remove them in campgrounds and in similar areas of concentrated human use (fig. 9).

Dead Tops

In conifers, dead tops vary in type and causation and may or may not be hazardous. Old so-called spike tops in pine and Douglas-fir that give evidence of long-time existence are usually dry and resin-impregnated and have shown no greater hazard potential than any other part of the tree. Redwood, incense-cedar, and giant sequoia are other species on which the presence of old spike tops does not appear to seriously increase the hazard, on the basis of common experience.

At the other end of the scale are dead tops in white and California red firs, including dead volunteer tops. These defects are particularly common on white fir from about the Mokelumne River drainage southward in the Sierra Nevada as a result of a leafy green mistletoe that concentrates in white fir tops in that part of California. It is absent from firs north of the Mokelumne. The parasite eventually leads to the death of the infected tops, apparently assisted by fir engraver beetles. Volunteer replacement tops may in turn be infected and killed. Dead tops in firs may also result from the direct attacks of fir engraver beetles in the absence of top mistletoe.

Wood of the true firs is nonresinous, relatively nondurable, and readily attacked by decay fungi, which may soon weaken dead fir tops and cause them to break out during strong winds.

Aside from those on redwood, giant sequoia, and incense-cedar, bark-laden dead tops on living conifers should be regarded as potentially hazardous. The bark is evidence that dying has been relatively recent and that enough time has not yet elapsed to determine whether the top might ultimately be regarded as nonhazardous. Most dead tops do become hazardous, and therefore all recently dead tops except those on the species mentioned above should be so regarded.

Occasionally an old, weathered dead top that

Figure 9.—Snags before felling on a slope immediately back of a heavily used forest lodge. (National Park Service photo.)

looks sound may be weakened at some point by nest holes of woodpeckers. Thus what had previously been regarded as a relatively safe top may become potentially hazardous because of woodpeckers.

Broken-Out and Volunteer Tops

Most missing tops represent dead tops that have been weakened by decay and have broken off during storms. The break usually comes near the base of the dead part, because moisture retention in the dead wood is ordinarily better there than higher up. The higher location favors the activity of decay fungi in that zone. A short length of decayed trunk often remains below the break, but only in exceptional cases is it a safety risk. Normally it erodes away slowly. Concurrently the decay progresses, also at a slow rate, down into the heartwood of the part of the main stem below the break where the sapwood is still alive.

The loss of a top stimulates the production of one or more volunteer tops from near the upper limits of the remaining live trunk. These tops commonly arise from near the bases of uppermost live branches. In the true firs, they are often called bayonet tops or, when multiple, candelabra tops (fig. 10). Even though the main stem supporting these tops may have a decayed heart, they practically never break off and fall during the recreational season as long as they remain green and thrifty. They can become hazardous if dead. The only cases known of green volunteers failing have been from heavy loads of ice or snow during winter storms. Because of this possibility, the removal of such tops in the vicinity of buildings of year-round occupancy or centers of congregation for winter sports may be advisable.

Figure 10.—Candelabra top formed by volunteers on a broken-topped white fir.

In older pines with broken tops, volunteer tops are sometimes slow to form. If the topmost green branches are thrifty in such trees, they should not be regarded as hazardous. In one or two areas numerous trees of this type have been needlessly removed in the past because it was thought that they were unsafe.

Forked Conifers

The term as used here refers to true forks and not to volunteer tops that have formed to replace a dead or broken top. The main stem divides, either from the division of the axis in the embryo stage before a terminal bud has formed, or as a result of injury to the terminal bud or shoot. In a few cases the forking habit appears to be genetic in origin; in others it may result from insect or other injury to the terminal bud or shoot. Forking from the latter cause is common in lodgepole pines in some parts of California.

The stems of a true fork generally diverge from each other at an acute angle and are joined at the base by a strong and tough crotch. As long as these members remain modest in size, they seem to offer no more of a hazard than the single stem of a normal tree. But as they become large and old, the diameter growth near their base brings mutual pressure on each fork base and ultimate flattening of each on that side, with layers of closely pressed bark between. If growth conditions are good, the individual forks may become long and heavy, exerting a strong leverage on the crotch during storm conditions. Thus a forked tree which presented no hazard when it was young may eventually become hazardous to at least a moderate degree when it becomes old. In rare cases, heart rot may extend up into a crotch, weakening it enough to cause breakage during a storm.

In very rare cases, mechanical splits may occur in the wood of a crotch without the presence of any decay and without the immediate breaking out of the individual forks. Such split crotches are distinctly weakened and should be considered as hazardous.

Dwarfmistletoe Brooms, Swellings, Cankers

Witches' brooms from dwarfmistletoe sometimes reach large sizes but, as long as they remain alive, do not appear to offer any hazard greater than that of normal branches. On white fir, old branch swellings sometimes become quite large and heavy and may be broken off by winter storms.

Main stem or trunk swellings, from stem infections by dwarfmistletoe when the host trees were

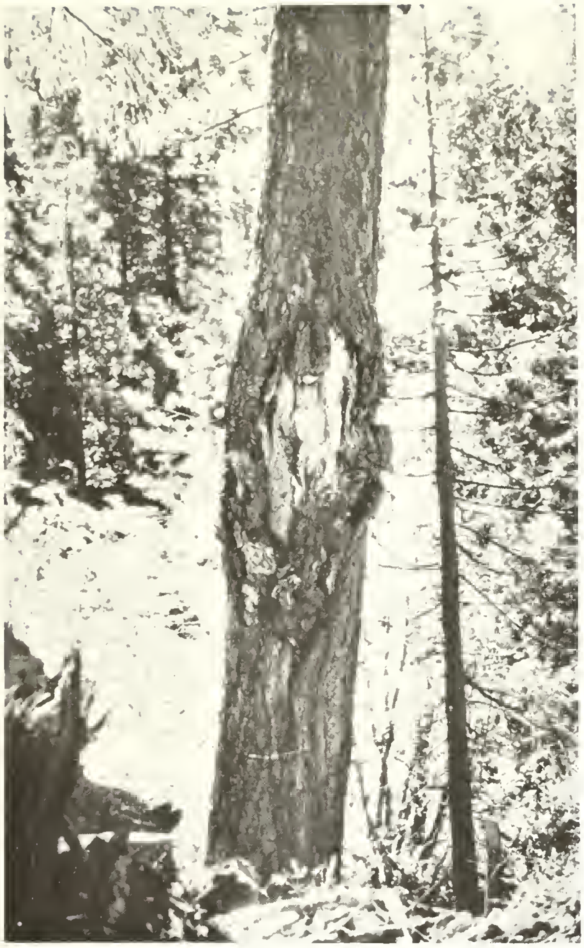

Figure 11.—An old dwarfmistletoe trunk swelling that has developed into an open, dead-faced canker on a white fir. This one would be rated as marginally hazardous.

young, may be quite prevalent on both white and red firs in some areas. As long as the swelling remains alive, it does not weaken the trunk, but eventually the cambium in the oldest part of the swelling dies. The bark over the dead part soon becomes broken, creating an open canker (fig. 11). Decay usually develops in the dead wood, although its progress in different cankers is very variable. The eventual result is a weakening of the trunk of the host tree at the site of the canker. The status of the weakening cannot be judged closely from surface indications, but when the width of the dead face approaches half the circumference of the swelling, the trunk may break at the canker site under the stress of heavy wind or snow conditions (fig. 12). Most such breaks occur during winter storms, but they can take place at other times. On this account it seems prudent to consider mistletoe cankers with a wide dead face on white or California red firs as potentially hazardous.

Open dwarfmistletoe cankers are sometimes found on the lower trunks of ponderosa and Jeffrey pines, but the wood around them becomes heavily resin-infiltrated, protecting them from decay. No case of breakage at such cankers is on record. They do not appear to contribute in any way to hazard.

Frost Cracks

In California, frost cracks are confined largely to white and California red firs. These cracks appear on the surface as raised lines of callus (frost ribs) in the bark, and follow the course of the grain of the wood in the lower trunk. Up to three or more cracks may be found on a single trunk, all

Figure 12.—A white fir trunk broken over at a large dwarfmistletoe canker. The long open wound on the trunk undoubtedly contributed to the failure.

starting near the butt and extending upward in a slightly spiraling course. They usually end within the first 16-foot log length, but sometimes extend into the second log.

Frost cracks are ordinarily formed by the contraction of wood in the outer parts of the trunk from freezing while the inner parts remain unfrozen. Thus they can form only in relatively sound wood and not in a trunk with extensive internal decay. They may somtimes be formed during freezing by the expansion of accumulated water in internal checks in the lower trunks of firs. The water accumulation in these internal checks appear to be an effect of associated wetwood in the trunk. Frost cracks are more common in the colder parts of California, such as east of the Sierra-Cascade crest, than in the milder parts.

Once formed, frost cracks ordinarily are closed by healing callus during the next growing season, but the callus is ruptured by contractive pull during the succeeding winter. This annual closing and rupture may continue over a period of years, but eventually the healing becomes complete over most frost cracks. A few stay open indefinitely and may be a source of leakage from the trunk.

Decay is often associated with frost cracks, but usually in limited amounts. Accordingly they do not indicate an unsafe condition within the tree.

Slime Flux

This term is applied to aqueous leakage, usually dark and rather foul-smelling, from openings or wounds in trees. It is relatively common in some types of hardwoods, but rare in conifers other than true firs. The presence of slime flux is not a sign that the tree is hazardous. It does not indicate decay in a tree because it is rarely associated with serious internal decay. However, it is sometimes present on trees in a generally decadent condition, although slime flux itself is not an indicator of decadence.

Slime flux may originate from either heartwood or sapwood and is caused by the presence of fermenting organisms in affected tissues, such as bacteria and yeasts. The organisms create an internal pressure by producing carbon dioxide gas as one product of fermentation. This pressure aids in forcing out excess water resulting from a wetwood condition within the wood. Wetwood is often present within a tree before the creation of the wound or opening through which the slime flux issues. It can occur in an otherwise perfectly sound tree. Bacteria are usually associated with the condition.

The slime-flux exudate often contains acids or aldehydes, some of which may be toxic to callus tissues over which the liquid flows. This action may interfere with the healing of the lower part of the wound. In any individual case a check can be made for toxic action by examining the callus over which the exudate has been flowing. If the callus there is alive and shows no signs of damage, one can assume that the flow is having no toxic effect. If indications of toxic action are found, they do not mean that the tree with the slime-flux condition is hazardous, but only that the opening through which the flux issued will be slow to close. Some internal toxic effect, limited to the particular column of wood through which the flow of exudate is occurring, may also be present. The effect does not promote decay; if anything, it inhibits the development of decay fungi.

Figure 13.—A leaning pine rated as offering a low potential hazard because the tree grew in this shape. The road toward which it leans receives only limited use.

Leaning Trees

The safety of leaning trees is often a question in recreational areas and around dwellings in wooded districts.

If a tree has grown in a leaning position throughout most of its life, it develops structural compensations for the lean as it grows. Instead of normal wood, special tension and compression wood is formed at places of stress. This wood is structurally stronger than the wood in a tree that is fully vertical at these locations. Figure 13 shows a leaning tree of this type that is of low potential hazard as long as it remains sound. But there are occasionally trees that have a lean because of root loosening caused by an outside force, such as heavy wind, flood waters, or a falling tree or snag. Such trees have not grown through life in adjustment with the lean and should ordinarily be regarded as potentially hazardous.

There are also cases in which trees have developed with extreme leans but are not particularly hazardous while small, if in a snow-free locality. Such trees are usually confined to understory hardwoods. As these trees become larger and lengthen, however, the leverage exerted by the lean becomes greater in proportion to the strength of the wood, and they may eventually fail. For example, in a coastal campground a cottonwood having a lean exceeding 45 degrees finally broke even though the trunk at the break appeared to be sound. The tree was located near a campsite which, fortunately, was unoccupied at the time it fell.

An old open fire wound may occasionally render a leaning tree potentially hazardous if the wound is in line with the axis of strain from the lean and if advanced rot is present in the wood back of the wound. This is particularly the case if the fungus causing the decay can also cause root rot, as *Fomes annosus* may do.

Figure 14.—A black cottonwood, with root anchorage impaired by high water in an adjoining stream, fell across this camp table. A smaller incense-cedar was carried down with it. (National Park Service photo.)

Asphalt Pavement Over Roots

In some more heavily used recreational areas, roads, parking areas, and similar places of concentrated travel have been paved with asphalt to check dust and mud. An attempt also has been made to leave as many native trees as possible for esthetic reasons and to retain as much of the park-like character of the area as practicable. Consequently, the asphalt layer often covers portions of the root system of adjoining trees. In some instances, the pavement extends over a large part of the root spread.

The pavement prevents moisture and nutrients from the decomposition of forest litter from entering the covered soil, but it also prevents the loss of moisture from the soil in the form of vapor. In a soil with a deep source of moisture, such as a water table, considerable moisture moves through the soil in a vapor phase. Because of its dark color, asphalt loses heat readily by radiation during night hours and cools enough to cause moisture to condense on its under surface. This loss tends to offset the absence of moisture infiltration from above. Consequently, trees surrounded by pavement often do not suffer as much from lack of moisture as popularly supposed.

The chief detrimental effect of pavements covering roots appears to be in the reduction of aeration. Roots need a continuing supply of oxygen to remain healthy, and they do not get enough in a soil covered by an asphalt pavement. A weakened condition results, and the roots become susceptible to root fungus attack. Roots of California oaks, when in a declining state, are particularly susceptible to the fungus *Armillaria mellea,* so much so that a common name of the organism is the "oak root fungus." If this fungus is present anywhere in the portion of the root system of an oak covered by asphalt pavement, the parasite is likely to spread rapidly to the root crown at the base of the tree and to cause ultimate death or failure. In conifers, pavement over major parts of root systems is likely to induce bark beetle attacks.

Native Tree Species and Hazard

The native tree species listed below include most trees likely to be found in public campgrounds and in portions of recreational areas receiving concentrated public use in California:

Common and Scientific Names of Species[1]

alder	*Alnus* spp.
aspen	*Poulus tremuloides*
California-laurel	*Umbellularia californica*
cottonwood	*Populus* spp.
Douglas-fir	*Pseudotsuga menziesii*
fir, California red	*Abies magnifica*
fir, white	*Abies concolor*
Incense-cedar	*Libocedrus decurrens*
madrone, Pacific	*Arbutus menziesii*
oak, California black	*Quercus kelloggii*
oak, California live	*Quercus agrifolia*
pine, digger	*Pinus sabiniana*
pine, Jeffrey	*Pinus jeffreyi*
pine, lodgepole	*Pinus contorta*
pine, ponderosa	*Pinus ponderosa*
pine, sugar	*Pinus lambertiana*
redwood	*Sequoia sempervirens*
sequoia, giant	*Sequoia gigantea*
tanoak	*Lithocarpus densiflorus*

Alder

Principal hazard: Root loosening by water.

In California, alders are primarily streamside trees and offer practically no hazard unless partially washed out or undermined by high water. This may make them subject to uprooting during high winds.

Aspen

Principal hazard: Killed trees or tops.

As a tree of recreational areas in California, aspen is found chiefly along the eastern slope of the Sierra Nevada. It does not stand up well under human use. Also in the past it has been subject to at least one wave of decline, probably of climatic origin, which resulted in the ultimate death of thousands of trees. This decline was not accom-

[1] Little, Elbert L., Jr. Check list of native and naturalized trees of the United States (including Alaska). 472 pp., Washington, D. C.: Forest Service. 1953.

panied by a high degree of hazard, however, because climatic conditions in which aspen is found in California do not favor rapid decay of the species. Dead trees are ordinarily cut for fuel soon after death. Locally a heart rot from the false tinder fungus *Fomes igniarius* is sometimes common in restricted patches of aspen, but for the most part has not weakened affected trees enough to be a safety factor.

California-Laurel

Principal hazard: Dead branches.

This species is not extensively represented in California parks and campgrounds, but is rather common in some north coast recreational areas. The heartwood near the butt is very commonly decayed by the fungus *Fomes applanatus,* but the tree is characteristically a vigorous grower. Its sapwood is usually strong enough to support the trunk and prevent failure even though decay in the heartwood may be well advanced. Accordingly the presence of *F. applanatus* conks near the base of a tree should not be regarded as an indication that the tree is unsafe. The conks are shelf-like and woody, dark brown on top, and have a whitish pore surface underneath composed of small round pores.

Cottonwood

Principal hazards: Cankers, heart and sap rots, undermined roots.

The wood of trees of this group is soft and quite brash, as well as having little resistence to decay. Cottonwoods are also subject to several bark canker diseases that may be followed by decay. On this account they should be inspected at least annually for defects that could lead to breakage. Prompt action should be taken to remedy any potentially hazardous conditions found. Near streams the undermining of root systems during high water should be watched (fig. 14).

Douglas-fir

Principal hazards: Usually none.

In some parts of the Pacific Coast, a root rot that leads to windfall is quite common in second-growth Douglas-fir, but the disease has not been found in this species in California. Even trees with basal red-brown butt rot are usually strong enough to be safe except under very extreme wind conditions when any forest area is likely to be unsafe. The high mechanical strength of the wood of this species contributes to its safety.

Fir

Principal hazards: Primary and volunteer dead tops, trunk cankers from dwarfmistletoe, trunk rots, butt and root rots.

White and California red firs are more subject to defects that may render them hazardous than almost any other native conifers in the State.

Dead tops, either from mistletoe or the work of fir engraver beetles, are very common in white fir, particularly in stands located south of the Mokelumne River drainage. Most of these dead tops later decay near the base and fall out during windy weather, creating a hazard.

In areas where dwarfmistletoe has been present for the life of the stand in white and red firs, old swellings of the trunk from stem infections by the parasite are likely to develop into open cankers (fig. 11). The exposed wood in these cankers is often invaded by decay fungi. The resulting weakening of trunks may end in their breaking over, usually during storms.

Old, long-standing cases of trunk rot from the Indian paint fungus *Echinodontium tinctorium* may occasionally weaken fir trunks enough to cause them to give way during storms, especially when the rot extends down into the tree butts. Combination defects, such as sap rot working in the outer shell of trees hollowed by trunk rot, are particularly likely to lead to trunks breaking over under the stresses of wind and a snow load. Usually these failures occur outside of the camping season, but they can damage buildings that may be located in the vicinity.

In white fir, either of two root and butt rots may be present: the shoestring fungus *Armillaria mellea* or the Fomes root fungus *Fomes annosus.* Both parasites cause white rots that eventually may hollow out the tree base and rot out portions of the roots. The weakened root system is likely to give way during high winds, causing the tree to become a windfall. In rare cases, an old decadent fir with either of these two rots may give way during warm, windless night or early morning hours. In most cases where these rots are present, they occur in trees with old, open basal fire wounds, through which the decay fungi originally entered. Occasional instances are found, however, in which the fire wound that originally served as the entrance court has become healed. Occasionally, also, the causal fungus may have entered the butt of the tree through a root, and no evidence of an open or closed wound will be present. Extensive root destruction in such trees is usually accompanied by a deteriorated crown, many dead branches scattered through it, and by very slow current growth. But if dwarfmistletoe is present, it can produce substantially the same crown symptoms and reduced growth. A person inspecting for possible hazards must try to decide whether such symptoms in a particular tree suggest root damage or the presence of dwarfmistletoe.

California red fir also is subject to a red-brown cubical butt and root rot from the velvet top fungus *Polyporus schweinitzii*. Root damage by this fungus is ordinarily not as extensive as it may be from the white-rot fungi previously mentioned. No case has been reported where windfall from this butt and root rot has resulted primarily from root failure, but occasional cases are found in which red firs have broken over at the base from this rot combined with a large open fire wound. In both white and red firs, similar basal failures may result from old, long-standing cases of mottled heart rot from the yellow cap fungus *Pholiota adiposa* and in red fir of brown cubical rot from the sulfur fungus *Polyporus sulphureus*.

Occasional white firs are encountered which appear very "rough" on the outside. An inspector may conclude that these trees must be very defective even if no conks are showing. They are usually former "wolf" trees, having large limbs that become heavy stubs as the lower crown dies off. Actually, such trees are often surprisingly sound and should not be regarded as hazardous unless other indications than the "rough" appearance are present to indicate a possible hazardous condition.

Slime flux from the lower bole is sometimes present in firs and is often mistakenly regarded as the sign of a dangerous condition, but it rarely is. In some districts, frost cracks, which are marked by somewhat spiraling lines of callus in the bark, occur along the grain in the lower trunk. The cracks do not indicate a hazard. Decay is often associated with them but rarely in extensive amounts.

Giant Sequoia

Principal hazard: Falling limbs.

A few cases, widely spaced in time of occurrence, are known in which giant trees of this species have fallen. In addition, a few standing sequoias are recognized as risks to fall, and thus present individual hazard problems. For the species as a whole, however, the danger from falling trees is remote. Practically the only hazard is from the falling of occasional huge limbs broken off by snow or lightning. We know of no cases of death or injury from such limbs.

Incense-Cedar

Principal hazard: None.

The wood of incense-cedar is relatively brash. This characteristic results in the breakage of dead limbs under the weight of snow, but uprooting and the breaking of tops or trunks is uncommon except in exposed locations. To date it has not proved to be hazardous in recreational areas. Pocket dry rot is common in the heartwood of the species. But under normal stresses, when affected trees are part of a stand, heartwood weakened by the rot has not been the cause of appreciable storm breakage.

Oak and Tanoak

Principal hazards: Sap rots of branches and trunks, heart rots, snowbreak, root disease.

The oaks as a group have been responsible for more accidents or potential accidents in California recreational centers than any other type of trees.

The native California black oak is often associated with conifers, particularly with pines. It is not a very long-lived tree and is not shade tolerant. Surrounding pines outstrip it in height sooner or later, bringing on gradual decadence in the oak because of side shade. In this condition the roots are quite susceptible to the shoestring fungus *Armillaria mellea*, also a cause of common butt rot in oaks. The tree is gradually weakened at the base by decay until it fails. Most known cases of oaks toppling, either during high winds or in periods of complete calm, have resulted from rot in the butt or roots by this fungus.

Figure 15.—A horizontal canker, probably from a tree rust, on the lower trunk of a ponderosa pine. Breakage at the canker sometimes occurs when the depression is deep and located higher than 16 feet from the ground.

Pacific Madrone

Principal hazards: Dead limbs and trees.

Madrone wood is relatively strong, and the species has given little trouble from mechanical failure. In some areas this tree has been subject to relatively rapid dieback and death, which has necessitated the removal of many trees in coastal districts. More than one cause seems to be involved in the mortality, the reasons for which are not yet completely understood.

Pine

Principal hazards: High horizontal cankers, heart rot from fire wounds, large low-crotched forks.

Damage to life and property from pines, aside from the hazard of falling green cones of such heavy-coned species as Coulter and sugar pines, has occurred almost exclusively during severe storms. These storms have been intense enough to cause the breakage of much sound wood or the uprooting of trees with relatively sound root systems. The sapwood of most California pines is quite thick in proportion to the total cross section, and the heartwood tends to be relatively sound except for occasional old, overmature specimens. In these trees the rot is usually in association with old fire wounds. On the other hand the wood is mechanically not as strong as in some other conifers, such as Douglas-fir. Consequently the wood of pines may break under the stress of exceptionally high winds, whereas species with tougher wood can be expected to remain intact when under the same stresses.

Any trunk abnormality that tends to seriously disrupt the normal round form at some particular point is likely to increase the possibility of breakage there. Thus, in at least one district in California, deep, horizontal cankers at some distance from the ground have resulted in an occasional breaking over of the cankered trunks at the canker during severe storms. On the other hand breakage has not been noted from cankers of the same type located within a few feet of the ground (fig. 15). The wood around these cankers (which are probably caused by a tree rust) is hard and tough. Only when the canker depressions become deep and occur 16 or more feet from the ground do they seem to weaken the trunk of the affected tree enough to cause breakage in occasional cases during severe windstorms.

In a few cases large forks in pines have broken out during heavy winds, and in one of these a fatality resulted. However, this does not mean that all forked pines should be considered hazardous.

The wood of pines on marginal interior sites near the zone of transition to desert conditions is likely to be more brash than normal wood.

Redwood

Principal hazards: Falling dead branches.

In old-growth redwood the chief hazard seems to be from falling dead branches or stubs. The sources of these parts are usually so far from the ground and crowns are so dense that detection is difficult. The tendency now is to move campgrounds away from old-growth stands. Young second-growth redwood is relatively free from this type of hazard.

One case is known of a fatality from a redwood that fell because of a strong lean and a base that was burned out on all but one side. The strength of the wood is such, however, that redwood trees with burned-out butts (commonly referred to as "goosepens") are ordinarily not hazardous.

Examining Trees for Hazards

Recommended Equipment

Axe, 3½-lb., single bit.—For tapping bark to detect dead cambium or for sounding tree butts or case-hardened surface wood in open tree wounds for hollowness or cavities. A single-bitted axe is better adapted than the double-bitted type for these purposes.

Increment borer, 12- or 15-inch.—For determining the current rate of growth of trees or the thickness of sound wood in tree butts with heart rot. A long twist bit, such as a car bit, may be substituted for the latter purpose.

Field glasses.—For checking the condition of tops in tall timber.

Shovel.—For checking the bark surface below ground for the presence of "shoe-strings" where the Armillaria fungus is suspected, or in sampling below ground for cambium killing by *Fomes annosus*.

Making the Examination

Usually the trees of any particular area will be confined to not more than two or three main species. Before starting an examination, review the kinds of defects likely to be associated with the species that could render them hazardous. Also note whether the timber is young and thrifty or old and declining in thrift, because a general condition assessment of this sort will have a bearing on what defects to anticipate and to what extent they may render individual trees hazardous. The chances for the development of serious defects are cumulative with age in a tree. Heart rots, for example, are usually minor in a young stand, but may prevail in an old stand. Basal fire wounds, open or closed, through which decay fungi often have entered are found chiefly in trees over 80 years old, when woods fires were frequent in California.

Be systematic in the examination, and cover all sides of each tree. On individual trees begin the inspection either at the top and proceed downward or at the butt and proceed up, but standardize on one procedure or the other and follow it consistently.

Checking the Top

At the top check for:

- Dead tops that may become weakened by rot and break off.

Checking the Crown

In the crown look for:

- Hanging broken or cracked branches that should be removed.
- Signs of general decadence, such as short and weak growth, and the presence of dead branches, either old or recent, scattered through the crown.
- Evidences of split crotches, both in hardwoods and between the forks of forked conifers. Unless the split is very recent, it will be marked by lines of healing callus similar to those that form along frost cracks.
- Evidences of dead cambium and associated sap rot on branches or trunks of hardwoods.

Checking the Trunk

On the trunk look for:

- Fungus conks or the remains of old weathered conks, indicating the presence of heart rots.

- Evidences of rot and hollowness in the heartwood of hardwoods where large branches have been sawn or broken off.
- Large open wounds showing rot within.
- Dwarfmistletoe swellings with exposed dead wood on the trunks of firs.
- Cankers on the main trunk deep enough to weaken it at the point where they occur.
- Excessive flattening of the trunk from any cause.

Checking the Butt

At the butt check for:

- Wounds, open and closed, from fire or mechanical injury and associated rots.
- Conks, or remains of conks, indicating basal decay, including those from roots near tree bases.
- Dead cambium.
- Reduced firmness of rooting from water or wind action.

The above list does not include every defect or indicator that might be encountered and that could influence the safety of the tree, but most of the major ones. Be alert for anything that might have a bearing on safety whether included in this list or not.

Checking for Heart Rot

One of the most common defects to look for and assess in old timber is heart rot or hollowness of the trunk resulting from it. Expect this defect particularly in trees bearing conks or showing old wounds, either open or closed. Occasionally, however, an old tree will be hollow with little outside evidence of heart rot (fig. 16). Keep in mind that a tree need not be large to be hollow.

The rate of recent diameter growth is a useful index of the probable safety of any tree with heart rot or hollowness. Trees that are making good growth will have thicker sapwood than those growing slowly and should be less likely to fail. The condition of callus growth around wounds is also of indicator value. If growth of the tree is good, callusing will be good and the bark over the callus will be thin and healthy in appearance. The crown will also be thrifty.

One test for heart rot or hollowness of the lower trunk consists in "sounding" the trunk by striking it sharply with the poll of an axe. If hollow or decayed and the surrounding wood is not too thick, the blow on the trunk will produce a hollow sound distinguishable from that produced when a solid trunk is struck in this manner.

For a more positive method of testing for hollowness, sample the lower trunk with an increment borer. If the borer breaks through into rot or a hollow resulting from the collapse of rot, the extracted core will give the thickness of the surrounding wall of solid wood at that point and also an opportunity to judge the rate of recent growth. If an increment borer is not available, a long twist bit may be used, but it will not give a very good index of recent growth. The chief disadvantage with sampling with either tool is the time and energy required to make the boring, which tends to limit its use to important questionable cases.

Do not rush a hazard inspection. In most recreational areas you are dealing with trees that are much more valuable in place than trees in the usual timber sale area and that from the practical standpoint are irreplaceable. On this account an inspection for hazardous trees should not be regarded as the equivalent of timber marking on the usual timber sale but rather a matter of individual tree diagnosis, more comparable to a health checkup in humans than to ordinary marking for cutting in a timber stand. Allow as much time as is needed to be reasonably sure of the decisions made. If a boring is needed, take time to make it.

Checking for Dead Cambium

Checking for dead cambium at the butt of the

Figure 16.—A 16-inch diameter lodgepole pine broken over in a campground from hollowness caused by rot. Only $1\frac{1}{4}$ to $1\frac{1}{2}$ inches of sound wood remained on the outside. No conks were present. Recent growth had been very slow, over 100 rings per inch.

tree is particularly important when examining decadent oaks. The most practical way of doing this is by tapping the bark on the outside with the poll of the axe. Bark over dead wood soon separates from it and emits a shallow, hollow sound when tapped. Dead cambium near the base may be caused either by insects or fungi. Decay of the dead area can be anticipated, if it is not already under way, and further decadence of the tree is to be expected.

Tapping or pounding the dead wood surface with an axe is also useful in determining how solid the wood is within large open basal wounds. Under climatic conditions often prevailing in California, exposed wood in open wounds on trees tends to "case-harden" in the outer layers, remaining relatively sound there even though the wood underneath this layer may be in an advanced state of decay. Sounding on the surface wood with the poll of an axe will often disclose such a condition.

If pavement covers a substantial portion of the soil above the area of root spread of oaks, this may create favorable conditions for the spread of *Armillaria mellea* in the roots. For this reason oaks with pavement around or near them should be closely inspected during tree safety examinations for any evidence of this fungus or of fungus-killed cambium. In particular, parts of the butt facing the paved area should be examined in detail to determine if the fungus has progressed into them along the roots from under the pavement. If the fungus has reached the tree butt and is still active, a felt of white mycelium will be present between bark and wood in the invaded part of the butt. Thin white wefts of hyphae, usually fan-shaped in pattern, will be produced between layers of the bark and will be noticeable when the bark is cut, split, or broken apart.

If dead areas of wood and bark are found at the base of oaks and *Armillaria mellea* is suspected as the cause, check for the presence of the fungus by removing a few shovelfuls of soil from next to the dead area and looking for the blackish, flattened rhizomorphs ("shoestrings") of the fungus over the bark surface below ground level. Rhizomorphs are not invariably produced by an established infection of *Armillaria mellea;* if they are found they provide positive evidence that the fungus is there.

Judging The Hazard

In actual practice the examination and assessment for safety are carried out together. Because of the wide differences between individual trees and their surroundings, each tree constitutes an individual case that requires an individual decision as to its safety.

Rots

Earlier we pointed out that the application of strength formulae to defective live trees can be only approximate because of the lack of uniformity of the defect. An internal column of heart rot is seldom uniform in radial dimension, either horizontally or vertically. It is also difficult to judge from the outside how defective a tree is within

Table 2.--Minimum safe standard for defective trees[1] applied as average thickness of outer sound wood of the trunk with center rot or hollow representing 70 percent of the total wood diameter, equivalent to one-third loss in strength

Diameter of tree inside bark	*Thickness of sound wood[2]*	*Diameter of tree inside bark*	*Thickness of sound wood[2]*
Inches	*Inches*	*Inches*	*Inches*
16	*2.5*	*44*	*6.5*
20	*3.0*	*48*	*7.0*
24	*3.5*	*52*	*8.0*
28	*4.0*	*56*	*8.5*
32	*4.5*	*60*	*9.0*
36	*5.5*	*64*	*9.5*
40	*6.0*	*68*	*10.0*

[1] *Assumes no modification is applicable.*

[2] *Figures rounded to the nearest half inch.*

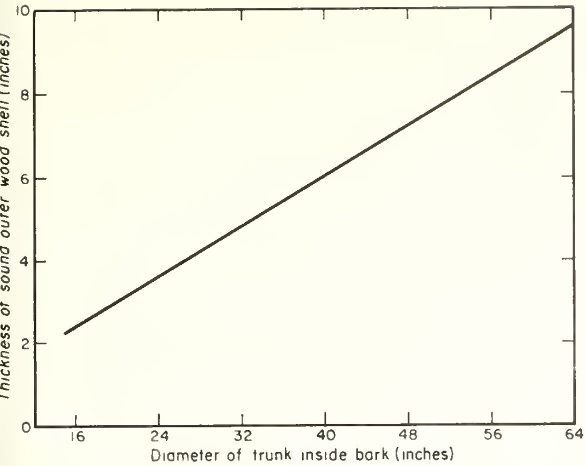

Figure 17.—Approximate radial thickness of outer sound wood required in a trunk with center heart rot if the strength reduction is not to exceed one-third.

and where the zone of maximum weakness may be located. Some of the most pronounced cases of failure from trunk rot ocur in trees that show little surface indication of the rot and in which loss of mechanical strength of the trunk has reached as much as 85 percent.

Field experience indicates that a conifer can suffer up to one-third loss in strength—equivalent to approximately a 70 percent loss in total wood diameter inside bark (fig. 3)—without materially affecting the safety of a tree if the weakening defect is heart rot uncomplicated by other defects. This standard can be applied most conveniently in the field as the thickness in inches of sound wood outside of the rot column or hollow (fig. 17 and table 2). If the indications are that the layer of sound wood is thinner than that shown in table 2 for a comparable wood diameter and there is no apparent reason for modifying the strength-loss ratio, the tree should be marked for cutting. A somewhat stricter standard may be advisable for conifers in highly exposed situations or in the vicinity of buildings occupied all year.

The one-third strength loss limit proposed above as allowable is by no means absolute. It represents a chosen average value, including a safety allowance, but not a limit based on specific studies or records because no such data exist. We regard it as the best working estimate we can make of a satisfactory average limit to serve until a better-grounded standard becomes available.

A specific standard of loss in strength, such as one-third, is less applicable to hardwoods because of the features of this group mentioned earlier: (a) the difference in basic form between hardwoods and conifers, (b) the strong and variant influence of leverage on the breakage potential, (c) the high mechanical strength of the wood of many hardwood species, and (d) the fact that trunk failures, aside from those near ground level from the honey fungus, are relatively rare in occurrence except in weak-wooded species such as the poplars. The condition of the main branches is often more important from the safety standpoint than the condition of the main trunk. Thus the decay at stump height in the oak shown in figure 8 does not render that part of the trunk hazardous, but the hollow in the section shown of a main branch does render the branch unsafe.

In virgin stands of true firs and occasionally in other timber, trees may show both conks on the trunk and old basal fire wounds. Almost invariably in the firs and commonly in other species, except incense-cedar, the rot associated with the trunk conks will be different than that associated with the fire wounds. The two rots may join in the trunk heartwood, but they will not overlap, and the development of each will be independent of that of the other. But both will be limited by the radial limits of the heartwood unless the causal fungi can invade the living sapwood, which is usually not the case (fig. 18).

The average person tends to overrate the hazard potential of trees with perennial conks, such as those of the Indian paint fungus, on the trunk as compared with defective trees without visible conks. A tree that is cull commercially is not necessarily a hazardous tree, as evidenced by the numerous white and red firs that have stood without failure for many decades, even though they bear Indian paint fungus conks.

In the case of trunk rots that center at some distance from the ground, direct sampling to determine the thickness of the outer wall of sound wood is not practicable. Accordingly, decisions must be made from indirect evidence. In the case of the Indian paint fungus only conk-bearing trees with (a) conks more than 6 inches wide, (b) the highest and lowest conks separated by 10 feet or more, and (c) current radial tree growth slow, indicating a thin sapwood, should be regarded as possibly hazardous under average conditions. In areas occupied year-round or in especially exposed situations, somewhat more stringent standards may be justified.

Figure 18.—Hollow from a white rot at the stump of a 67-inch d.b.h. white fir. About 3 inches of sound wood remained around the outside. A second heart rot higher in the trunk caused the upper 90 feet to disintegrate when the tree was felled. (National Park Service photo.)

Conks of the ring scale fungus on the trunks of Douglas-fir and other conifers, and of *Polyporus amarus* or its shot-hole cups on incense-cedar are not signs that the trees are unsafe. The same applies to conks of the false tinder fungus on aspen trunks *in California.*

For butt rots that do not seriously involve the roots in trees, such as brown rot caused by the sulfur fungus, a reasonably close estimate of the thickness of the sound shell can be obtained and a decision made based on such guides as table 2 (fig. 19).

So far as known, all cases of basal failures of trees from advanced butt and root fungus infections that have resulted in accidents or near accidents on recreational areas have been in trees with unmistakably large basal hollows and in a plainly decadent condition. Oaks that have toppled from weakening by the honey ("oak root") fungus have had as much as 85 percent of the basal wood destroyed. This destruction was often accompanied by patches of dead sapwood at the butt. Primarily, however, it is the killing of roots that causes the failure, both in oaks affected by the honey fungus and in firs weakened by the Fomes root fungus. Where decay typical for these fungi is present and the trunk contains large openings into a central hollow, it is often fairly evident that the decay extends into the roots. Recent radial growth of such trees is normally slow, and the crowns are in poor condition. Regard trees showing these defects and in this condition as hazardous and mark them for removal. This is particularly true if Armillaria "shoestrings" are found over the bark surface just below ground level in oaks. In firs affected with

Figure 19.—About 83 percent of the wood in a cross section of this oak trunk had been destroyed by decay, equivalent to about 65 percent reduction in mechanical strength. The tree would be rated as potentially hazardous. (National Park Service photo.)

the Fomes root fungus, open basal fire wounds through which the decayed internal condition of the butt can be seen may not be present. In these cases, if a "sounding" test with the axe does not indicate a hollow butt, the tree should be bored. In judging trees, also look for such indicators as slow growth and a decadent condition of the crown not attributable to dwarfmistletoe. Consider as hazardous those with advanced cases of root rot as judged from the combination of indicators.

Sap rots in living trees are usually local and, except in the case of oaks attacked by the honey fungus, are in sapwood killed by some other cause. When rots occur on branches, they normally affect the safety only of those branches and not that of the entire tree.

Sap rots on trunks already weakened by advanced cases of heart rot may render the trees highly hazardous if the rot in the sapwood approaches half of the circumference of the tree in extent. Such cases are sometimes hard to detect, but where they can be recognized mark the affected tree for removal. Trunks with excessive areas of dead sapwood, whether or not associated with heart rot, are likely to be present only on very decadent trees, which should be condemned and removed.

Other Defects and Conditions

The hazard status of the defects or tree conditions listed below has already been described. The ratings indicated there are summarized below. The reader should remember that in some cases no sharp distinction exists between the hazardous and nonhazardous classifications.

Nonhazardous	Hazardous
Brooms, dwarfmistletoe, live.	Brooms, dwarfmistletoe, dead.
Cankers, dwarfmistletoe, on pines.	Cankers, dwarfmistletoe, on trunk swellings on true firs, when the dead face of the cankered area approaches half the circumference of the swelling.
Cankers, horizontal, on ponderosa pines, when low on trunks.	Cankers, horizontal, on ponderosa pines, when deep and above 16 feet from the ground.
Forked conifers; in general (see also: Tops, volunteer).	Forked conifers, when forks are long and heavy, and the crotch is at right angles to the direction of heaviest winds.
Frost cracks.	
Leaning conifers, that have grown in a leaning position.	Leaning conifers if (a) the lean has been caused by an outside force, and (b) an open wound with advanced decay and poor calluses is in line with the direction of lean.
	Leaning hardwoods, if the lean is extreme and the leverage great for the strength of the wood.
Pavement, asphalt, over roots; not hazardous in itself but favors the development of hazardous conditions.	
Slime flux.	Snags.
Swellings, dwarfmistletoe, live.	
Swellings, dwarfmistletoe, cankered, on true firs if canker is small (compare under "Cankers").	
Tops, broken out, if top branches are thrifty.	
Tops, dead spike, on giant sequoia, incense-cedar, and redwood, if not structurally weakened by woodpecker holes. Also on pines and Douglas-firs if old, without bark and deeply weathered.	Tops, dead, on other species, or bark-covered on pine or Douglas-fir (includes dead volunteer tops).
Tops, volunteer, if live and thrifty.	Tops, volunteer, live, of borderline hazard in areas of winter use.

Figure 20.—The dead limbs on this veteran pine emphasize the rugged character of the mountain-top location, but the long ones are a hazard to users below. If these long limbs were removed, the danger can be abated without sacrificing the rugged appearance of the tree or incurring a rot hazard.

Multiple Defects or Conditions

Two or more defects occurring together may sometimes render a tree hazardous when it might not be if it had only one defect. Cases already mentioned are the combination of a sap rot and a heart rot, and one of a leaning tree with a large basal wound in line with the direction of lean. Other combinations are possible and should be looked for in the course of inspections.

Inspection and Hazard Reduction

The necessity of tree inspections for safety in recreational areas differs somewhat because of differences in the length of season of use, the intensity of use, and the character of the stand. In general, a programed inspection probably should be made once a year, supplemented by special inspections whenever required by circumstances, such as the occurrence of an abnormally severe storm that is known to have caused general damage in the district. A record of each inspection should be carefully made and preserved in case the safety of any tree examined should later be questioned.

Until recently the standard method of eliminating tree hazards in forest recreational areas has been to fell the affected trees. From a practical standpoint such an action is irreversible and results in the gradual depletion of cover on the area involved. More than one long-established campground now receives only sporadic use because the loss of tree cover makes the area too open to attract campers.

One means of reducing this type of recreational value erosion is to remove or correct the hazard without sacrificing the tree. Smaller dead tops, broken and hanging branches, and dead limbs with sap rot are types of defect that can be corrected in this manner. Cracked crotches and limb splits, particularly in hardwoods, can also sometimes be repaired by the use of tie bolts.

Work of this kind requires an experienced and properly equipped tree man or crew, but has the advantage of retaining the tree and often of eliminating the greater part of the cleanup work involved when an entire tree is felled. At least one National Park in California now has its own trained crew for this type of hazard correction. In other instances, jobs have been handled by commercial tree repair firms under contract. Regardless of how undertaken, this type of corrective treatment deserves increasing consideration where appropriate types of defect are involved.

Above all, intelligent consideration should be given to all aspects presented by an individual case before deciding on the best means of eliminating the hazard that it presents. For illustration, the grizzled old pine in figure 20 stands in a mountaintop recreational area receiving year-long use in southern California. Large trees are scarce in the area, and thus unusually valuable. But this rugged-looking tree also adds much to the general character of the site. Its long dead limbs are a hazard to users of the area, but they also demonstrate that climatic conditions there are very unfavorable for decay or else that the tree is very resistant to it. Otherwise it would not have such long limbs. The short dead branch stubs are eroding slowly and show no evidence of contributing to the risk.

The danger could be removed by felling the tree or by sawing off all dead branches. But either practice would entail an unwarranted destruction of plus values. The most acceptable treatment for this tree would appear to be breaking off mechanically the long dead branches that create the hazard, and allowing the broken stubs to remain. The interests of utility, safety, and esthetic appeal would thus all be served by the one treatment. But the measure suggested could be entirely unacceptable in a different environment or with a different tree species.

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1. A numbered series, **U.S. Forest Service Research Papers.**
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The publishing unit will be identified by letters before the number, and the numbers will be consecutive in the order of publication dates. For example, this Station's first Research Paper in 1963 is designated U.S. Forest Service Research Paper PSW-P1.

Soil Moisture Constants and Physical Properties of Selected Soils in Hawaii

Teruo Yamamoto

. FOREST SERVICE RESEARCH PAPER PSW-P2 1963

PSW

Pacific Southwest Forest and Range
Experiment Station - Berkeley, California
Forest Service - U. S. Department of Agriculture

Contents

The Author

Teruo Yamamoto is a geologist with the Pacific Southwest Station's watershed management research project in Honolulu, Hawaii. He was graduated from the University of Kansas City, Mo., and obtained a master's degree from Indiana University, Bloomington. He joined the Forest Service in 1957 as a geologist at the Southern Forest Experiment Station in Vicksburg, Miss., and was transferred to Hawaii in 1959.

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The nature of soils influences and often deter-
iines the use of land. Information on the physical haracteristics of soils is needed as a guide to ianaging land for water production and other ses. In 1961 a detailed study was made of the :rength and soil moisture characteristics of 25 oil types in Hawaii.[1] Samples were obtained from ie surface to the 12-inch depth at 34 sites on the lands of Hawaii, Kauai, and Oahu. These soils epresent 10 great soil groups commonly found in ie State of Hawaii.

Analyses were made of the differences in sur-ace properties of fine-textured soils found under orest cover, in cultivated areas, in pastures, and i idle grassland. These studies provided data on oil texture, Atterberg limits, bulk density, organic iatter content, specific gravity, pH, and soil mois-ire constants. This paper reports the results of iese analyses.

Methods and Procedures

At each sampling site, we dug two to four pits, ach about 2 feet deep. The exposed profile was escribed by a soil scientist of the U.S. Soil Con-:rvation Service. Bulk samples composited from iree locations within a 21- by 36-foot plot were iken from the 0- to 3-, 3- to 6-, 6- to 9-, and 9- › 12-inch depths. Particle size distribution, Atter-:rg limits,[2] and specific gravity of soil particles were determined by following standard methods at the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss. The pH of soils was determined by using a standard colorimetric kit.[3] Organic matter content of most soils was determined at the Mississippi Agricultural Experiment Station, Starkville, by using a modified Walkley rapid-dichromate method (Peech et al. 1947). Certain samples high in organic matter content were analyzed by the loss-on-ignition method (Association of Official Agricultural Chemists 1945).

Soil moisture retained at 15 atmospheres pressure (wilting point) was determined by the pressure-membrane method (Richards 1947). Undisturbed cores in triplicate were obtained to determine bulk density and soil moisture retained at 0 and 0.06 atmosphere tension using the method of Leamer and Shaw (1941). Soil moisture retained at 60 centimeters water tension was taken as the upper limit of available soil moisture or field capacity.[4] Permanent wilting point was taken as the moisture retained at 15 atmospheres pressure. Available water capacity was calculated by subtracting the water held at 15 atmospheres pressure from the water retained at 60 centimeters tension.

Volume of large pores or readily drained pores was calculated by subtracting the total pore space occupied by water at 0.06 atmosphere tension from the total pore volume (Broadfoot and Burke 1958). The total pore volume was calculated from the average bulk density and average specific gravity of the soil particles.

We grouped the data representing known land use conditions into four categories: forest, pasture, cultivated area, and idle grassland (table 4, appendix).

The forest category consisted of soils supporting trees and associated vegetation. Soils in pastures were mainly under grasses, but some were under a mixed growth of grass, guava, ferns, and herbaceous cover. Eight of the cultivated soils were under sugar cane; one under pineapple; and

[1]A joint research project of the Pacific Southwest For-t and Range Experiment Station, Forest Service, U.S. :partment of Agriculture, and the U.S. Army Corps of igineers, Waterways Experiment Station, in coopera-›n with the Hawaii Forestry Division and the Hawaiian gar Planters Association.

[2]Atterberg limits or consistency limits are the bound-es determined by moisture content (percent by weight) which a soil may exist in different states: (a) Liquid iit—the boundary between liquid and plastic states; › plastic limit—the boundary between the plastic and ni-solid states; and (c) shrinkage limit—the boundary tween semi-solid and solid states. Plasticity index is the merical difference between the liquid limit and plastic iit.

[3]Truog soil reaction tester by Hellige, Inc.

[4]Data collected at the Vicksburg Research Center, Southern Forest Experiment Station, by Broadfoot and Burke (1958) indicated that the 60-centimeter determination closely approximated field capacity for all textural classes of soils in the United States.

one under a stand of papaya, grass, and guava. Idle grassland areas are those formerly cultivated or used as pasture several years ago but now idle and under grass cover.

Soil Properties

In spite of apparent textures, most soils of Hawaii fully dispersed are clay to colloidal in particle size (Hough and Byers 1937; Hough et al. 1941; Kelley et al. 1915; Tanada 1951; Richter 1931; Sherman 1955). They are aggregates of clay and colloidal particles and very difficult to disperse. Hough et al. (1941) concluded that conventional methods of analysis were useless, because the soils of Hawaii they studied consisted almost entirely of colloidal material. The hydrometer method is more reliable for dry area soils in which leaching is not a significant factor, according to Wadsworth (1936).

The dominance of colloids strongly affects other soil properties. Fieldes (1955) has shown that dispersion is difficult when pumice soils have allophane. Packard (1957) found that the surface area method gave 9.6 percent more clay than th mechanical analysis of the same soils. Hough an Byers (1957) found that concretionary or aggre gate material with a low degree of dispersio accounts for the high permeability and greate distribution of organic matter throughout the so horizon. During our field investigations of so strength and moisture characteristics, we foun that soil structure was water stable and retain high permeability under wet conditions.

Texture and Structure

The majority of the soils sampled were fin textured by mechanical analysis (figs. 1 and 2. The 0- to 6-inch layers of 7 out of 11 soils und forest cover were classified in the field as loan type. Laboratory analysis indicates that three these soils were of clay texture. Loamy soils ar in general, more favorable for forest growth th coarse sands or fine clays (Lutz and Chandl 1951). Of the 11 grass-covered soils classified the field, 4 were clay in texture, 3 silty clay loa and 4 silty clay.

Soil structure is greatly influenced by differe land usage. Total pore volume and volume large pores are highest in soils under forest (tal 1 and fig. 3).

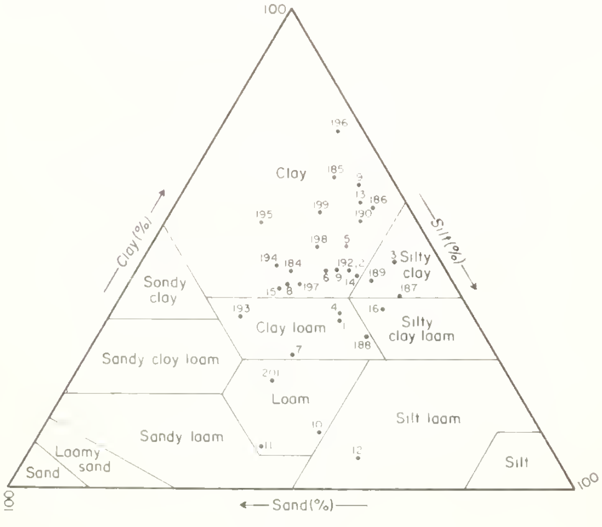

Figure 1.—Classification of soil texture of 34 soil sites studied, 0- to 6-inch depth.

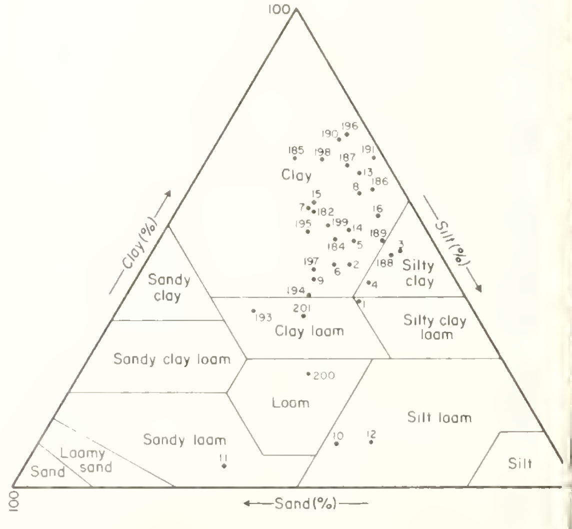

Figure 2.—Classification of soil texture of 34 soil sites studied, 6- to 12-inch depth.

Table 1. Porosity and soil moisture constants (percent by volume) of soils, 0- to 12-inch depth, under four different land uses

Land use	Total pore volume		Large pore volume		Field capacity		Wilting point		Available moisture	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
orest: 11 sites--------	74	6	18	7	57	12	28	7	28	10
astureland: 6 sites-------	71	11	14	6	56	8	38***	5	19*	4
ultivated areas: 10 sites--------	69	8	10**	4	58	9	35***	4	24	11
lle grassland: 7 sites--------	68	11	10**	6	58	13	32	5	26	12

* Significant at .10 level when compared to forest soils.
** Significant at .95 level when compared to forest soils.
*** Significant at .01 level when compared to forest soils.

Bulk Density

Low volume weight signifies relative porous il condition and high values indicate greater mpactness, lowered field capacity, and lower filtration rates.

Except for some ash soils of Hawaii, analysis the limited data indicates that bulk density nds to decrease with increased rainfall. Soils der low rainfall may have moderately low bulk nsity, but no soils under high rainfall have high nsity. Wadsworth (1936) also reported that il bulk density decreased as rainfall increased.

Forest soils had the lowest average bulk density able 2). Pasture and cultivated soils as expected d higher average bulk densities, although unazed grassland soils had the highest average lue. Trouse and Humbert (1960) reported that me soils of Hawaii will compact and puddle

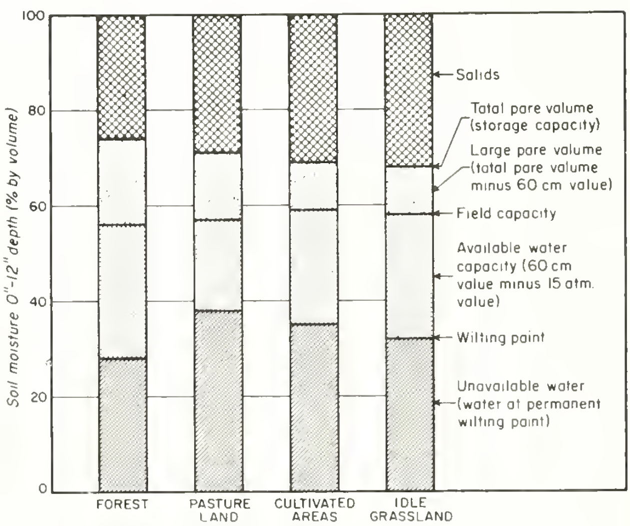

Figure 3.—Soil moisture constants (percent by volume, 0- to 12-inch depth) related to vegetative cover.

Table 2. Properties of soils under four different land uses, 9- to 12-inch depth

Land use	pH		Specific gravity		Organic matter		Bulk density	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
			Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
orest: 11 sites--------	6.2	3.3	2.94	0.34	6.5	3.0	0.76	0.22
astureland: 6 sites-------	5.9	0.4	2.75	0.18	8.7	8.7	0.81	0.34
ultivated areas: 10 sites--------	6.2	1.3	2.82	0.26	5.0	5.0	0.88	0.26
lle grassland: 7 sites--------	7.0	1.3	2.91	0.16	5.1	4.2	0.93	0.36

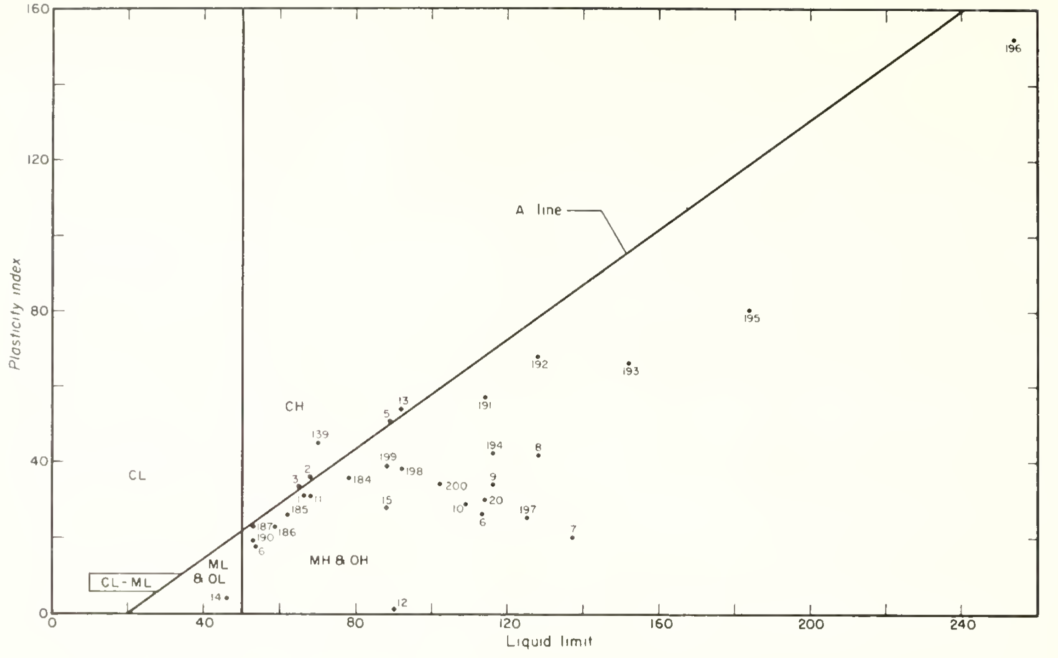

Figure 4.—Classification of surface (0-6 inches) soils by the Casagrande plasticity chart, showing that most points in the soils of Hawaii that were studied fell below the arbitrarily set "A" line, and beyond the 50 percent moisture content line.

drastically with traffic. The resulting increase in bulk density reduced soil moisture. The reduction of soil moisture with increase in bulk density was significant for the Hydrol Humic Latosols in which water is not held in the interstices of the soil particles. In other soils, the increase in bulk density significantly lowered porosity, but increased the water held at field capacity.

Soil Consistency

Ash-formed soils on the island of Hawaii have the highest plastic limits, the wet area soils of Kauai and Oahu have intermediate values, and the dry area soils on the three islands generally have lower values of plastic limit.

Soils should not be disturbed at or beyond their plastic limit because puddling occurs at these moisture contents. Plasticity is not as important in forest soils as in agricultural soils under intense cultivation. Nevertheless forest soils, if highly plastic, can be damaged by disturbance during wet periods. Soils disturbed at or beyond their liquid limit will behave as a liquid.[5] Data on soil con[sistency] (table 3) can be used as a guide to tillag[e] as well as to logging practices.

The liquid limit and the plasticity index of th[e] surface (0 to 6 inches) soils were plotted on th[e] Casagrande plasticity chart[6] by extending the rang[e] of plasticity index and liquid limit. Most soils wer[e] in the MH class (fig. 4). "C" represents cla[y] soils, "M" silty soils, and "O" organic soils. "L" represents liquid limits below 50, and "H" abov[e] 50. The "A" line represents the empirical boun[d]ary between the various plasticity groups. "MH" therefore, means that the soil material behaves a[s] though it was predominantly silty with liquid lim[it] above 50.

The Dark Magnesium Clay soil and one of th[e] Alluvial soils have the lowest plastic limits at th[e] 0- to 6-inch depth. These soils should not be di[s-]

[5]For trafficability, the liquid and plastic limits of t[he] 6- to 12-inch layer are critical (Carlson and Hort[on] 1957).

[6]U.S. Army Corps of Engineers Waterways Experim[ent] Station. The unified soil classification system. Tec[h] Memo. 3-357, 30 pp., illus. 1953.

turbed when the moisture content exceeds their plastic limit (25 percent by dry weight). The highest plastic limit (117 percent) was found in the Latosolic Brown Forest soil. This soil would not be easily compacted except at very high moisture contents, above 117 percent moisture (by dry weight).

Organic Matter, pH, Specific Gravity

Pasture and forest soils had the highest average organic matter contents. The average pH for soils under all types of land use ranged from medium acid to neutral (table 2). The greater range in pH of forest soils indicates a greater range of rainfall and elevation between sampling sites. Kanehiro et al. (1951) reported that soils of the dry lowland areas tend to increase in acidity during hot summer months, but upland soils showed no increase in pH during summer months. There are no pronounced seasonal leaf falls, and the contribution of basic ions from leaves may not be significant.

The specific gravity of soil particles averaged 2.86, which is in contrast to the low bulk densities of some soils (table 2).

Table 3. Atterberg limits of selected soils in Hawaii

Great soil group	Site number	0- to 6-inch layer			6- to 12-inch layer		
		Liquid limit	Plastic limit	Plasticity index	Liquid limit	Plastic limit	Plasticity index
		Percent by dry weight			Percent by dry weight		
Alluvial	1	66	34	32	68	34	34
	4	94	45	49	85	41	44
	188	53	25	28	52	23	29
Dark Magnesium Clay	189	70	25	45	72	25	47
Gray Hydromorphic	5	89	38	51	96	39	57
	13	92	38	54	108	41	67
Humic Ferruginous Latosol	14	46	42	4	50	38	12
	186	59	36	23	62	38	24
	187	53	30	23	66	32	34
	198	92	54	38	110	57	53
	199	88	49	39	81	45	36
Humic Latosol	8	128	86	42	213	142	71
	9	116	82	34	143	112	31
	15	88	60	28	89	64	25
	16	54	36	18	55	32	23
	191	114	57	57	112	57	55
	192	129	61	68	104	55	49
	193	153	86	67	133	76	57
	194	116	73	43	101	65	36
	201	114	84	30	136	98	38
Hydrol Humic Latosol	6	113	87	26	144	109	35
	195	183	103	80	251	172	79
	196	254	102	152	328	193	135
	197	125	98	27	160	101	59
Latosolic Brown Forest	7	137	117	20	222	181	41
	12	90	89	1	110	101	9
	200	102	68	34	141	80	61
Low Humic Latosol	2	68	32	36	71	32	39
	3	65	32	33	66	33	33
	184	77	42	35	69	43	26
	185	62	35	27	64	38	26
	190	53	34	19	64	38	26
Reddish Brown	11	68	37	31	68	41	27
Reddish Prairie	10	109	80	29	130	118	12

Soil Moisture Constants and Land Use

Soil moisture constants, total pore volume, and aeration of soils were compared under the four categories: forest, pasture, cultivated area, and idle grassland (fig. 3 and table 1).

The data indicate that average total pore volume was highest under forest cover, but the difference with the other categories were not statistically significant (table 1).

Infiltration rates were not measured, but forest soils probably have a greater infiltration capacity[7] as indicated by average higher total pore volume and large pore volume. By the same assumption pasture soils have a higher infiltration capacity than cultivated or idle land soils. These differences may indicate that some pastures are not heavily grazed. Also, inherent properties of the soil as well as land use influence infiltration capacity.

No significant difference in field capacity among the four categories of land use was found.

Average available moisture was highest in the forest soils and lowest in the pasture soils. The difference of 9 percent between the forest and pasture is significant at the 10 percent level. No significant differences in average available moisture existed between forest and cultivated soils or between forest and idle grassland soils.

The average volume of large pores was highest in the forested soils and lowest in the cultivated and idle grassland soils. The differences compared to forest soils are statistically significant.

The average wilting point was lowest for soils under forest, higher for idle grassland and cultivated land, and highest under pastures. The difference in wilting point of 10 percent moisture (by volume) between forest and pasture and a difference of 7 percent moisture (by volume) between forest and cultivated soils were highly significant at the 1 percent level (table 1).

Individual differences in total pore space, available water, unavailable water, large pores, and wilting point are shown in figure 3 and table 5 (appendix).

Total pore volume is generally lower for Low Humic Latosols and Alluvial soils and highest in Hydrol Humic Latosols. Available moisture capacity is higher under Hydrol Humic Latosols and some Latosolic Brown Forest soils. The volume of large pores is lower for Hydrol Humic Latosols, Alluvial, Gray Hydromorphic, and Dark Magnesium Clay soils. Eleven soils had a wilting point of greater than 30 percent moisture (by volume) of which 7 were under forest cover, 1 under cultivation and 3 in idle grassland. Soils with higher wilting points (40 percent by volume) are the Gray Hydromorphics and some of the Humic Latosols.

[7]The maximum rate at which water can enter the soil surface (Lassen et al. 1952).

Summary

- Most surface soils in Hawaii are fine textured and composed of aggregates of clay and colloidal particles. Data show that forest soils have structures which favor infiltration and percolation of water.
- Forest soils were found to have the lowest average bulk density; pasture and cultivated soils, as expected, have higher bulk densities. Except for some of the ash soils of Hawaii, bulk density tended to decrease as rainfall increased.
- Soils studied on the island of Hawaii have the highest plastic limits, the wet area soils of Kauai and Oahu have intermediate values, and the dry area soils on the three islands have lower values of plastic limit. The majority of the soils have liquid limits above 50 and therefore should behave like a silty soil or clay soil relatively high in organic matter.
- Pasture and forest soils have the highest average organic matter content.
- The specific gravity of soil particles of all soils sampled averaged 2.86.
- Average total pore volume is highest under forest cover, although the difference from other categories was not statistically significant.
- The average volume of large pores is highest in the forest soils and lowest in the cultivated and idle grassland soils.
- Average field capacity is about the same under each of the four land use categories.
- Average available moisture is highest in the forest soils and lowest in the pasture soils.
- The average wilting point of the soil is lowest under forest and highest under pasture.

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Appendix

Table 4. Description of soils and sampling sites, by land use

Site number	Great soil group	Soil type (field classification)1/	Texture (lab classification)1/ 0 to 6 inches	Texture 6 to 12 inches	Slope	Elevation	Position	Annual rainfall	Location	Vegetation
					Percent	Feet		Inches		
	FOREST									
1	[illegible] Brown	Waikaloa sicl	l	sl	[illegible]	[illegible]	Upland [illegible]	[illegible]	[illegible], Hawaii	Eucalypt
[illegible]	Latosolic Brown Forest	Hanaipoe sil	sil	sil	[illegible]	[illegible]	Upland upper [illegible]	[illegible]	Waikii, Hawaii	Eucalypt
4	Humic Ferruginous	Mahana vfsl	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]kee, Kauai	[illegible], silk-oak
[illegible]	Humic Latosol	Paaiki sicl	[illegible]	[illegible]	[illegible]	[illegible]	Upland lower [illegible]	[illegible]	[illegible]	[illegible], Monterey cypress, Moreton-Bay chestnut
[illegible]	Humic Ferruginous Latosol	Paaiki sicl	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yellow foxtail, eucalypt
84	Low Humic Latosol	Wahiawa si	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]awa, Oahu	Eucalypt
[illegible]7	Humic Ferruginous Latosol	Leilehua si[illegible]	sic	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible], Oahu	[illegible] staghorn [illegible], ohi'a-lehua
[illegible]	Humic Latosol	Iolekaa si	c	[illegible]	[illegible]	[illegible]	Upland upper [illegible]	[illegible]	[illegible], Oahu	Bamboo
[illegible]	Humic Latosol	Iolekaa si	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible], Oahu	[illegible] eucalypt
[illegible]4	Humic Latosol	Kahanikí sicl	[illegible]	[illegible]	[illegible]	[illegible]	Upland upper [illegible]	100	[illegible]lus, Oahu	Australian redcedar
[illegible]6	Hydrol Humic Latosol	Akaka sicl	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible], Hawaii	[illegible] eucalypt
	PASTURE									
4	Alluvial	Hanalei c	[illegible]	[illegible]	[illegible]	[illegible]	Bottom land [illegible]	[illegible]	[illegible], Oahu	[illegible]
7	Latosolic Brown Forest	Maile [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Upland [illegible]	[illegible]	Umik[illegible], Hawaii	[illegible]
[illegible]	Humic Latosol	Niupea [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Upland lower [illegible]	[illegible]	[illegible]kaiau, Hawaii	[illegible]
9	Humic Latosol	Kukaiau [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Upland [illegible]	[illegible]	Honokaa, Hawaii	[illegible]
[illegible]0	Low Humic Latosol	Alaeloa [illegible]	[illegible]	[illegible]	[illegible]	[illegible]00	Upland lower [illegible]	[illegible]	Waimanalo, Oahu	[illegible]
[illegible]9	Humic Ferruginous Latosol	Puhi sicl	[illegible]	[illegible]	[illegible]	[illegible]	Upland flat	[illegible]	Waialua, Kauai	[illegible] wood, [illegible] grass
	CULTIVATED AREA									
1	Alluvial	Haleiwa si	[illegible]	[illegible]	4	[illegible]	Bottom land [illegible]tion	[illegible]	Waialua, Oahu	Sugar cane
2	Low Humic Latosol	Waialua	[illegible]	[illegible]	4	[illegible]	Bottom land upper slope	[illegible]	Waialua, Oahu	Sugar cane
3	Low Humic Latosol	Waialua c	sic	[illegible]	4	[illegible]	Bottom land upper slope	[illegible]	Waialua, Oahu	Sugar cane
6	Hydrol Humic Latosol	Hilo sicl	[illegible]	[illegible]	3	[illegible]	Upland lower slope	[illegible]	Waiaka[illegible], Hawaii	Sugar cane
[illegible]3	Gray Hydromorphic	Nohili	[illegible]	[illegible]	2	[illegible]	Bottom land flat	[illegible]	Kekaha, Kauai	Sugar cane
[illegible]5	Low Humic Latosol	Wahiawa sic	[illegible]	[illegible]	[illegible]	[illegible]	Upland flat	[illegible]	Wahiawa, Oahu	Pineapple
[illegible]1	Humic Latosol	Iolekaa si[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Terrace slope	[illegible]	[illegible], Oahu	Banana, panicum grass
[illegible]7	Hydrol Humic Latosol	Hilo sicl	[illegible]	[illegible]	[illegible]	[illegible]	Upland lower slope	140	[illegible]omu, Hawaii	Sugar cane
[illegible]	Latosolic Brown Forest	Waihaka vfsl	[illegible]	[illegible]	[illegible]	[illegible]	Upland upper slope	75	[illegible]hala, Hawaii	Sugar cane
[illegible]1	Humic Latosol	Niupea sicl	[illegible]	[illegible]	[illegible]	[illegible]	Upland upper slope	100	Kukaiau, Hawaii	Sugar cane
	WILD GRASSLAND									
[illegible]	Gray Hydromorphic	Laie c	[illegible]	c	[illegible]	7[illegible]	Bottom land flat	40	Waimanalo, Oahu	Panicum grass
10	Reddish Prairie	Puukapu sil	l	sil	[illegible]	2,[illegible]	Upland flat	36	Kamuela, Hawaii	Bermuda, [illegible] grass
[illegible]6	Humic Ferruginous Latosol	Manana sic	[illegible]	[illegible]	4	1,[illegible]	Upland ridge	75	Helemano, Oahu	Dallis, rice, broom-sedge, carpet grass
[illegible]8	Alluvial	Waianae	[illegible]	[illegible]	[illegible]	[illegible]	Bottom land flat	20	Lualualei, Oahu	Swollen fingergrass, plush grass, buffel grass
[illegible]9	Dark Magnesium Clay	Lualualei c	sic	[illegible]	[illegible]	[illegible]	Terrace flat	20	Lualualei, Oahu	Swollen fingergrass, plush grass, buffel grass, klu
[illegible]5	Hydrol Humic Latosol	Akaka sicl	[illegible]	[illegible]	1[illegible]	1,[illegible]	Upland lower slope	[illegible]50	Honomu, Hawaii	Rice, hilo grass, sugar cane
[illegible]8	Humic Ferruginous Latosol	Kapaa sicl	[illegible]	[illegible]	[illegible]	[illegible]	Upland ridge	80	Waialua, Kauai	Yellow foxtail, glen-wood grass

1/ l: loam; sl: sandy loam; sil: silt loam; c: clay; sic: silty clay; sicl: silty clay loam; cl: clay loam; vf: very fine.

Table 5. Properties of selected soils in Hawaii, by great soil group

Soil type[1]	Site no.	Soil layer (inches)	Total pore space percent by volume	Large pores, 0 atm. minus .06 atm.	Soil moisture in percent by volume: 0 atm.	.06 atm.	3 atm.	15 atm.	Available moisture .06-15 atm.	Bulk density g/cc	Specific gravity g/cc	Organic matter by weight percent	pH	Mechanical analyses by weight percent: Sand	Silt	Clay
ALLUVIAL																
[illegible] sic	[illegible]	0-6	61.0	[illegible]	[illegible]	56.3	41.0	34.1	[illegible]	1.14	[illegible]	2.0	8.0	24	41	35
		6-12	61.2	[illegible]	[illegible]	56.7	[illegible]	[illegible]	20.9	1.14	2.94	[illegible]	8.0	20	41	39
[illegible]	[illegible]	[illegible]	61.0	[illegible]	[illegible]	[illegible]	[illegible]	37.6	[illegible]	1.06	[illegible]	[illegible]	7.0	23	40	37
		[illegible]	[illegible]	[illegible]	56.3	[illegible]	48.0	40.0	13.6	1.20	[illegible]	2.0	6.5	16	41	43
Wa[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	61.0	45.6	33.6	23.4	[illegible]	1.22	[illegible]	2.2	8.0	21	47	32
		[illegible]	[illegible]	[illegible]	[illegible]	45.7	35.5	[illegible]	[illegible]	1.42	3.00	1.2	8.0	[illegible]	[illegible]	49
DARK MAGNESIUM CLAY																
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.04	3.00	1.1	8.0	14	[illegible]	44
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.24	3.00	1.0	[illegible]	[illegible]	39	52
GRAY HYDROMORPHIC																
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.5	45.9	[illegible]	21.3	1.12	[illegible]	[illegible]	8.0	[illegible]	34	51
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60
		[illegible]	[illegible]	4.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	66
HUMIC FERRUGINOUS LATOSOL																
Kapa[illegible]	198	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42.0	[illegible]	20.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	49	40
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31.4	[illegible]	[illegible]	[illegible]	[illegible]	4.5	7	[illegible]	66
Mahana vf[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	11.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.54	7.7	[illegible]	14	[illegible]	54
Manana [illegible]	186	[illegible]	[illegible]	13.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.0	[illegible]	[illegible]	[illegible]	7.0	[illegible]	[illegible]	59
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.20	[illegible]	[illegible]	[illegible]	[illegible]	32	63
[illegible]hi [illegible]	199	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.95	[illegible]	[illegible]	[illegible]	26	58
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[1] l loam, [illegible] sandy loam, [illegible] silt loam, c clay, sic silty clay, sicl silty clay loam, cl clay loam, [illegible] very fine.

GPO 967187

An Analysis Technique for Testing Log Grades

Carl A. Newport and William G. O'Regan

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Pacific Southwest Forest and Range
Experiment Station - Berkeley, California
Forest Service - U. S. Department of Agriculture

Contents

The Authors

Carl A. Newport is chief, division of forest economics research, Pacific Northwest Forest and Range Experiment Station, Portland, Ore. The work reported in this paper was done while Dr. Newport was a member of the staff of the Pacific Southwest Station.

William G. O'Regan has been mathematical statistician of the Pacific Southwest Station since 1957. He earned both his B.S. (in 1949) and Ph.D. (in 1962) degrees at the University of California, Berkeley. He studied at the London School of Economics under a Fulbright grant, 1951-52, and was a postdoctoral fellow at Harvard University, 1962-63.

Vorkable log grading systems are needed as aids o marketing timber and other phases of forest nanagement. How can one system be evaluated and ompared with other systems? The question of com- arisons arose soon after the Western Pine Section f the Forest Service's National Log Grade Project vas established in 1958.

The analytical technique described in this report[1] vas developed as an objective, statistically sound nethod of evaluating log-grading systems. It has een used as the major analytical procedure in eveloping an advanced system for grading pon- erosa pine (*Pinus ponderosa* Dougl.) and sugar ine (*Pinus lambertiana* Dougl.) saw logs in trees Gaines 1962). Computations were done first on an BM 701 computer and later reprogrammed and ompleted on an IBM 704 computer. These operations demonstrated the usefulness of the technique and confirmed some anticipated limitations.

The Western Pine Log Grade Project later began developing other procedures for evaluating log grading systems. It appears that the technique described in this report will in time be superseded by other methods that have the advantages of greater flexibility, broader application, and easier interpretation.

This report is published to make available the full description of a technique that has proved useful in a major log grade development project.[2] It briefly explains the technique, includes an example of its application, and provides details of the statistical analysis. Log grade researchers possibly may wish to use the technique, at least to compare with alternative methods.

Objectives of Log Grade Testing

log grading system is a set of specifications used segregate a given lot of logs into two or more rades. The specifications are drawn up in many ays, but generally include limitations of knot size, not character, clear surface area, and other out- ard log characteristics. These characteristics are ifficult to define and combine in numerical expres- on. Consequently, most log grading systems are eveloped from a more or less arbitrary selection of pecifications for the grades within the system. In a w instances, a correlation analysis is used to isolate e significant characteristics controlling quality.

Regardless of the manner of selecting the grade pecifications—arbitrary or by correlation analysis— ey need testing to determine the effectiveness of ratification. Therefore, in any analysis of log grade testing, we must answer four questions:

1. Does the grading system separate the logs into grades that are distinctly different in average value of end products?
2. Is the variability around the average value for each log grade reasonably small?
3. If the differences in value are not significant, can it be shown that the end-product grade yields are significantly different?
4. If segregation of value is satisfactory, does the system predict gross value within reasonable limits of error?

A log grading system is satisfactory if the answers to the first three questions are "yes." The last question requires the application of the proposed

[1] he authors gratefully acknowledge the assistance of Edward M. aines in updating and revising this report.

[2] Brief summaries of the technique are given and Gaines (1962).

system to a sample of logs drawn from the same population as the logs used to develop and test the specifications. The performance of each log grade in a proposed system may vary with factors other than the grade, such as sawing method and equipment and local market conditions. This question of performance calculations for log grade systems and their accuracy in application is not investigated here. We shall only say that a grading system that stratifies logs into value groups, as determined by the tests proposed in this paper, will give better prediction of value than no log grading system at all. And the system doing the best job c stratification by the following tests will do the bes job of prediction.

The first three questions above are the concern c this analysis method. They have purposely bee stated in a way which permits the use of statistica methods in deciding upon an answer. Statistics ca not provide the exact answer, but they can provid strong evidence in support of the answers. An statistics must be used with knowledge of their limita tions when applied to the kind of data available fc log grade testing.

Necessary Data

The data needed in log grade testing come from end-product recovery studies. The end products may be lumber, veneer, ties, or other products or combinations of products. Generally each end-product use class is divided into quality groups which are called log grades. For example, logs suitable for lumber may be classed as lumber logs ("saw logs"), and a log grading system can be used to divide the lumber use class into quality groups. A lumber grade recovery study is needed to test a lumber-log grading system.

Each log is graded by the system or systems be tested. The lumber grade recovery is record for each log as it is sawed. Prices, either current average, for each lumber grade are applied to t recovery data to obtain the value of each log. Th of course, is an oversimplification of the data coll tion job, but illustrates that the data must give t grade, volume, and value of each study log to used in testing.

Testing Procedure

A test of any log grading system can be made by determining the answers to the first three key questions mentioned above. Briefly, the procedure we followed was to:

1. Determine the total lumber recovery and total value recovery for each log from a random sample of the complete range of logs for each log grade. Note that unit value is not used.
2. Convert these volumes and values to logarithms.
3. Compute regressions for each log grade of the form $y = a + bx + cx^2$ in which y = logarithm of value and x = logarithm of volume.
4. Test the quadratic term of this regression to determine its significance.
5. Test the regressions in their appropriate quadratic or linear form for significant differences between log grades.
6. Compute the variability around each regression that is different from every other and check this against a standard. In the example in this pap we used 7 percent as a standard. We later fou that maximum acceptable variability depends u on the number of log grades and the range fr lowest to highest lumber-grade price. We the fore modified the concept of a standard to th given in step 9.
7. Test for differences in the yields of key luml grades when any two log grade value differen are not significant.
8. Choose the log grading system (if several being tested) which has significant difference either value or grade yields for all grades a which has lowest or nearly the lowest variabil
9. Modify the chosen system in successive steps reduce variability. Such modification requ that complete diagrams be made of the st logs before sawing. The reduction in variabil if any, can be weighed against the increa

complexity of the grade specifications after each modification. This step would be a matter of judgment. After each modification, repeat steps 3 through 6 to determine whether variability has been reduced significantly. An acceptable standard of variability becomes one that cannot be reduced by reasonable modifications of specifications.

Analysis of the White Fir Grading System

Study Data

. lumber recovery study of old-growth white fir *Abies concolor* Gord. & Glend. [Lindl.]) (Wise and Iay 1958) provided typical data for testing the pplication of this analysis technique. The data vere conveniently available on IBM punch cards Miller 1956). The tentative log grading system in ne study had been applied to the logs at the study nill before sawing began. Specifications for the log rades are found in the appendix.

The logs milled in this study (table 1) were awed by a single band headsaw, an edger, and a rimmer in a mill which has a capacity of about 5,000 board feet per 8-hour day. An attempt was nade to produce the maximum amount of the tradiionally "better" lumber grades, regardless of curent market or company considerations.

The following standard Western Pine Association nd average prices for white fir lumber were used:

umber grade	1954 net average price per M
; & Better	$149.69
) Select	135.72
Moulding & Better	115.98
Number 3 Clear	113.99
Number 1 Shop	105.08
Number 2 Shop	80.11
Number 3 Shop	61.61
Numbers 1 & 2 Common	77.72
Number 3 Common	67.24
Number 4 Common	51.97
Number 5 Common	40.16
Numbers 1 & 2 Dimension	71.31
Number 3 Dimension	56.40
Number 4 Dimension	33.31

The lumber from each log was followed through he rough-dry stage of manufacture. A sample of each rough-dry grade was surfaced to get informaion on change in grade. However, the values in his report have been computed using the surfaced-lry lumber prices and rough-dry volumes because of the difficulty of computation by individual logs. An electronic computer program has been developed to make this calculation easier (Newport and Leach 1959).

The log length distribution was:

	Percent of total number of logs
16-foot	60
14-foot	17
12-foot	21
10-foot	2
	100

More than 90 percent of the grade 1 logs and 80 percent of the grade 2 logs were 16 feet long. It was assumed that the shorter logs were cut for reasons other than to improve log quality.

Logs more than 50 percent defective in scaling were considered culls and excluded from this study.

Preliminary Calculations and Observations

We suspected a greater variability in defective log values than in sound log values. For this reason we divided each of the four log grades into sound and defective groups. From this point on we will be considering seven grades instead of four, because we found only one sound grade 1 log.

The variability in log value tends to increase as volume increases. Statistical analysis is based upon the requirement that variance be homogeneous. In this case, we do not want the variance to be a function of size or class, but we find that the variance around a regression of log value on lumber recovery volume for all sound logs tends to become greater as volume per log increases (fig. 1).

A logarithmic transformation of the dependent variable would tend to destroy the relationship between variance and average value of Y. We hoped a similar transformation on X would render the resulting relationship (between log Y and log X) linear. But a polynominal approximation approach was taken because of uncertainty about the shape of the logarithmic relationship. This approach called for the testing of at least the quadratic term in X.

Table 1.—Number of study logs, by top-diameter group, soundness, and log grade

Diameter group (inches)	Grade 1		Grade 2		Grade 3		Grade 4		Total
	Sound	Defective	Sound	Defective	Sound	Defective	Sound	Defective	
6-9	--	--	--	--	13	--	1	--	14
10-13	--	--	--	--	29	4	5	--	38
14-17	--	--	--	--	27	3	21	4	55
18-21	--	--	2	--	19	6	13	9	49
22-25	--	--	4	3	12	5	19	22	65
26-29	1	1	5	3	2	10	14	24	60
30-33	--	1	--	5	--	--	4	17	27
34-37	--	3	--	5	--	--	1	20	29
38-41	--	9	--	14	--	--	--	13	36
42-45	--	5	--	2	--	--	--	3	10
46-49	--	2	--	2	--	--	--	2	6
50-53	--	1	--	--	--	--	--	4	5
54-57	--	--	--	1	--	--	--	--	1
Totals	1	23	11	35	102	28	78	118	395

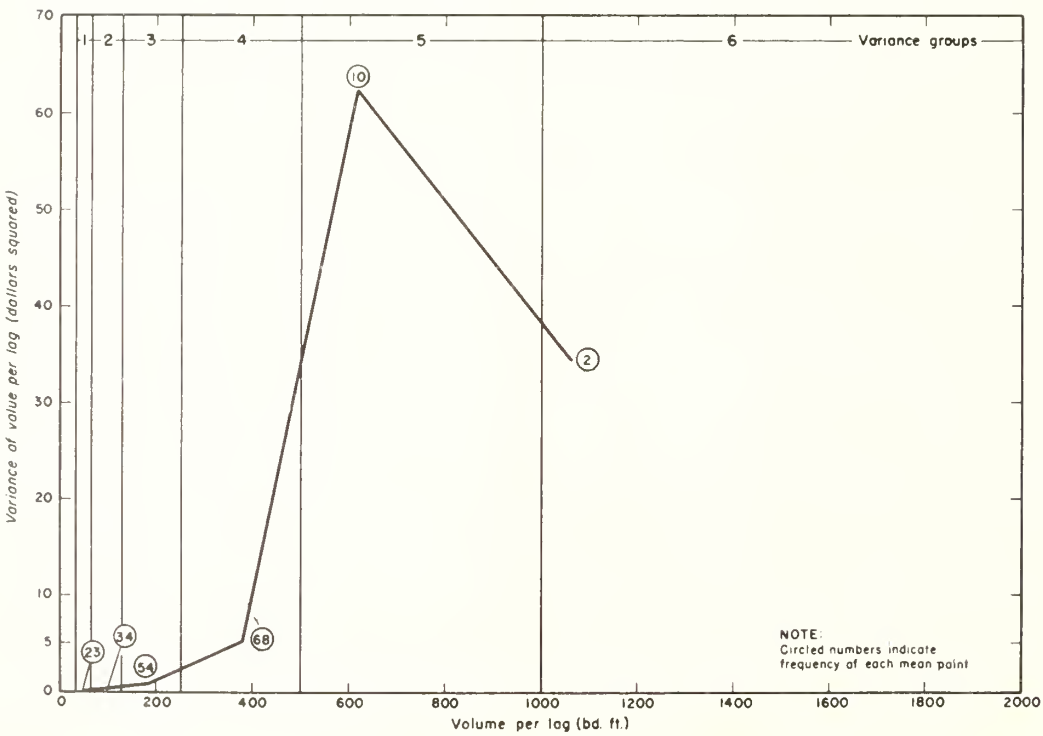

Figure 1. — Variance of value per log around a single regression for sound logs of all grades for white fir.

Results

1. Does the grading system separate the logs into grades that are distinctly different in average value of end products?

The log grade specifications were used to group the logs into four grades. In this analysis each grade was subdivided into two classes: (a) sound, if the gross scale equaled the net scale and (b) defective, if it did not. Because we found only one sound grade 1 log, our analysis was limited to seven grade-defect classes:

- 1_d —Grade 1 - defective
- 2_s —Grade 2 - sound
- 2_d —Grade 2 - defective
- 3_s —Grade 3 - sound
- 3_d —Grade 3 - defective
- 4_s —Grade 4 - sound
- 4_d —Grade 4 - defective

After the dollar value and lumber recovery volume for each log were converted to logarithms an equation of the general quadratic form: $y = a + bx + cx^2$ in which y = logarithm of log value and x = logarithm of lumber recovery was computed for each grade-defect class.

The analysis to answer the above question was carried out within this model.

Tests, by defect class, led to the conclusion that the quadratic coefficient was not different from zero. The logarithmic equations therefore reduced to the linear form: $y = a + bx$.[3]

Tests were carried out be defect class because of the evident homogeneity of variance within defect class and the equally evident heterogeneity across defect class. We found that within defect class the linear regression coefficients were significantly different from each other. We also found that for both defect classes of grade 3, unit slope of Y on X was acceptable.

In answer to our first question we concluded that white fir has seven distinctively different log grade-defect classes as previously listed.

The accepted linear logarithmic regression for each of these grades has been converted to its arithmetic form:

$$Y_{1d} = \frac{X^{1.130246}}{25.714}$$

$$Y_{2s} = \frac{X^{1.146710}}{31.982}$$

$$Y_{2d} = \frac{X^{1.206757}}{49.068}$$

$$Y_{3s} = \frac{X}{14.558}$$

$$Y_{3d} = \frac{X}{15.192}$$

$$Y_{4s} = \frac{X^{1.054615}}{20.135}$$

$$Y_{4d} = \frac{X^{1.161435}}{39.773}$$

in which Y = value per log and X = volume per log.

We are also more accustomed to thinking in terms of value per unit of volume. The above equations have been used to compute the value per thousand board feet for various volumes for each log grade (table 2).[4] This information also is shown graphically in figures 2 through 6. The individual log data are plotted on these graphs.

The differences in value per thousand board feet for a given log size not only need to be significant statistically but should also be of enough real magnitude to justify grading. The report of the National Log Grade Working Group (Newport, Lockard, and Vaughan 1958) suggests that for a given log size the value per thousand for a log grade should differ from the next lower grade value per thousand by 10 percent of the higher. The log grade values in this study are given for selected log sizes in table 2. Grades 1_d and 2_s are the only ones which meet the suggested standard. It is necessary to give further consideration to the differences between grades 2_s, 2_d, 3_s, 3_d, 4_s and 4_d. This procedure will be followed through later.

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[3] The quadratic terms were retained in the regressions used for testing and developing the Improved System for Grading Ponderosa and Sugar Pine Saw Logs (Gaines 1962). Some of the quadratic coefficients were significant, and we decided to retain the quadratic term in all regressions to ensure consistency in the subsequent covariance analyses and other comparisons that we made.

[4] It may be noted that the regressions of value on volume can be converted to regressions of value per thousand board feet by dividing both sides by $\frac{X}{1000}$. The arithmetic form reduces to $V = \frac{1000Y}{X} = \frac{X^{b-1}}{A}$ in which V is value per thousand board feet of lumber.

Table 2.—Values per thousand board feet for each log grade at selected volume of lumber recovered

Grade	Value[1] when volume of lumber recovered per log is—			
	100 bd. ft.	500 bd. ft.	1,000 bd. ft.	1,500 bd. ft.
1_d	--	$(87.37)	$ 95.60	$100.50
2_s	--	77.80	(86.20)	--
2_d	--	73.70	85.00	92.40
3_s	$68.70	68.70	(68.70)	--
3_d	65.82	65.82	(65.82)	--
4_s	63.50	69.80	72.40	--
4_d	52.50	68.60	76.70	82.00

[1] Values in parentheses are from beyond the range of the actual study data.

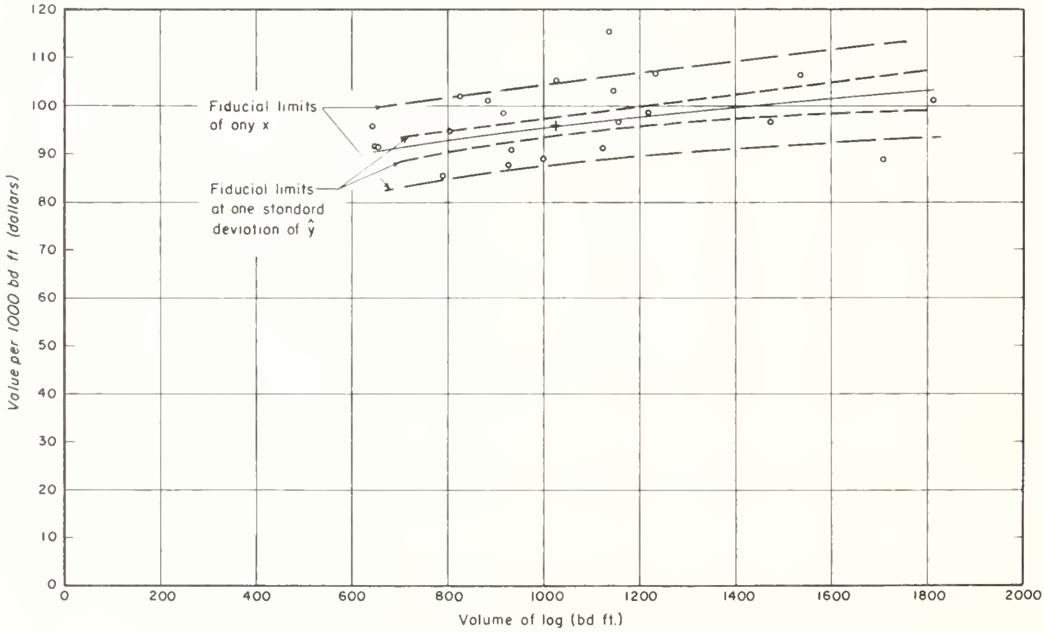

Figure 2. — Value per M board ft. for grade 1 white fir logs.

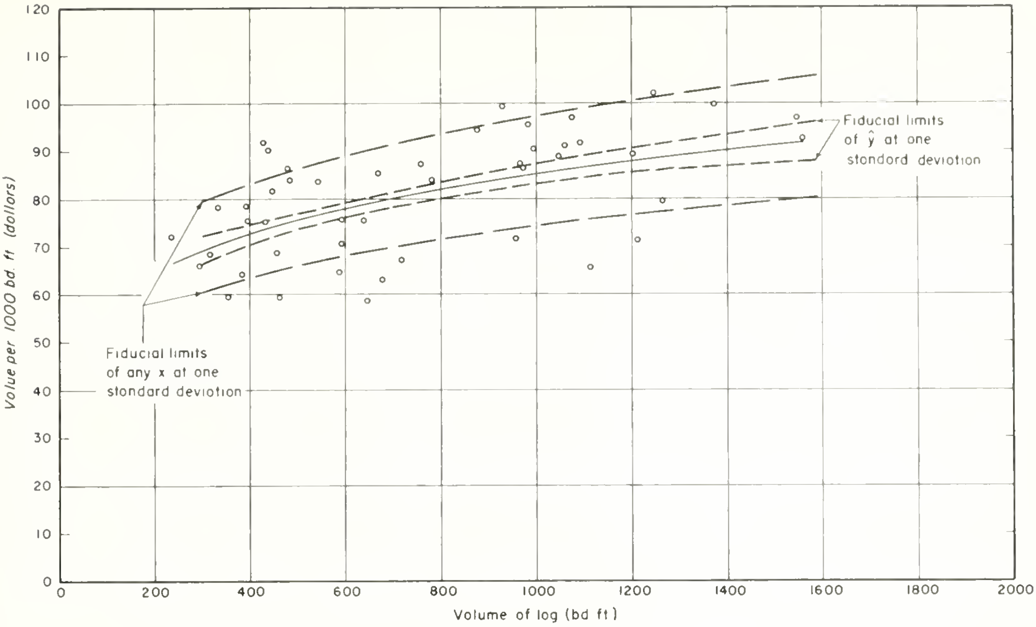

Figure 3. — Value per M board ft. for grade 2 (sound and defective combined) white fir logs.

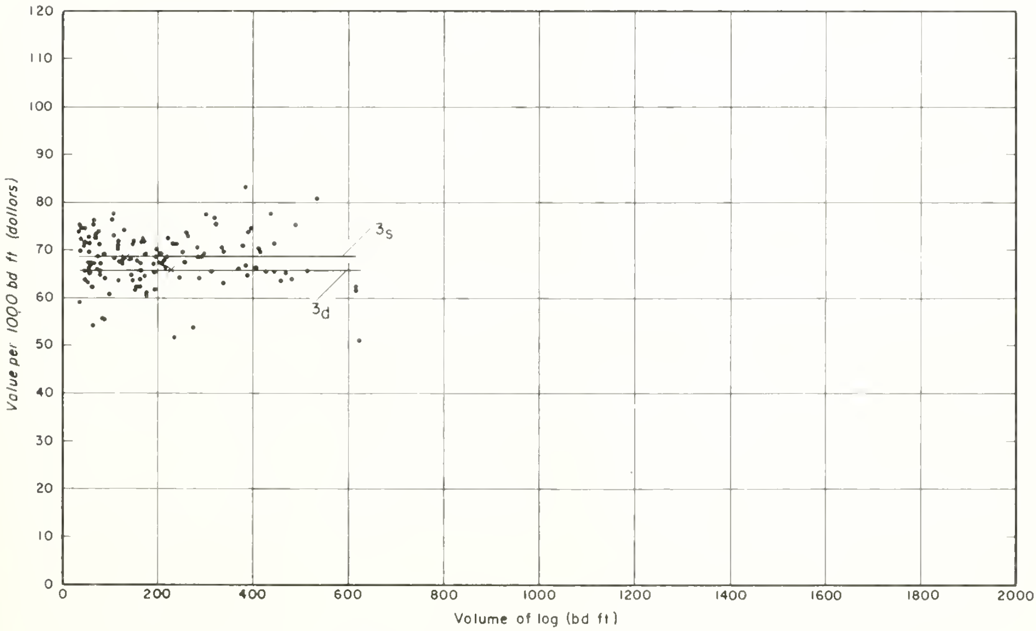

Figure 4. — Value per M for grades 3_s and 3_d white fir logs.

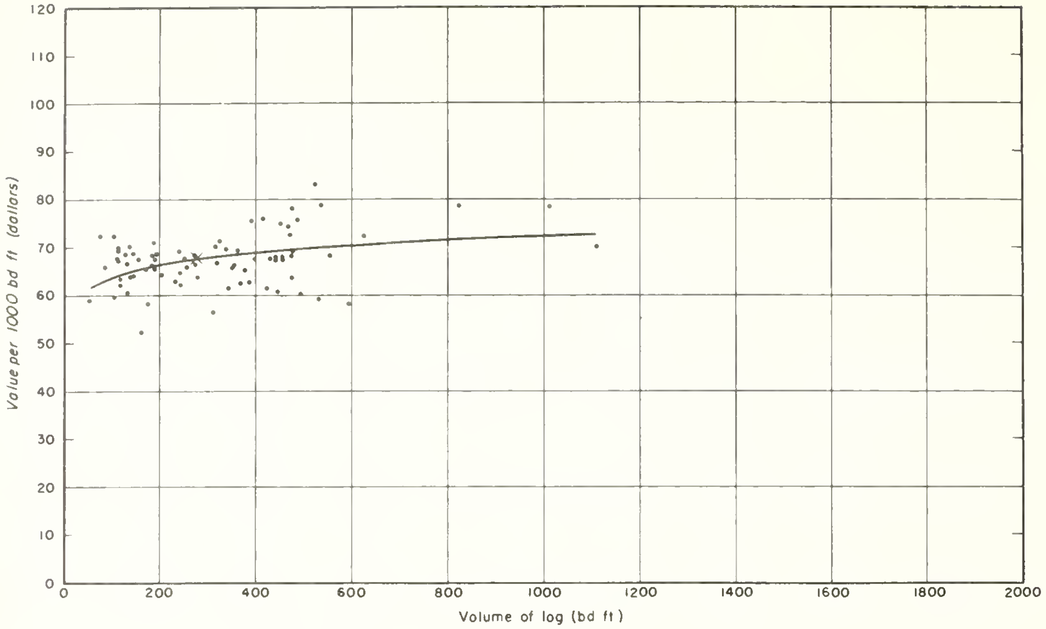

Figure 5. — Value per M for grade 4_s white fir logs.

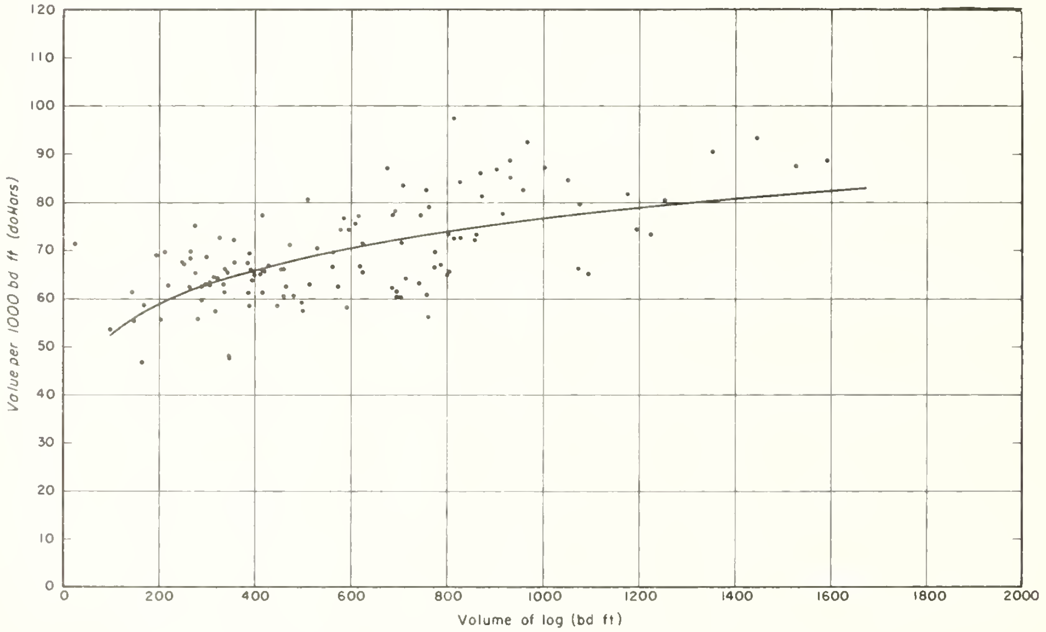

Figure 6. — Value per M for grade 4_d white fir logs.

2. Is the variability around the mean value for each log grade reasonably small?

We have already pointed out that the variability of value within a log grade tends to become greater as log size increases. But we have found that it tends to be a constant percent of the average value for all sizes within each log grade or at all levels of volume in the regression. (This tendency, in fact, is what makes the logarithmic transformation appropriate.) The square root of variance is a measure of dispersion. These are stated as a percent of regression value for each log grade:[5]

	Percent
Grade 1 — defective	8.7
Grade 2 — sound	10.0
Grade 2 — defective	15.6
Grade 3 — sound	7.6
Grade 3 — defective	11.1
Grade 4 — sound	8.6
Grade 4 — defective	12.0

A limit of 7 percent was recommended by the National Log Grade Working Group (Newport, Lockard, and Vaughn 1958). None of these variation percentages meets this standard although grade 3_s is very close.

Further investigation was made of the 7 percent variability standard. We discovered that such a standard must be accompanied by other restrictions in the analysis. An important factor in the magnitude of the percent variability is the relationship between the range and the level of the lumber grade prices used in the analysis. For example, a one hundred dollar difference from the lowest to highest lumber grade price used in an analysis will result in the same absolute variability around log grade regressions regardless of whether the lowest lumber grade price is $1 or $50. However, the percent variability would be considerably different for these two price levels. Furthermore, the percent variability is a function of the number of lumber grades and the physical relationship between them. We finally concluded that a satisfactory maximum acceptable variability cannot be set unless a rigid set of lumber prices and lumber grades is also specified. Therefore, a log grading system cannot be developed to meet a universal standard of accuracy in value estimation unless lumber grades and lumber grade prices are universally standard for all log grade analysis.

In this analysis of white fir grades we suggest that the 7 percent standard is compatible with the lumber grades and with the level and range of lumber grade prices. Obviously then, a change in lumber grades or prices might make a log grading system appear to be unsatisfactory. For this reason we recommend that our model for analysis be used with a method of measuring progressive reasonable improvement in grade specifications in terms of relative reduction in pooled variance.

Assume that reductions in pooled variance can be obtained by successive revisions of the existing log grading system which has the lowest variance. If the first major and reasonable revision reduces the variance considerably, further revisions should be tried, using generally less reasonable and/or more complex grade specifications.[6] A record of the variance after each revision should show a tendency for the pooled variance to be reduced less and less by successive revisions. A balance must then be made between specification complexity and variability. This procedure for log grade testing is valid for any lumber grades and any price range and level.

In figures 2 and 3 the fiducial limits for any x and $\hat{y}$ are shown for grade 1_d and grade 2 (sound and defective combined). The limits for x show graphically how the absolute variability increases as log size increases.

3. If the differences in value are not significant, can it be shown that the end-product grade yields are significantly different?

The value of a log is the weighted average value of the various grades of lumber it produces. Before using any set of prices in an analysis they should be examined to make certain that no two lumber prices are the same or nearly the same. Actual market prices frequently are about the same for two physically different lumber grades. For purposes of log grade analysis there is no reason why a set of market prices cannot be adjusted so that differences (say at least $5) exist between any two lumber grades. Even with this restriction two log grades

[5] The computation of these figures is as follows: The variance about the linear logarithmic regression $Y_{1d} = 1.130246X - 1.410162$ (where y = logarithm of log value and X = logarithm of log volume) is .001314. The square root of this is the logarithm .03625. The antilog of this is 1.087. A diviation of .03625 in the logarithm of the value means that the value has been multiplied (or divided) by 1.087. Therefore, we may say that one standard deviation in the logarithm corresponds to a percentage standard deviation of 8.7 percent in the value. This is the coefficient of variation.

[6] In practice, the revisions will include those which are merely different but not necessarily less reasonable or more complex.

that do not show differences in the value analysis can actually differ in lumber grade yields. But the reverse is not true. When value differences between log grades are significant there must be significant differences in lumber grade yields, even though we do not know which lumber grades differ.

The values of the lumber grades used in the analysis are shown elsewhere. Four differences between lumber grades are less than $5, but in view of the large number of grades we decided to use this set of actual average prices without adjustment.

Log grades 2_s and 2_d did not show significant difference in value per log, but the two variances are different. An inspection of the lumber grade yields indicated no differences. However, since the different variances indicate population differences, the two grades were kept.

The value analysis of grades 3_s, 3_d, 4_s, and 4_d has already shown that the values per log are significantly different. This is strong evidence that each also has different individual lumber grade yields in most size classes.

Sometimes lumber grade yields for two log grades are not as obviously different as they were in this study. If so, the following steps can be taken. Select a lumber grade whose yield in both log grades under comparison exceeds 10 percent of the total yield for most log sizes. Compute regressions of lumber tally in this lumber grade on total lumber tally for each of the two log grades. Test for significance of difference in the slopes and levels of the two regressions. The test may be repeated for other lumber grades which make up 10 percent or more or the total lumber yield. If no one lumber grade makes up 10 percent of yield, then combine two or more related grades, such as No. 1 and No. 2 shop or C and D selects.

If one or more of the lumber grades or grade combinations tested have significantly different yields, then the log grades should be considered sufficiently different. In essence, this means that some set of lumber price data other than the set used in the value analysis would give significant differences between these log grades. Since we cannot be absolutely certain as to the suitability of the price data for the value analysis, this lumber grade analysis is used to make certain that lumber grade differences do not exist when value differences do not.

Conclusions

The answers to the three questions put to the white fir data were not all "yes." We concluded that the grading system was not satisfactory, but we did obtain some favorable answers. Therefore, we suggest the following steps for improving the specifications. After revised grades are applied, the testing technique can be repeated:

1. Defect should be considered in grading logs. Even though defect cannot be "scaled out" in the application of the grades to 16-foot logs in the standing tree, every known indicator of defect should be used to grade the logs as apparently sound or defective within each log grade.
2. All statements regarding the amount of certain lumber grades that a log in a grade must produce should be omitted. This is necessary because foresters cannot be expected to apply consistently specifications that require judgment of lumber grade recovery.
3. Log diagrams should be inspected in order to find additional factors that could be used to make a better segregation of logs into value groups. Diagrams were not made of all the logs in this study. Consequently, no attempt has been made to improve the specifications to any greater extent, although that has been shown to be the logical next step.

Statistical Analysis

We have mentioned the need for a transformation of the data to improve the form of the statistical model and to make the variance homogeneous. An analysis of the interim southern pine log grades (Southern Forest Experiment Station 1953) was based upon the assumption that the variance of log value within a log grade is proportional to the log volume (lumber tally). In that analysis homogeneous variance was obtained by weighting the observations by the inverse of log volume. In an earlier suggestion for comparing log grading systems (Forest Products Laboratory 1958), it was assumed that the variance of log value varies directly as the square of the log volume. Homogeneous variance is obtained by weighting the observations by the inverse of the square of log volume.

Study of the plotted Dinuba data suggested that the standard deviation of log value at a given log volume was proportional to the expected log value at that log volume. A linear relationship between the standard deviation of a value and the expected value of a variable indicates the need for a logarithmic transformation of the variable (Kempthorne 1952; Snedecor 1956).

Transforming log value to logarithms, however, could lead to difficulties in the form of the relationship between log value and log volume. The theoretal curvilinear relationship between log value and og volume led us to hope that a logarithmic transormation of both variables might lead to homogneous variances about the regression line (or urve) and a simpler regression line (or curve). herefore, logarithmic transformation of both varables was chosen. The plotted transformed data eemed to indicate a linear relationship, but some rades showed a slight indication of curvilinearity.

General Model

he basic data were transformed from arithmetic rms so that:

$_{ijk}$ = logarithm of total value of the lumber recovered from the i^{th} log in the j^{th} log grade, k^{th} defect class.

$_{ijk}$ = logarithm of volume of lumber recovered from the i^{th} log in the j^{th} log grade, k^{th} defect class.

ith

= 1, 2, 3 . . . . n_{jk}

= 1, 2, 3 and 4 corresponding to log grades 1, 2, 3 and 4.

= 1 for logs with no scaling deductions (sound) and 2 for logs with scaling deductions (defective).

The general quadratic regression model is as follows:

$$Y_{ijk} = \mu + \lambda_1 G_{1ijk} + \lambda_2 G_{2ijk} + \lambda_3 G_{3ijk} + \lambda_4 G_{4ijk} + \delta_1 D_{1ijk} + \delta_2 D_{2ijk} + \beta_{jk} X_{ijk} + \theta_{jk} X^2_{ijk} + \epsilon_{ijk}$$

in which

Y_{ijk}, X_{ijk} are defined as before

μ = general effect

G_{1ijk} = 1 for all Y_{ijk} with j = 1, and = 0 for all other Y_{ijk}.[7]

G_{2ijk} = 1 for all Y_{ijk} with j = 2, and = 0 for all other Y_{ijk}.

G_{3ijk} = 1 for all Y_{ijk}, with j = 3, and = 0 for all other Y_{ijk}.

G_{4ijk} = 1 for all Y_{ijk} with j = 4, and = 0 for all other Y_{ijk}.

λ_j = constant effect of j^{th} grade.

D_{1ijk} = 1 for all Y_{ijk} with k = 1, and = 0 for all other Y_{ijk}.

D_{2ijk} = 1 for all Y_{ijk} with k = 2, and = 0 for all other Y_{ijk}.

[7] The sample contained no sound grade 1 logs. The necessary modification of the model is obvious.

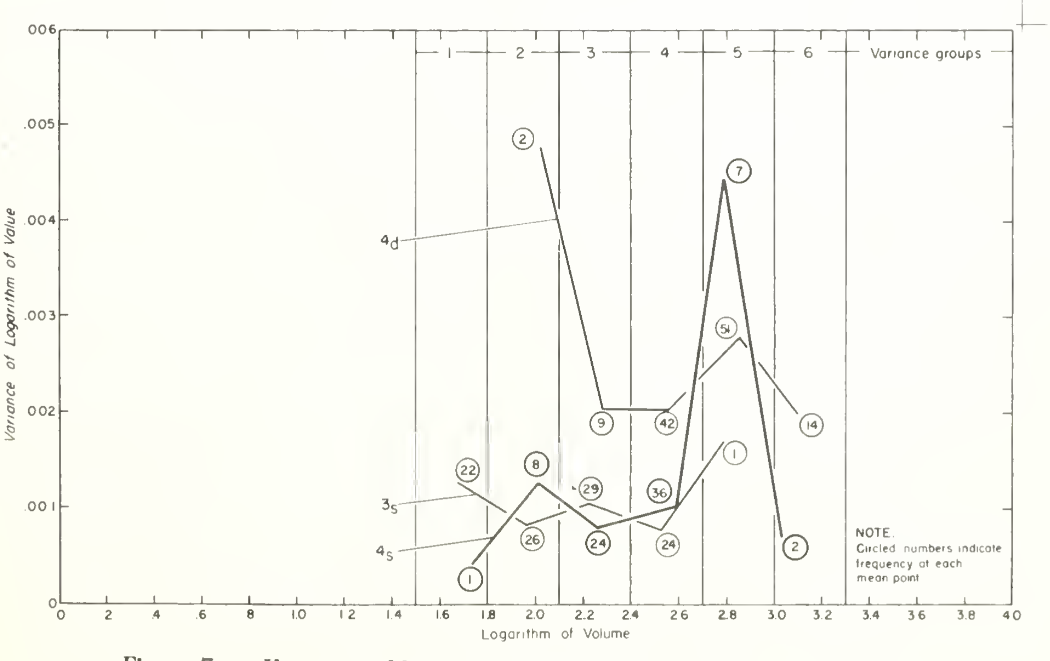

Figure 7. — Variance of logarithm of value around linear regressions for grades 3_s, 4_s, and 4_d white fir logs.

δ_k = constant effect of k^{th} defect class.[8]

β_{jk} = linear regression coefficient for j^{th} grade, k^{th} defect class.

θ_{jk} = quadratic regression coefficient for j^{th} grade, k^{th} defect class.

ϵ_{ijk} = random component.

The G_{pijk} and the D_{1ijk} are dummy variables which, along with the λ_j and δ_k, modify the μ so that each grade defect class has a potentially different intercept. The β_{jk} and θ_{jk} allow for different quadratic curves for each grade-defect class.

We make the following additional assumption: $\epsilon_{ijk} = NID\ (o, \sigma^2)$. That is, that following the transformation we have random elements that are normally and independently distributed, with mean zero and constant variance.

In general, we would like to decide whether the regression of Y on X is quadratic, linear, or nonexistent. Given the degree of the regression relationship, we would like to decide whether there is a single regression of Y on X (that is, grades and defect classes are not different at all); whether there are parallel regressions; *or whether there are separate* regressions for at least some classes.

The usual tests of these hypotheses depend, for their strict validity, upon the homogeneous variance assumption, which could break down in one or both of two cases:

1. The variance is variable within grade-defect class. That is, the dependent variable does not have constant variance about the regression curve, within class.
2. Or the variance between classes is not constant, even though it is constant within class.

Visual inspection of figure 7 leads us to believe that the logarithmic transformation apparently does "homogenize" the variance over the range of log sizes within a given grade-defect class.

Given that each grade-defect class has the variance in logarithm of log value independent of the logarithm of log volume, do the grade-defect classes have homogeneous variance? Or, for example, is the variance about the regression curve in sound logs of grade 2 the same as that for defective logs in grade 1? Bartlett's test (Snedecor 1956) indicated that over all the variance was heterogeneous (ch square = 36.25, with 6 degrees of freedom). How ever, when Bartlett's test was applied separately to the defective group and then to the nondefectiv group, nonsignificant chi squares resulted. We the conclude that within the two defect classes we hav homogeneous variance about the regression curve and between grade classes. This type of varianc will allow us to make the usual tests of regressio coefficients within defect classes. But we would als like to test hypotheses about regression coefficient within grade classes, but over defect classes. Fo instance, given that grade 2 logs in both defec classes have linear-in-logarithm regressions of lo value on log volume, are the regression lines iden tical, parallel, or intersecting? If only two variance are involved, a test of their homogeneity can b achieved by use of the F ratio. Furthermore, expe rience tells us that defective logs are more variabl than sound logs, so that we can reduce the F tes to a 1-tailed test by taking the ratio of estimate variance, defective logs, overestimated variance sound logs, and using the upper end of the F dis tribution for our region of rejection.

	Defect Class 1		Defect Class 2		
Grade	Est. var.	df	Est. var.	df	Var. ratio
2	.001729	8	.003974	32	2.298
3	.001026	99	.002177	25	2.122
4	.001257	75	.002326	115	1.850

These ratios are large enough to indicate tha tests across defect classes within grade, if made a all, must be considered as approximations. "Typi cally, the ordinary t - test, incorrectly applied $\sigma_1 \neq \sigma_2$, causes more than the expected number c rejections if Ho is true" (Snedecor 1956, p.98

We conclude that hypotheses can safely be teste within defect class, but that tests involving data fro two or more defect classes—if made at all—shoul be viewed with some reservations.

We first tested, by defect class, the hypothesis th the quadratic coefficients are all zero. This hypot esis is tested as follows:

Source of variation	df	Sum of squares	Mean square
Three individual quadratic regressions (k-1)	182	.209666	.00115
Reduction due to quadratic regressions	6	16.930394	

[8] As defined the λ's and δ's are not linearly independent. Linear restrictions

$$\sum_{j=1} n_j \lambda_j = 0$$

$$\sum_{k=1}^{2} n_k \delta_k = 0$$

suffice to remove this difficulty.

:eduction due to linear regressions	3	16.924516	
:dditional reduction due to quadratic regressions	3	.005878	.001959

$$F = \frac{.001959}{.001152} = 1.70\ N.S.$$

our individual quadratic regressions (k-2)	191	.474405	.002484
:eduction due to quadratic regressions	8	15.598224	
eduction due to linear regressions	4	15.576544	
dditional reduction due to quadratic	4	.021680	.005420

$$F = \frac{.005420}{.002484} = 2.18\ N.S.$$

The acceptance of these hypotheses is equivalent › choosing the model

$$_{jk} = \mu + \sum_{p=1}^{m_k} \lambda_p G_{pjk} + \sum_{l=1}^{2} \delta_l D_{ljk} + \beta_{jk} X_{ijk} + \epsilon_{ijk}$$

ith variables and parameters defined as before. The β_{jk} are obviously different from zero on the vidence of the preceding table. We can ask questions bout the β_{jk} (within defect class) and about the λ_p. ı fact, if we are to be guided by our conclusions ıat the variance in defect-class 2 is larger than ıat in defect-class 1, we should restate the model as ›llows:

$$Y_{ijk} = \mu_k + \sum_{p=1}^{m_k} \lambda_{pk} G_{pjk} + \beta_{jk} X_{ijk} + \epsilon_{ijk}$$

This, in effect, gives us seven separate regressions ›ne for each grade-defect class).

We have concluded that $\epsilon_{ijk} \rightarrow NID\,(0_1\sigma_k^2)$, ıat is, that variance is a function of defect class. We are at liberty then to test hypothesis within efect class, but will have some reservations about ny test which includes both defect classes.

Our first effort will be to reduce the number of arameters within defect class.

We first test the hypotheses that there is only one quation per defect class:

$$\lambda_{nk} = 0$$

$$\beta_{jk} = \beta_k$$

Source	df	Sum of squares	Mean square
Defect Class 1			
About single regression line	189	0.8854	
About three regression lines	185	0.2156	0.001159
Additional reduction due to individual regression lines	4	0.6698	0.167450

$$F_{4,185} = 144.48$$

Source	df	Sum of squares	Mean square
Defect Class 2			
About single regression line	201	0.7370	
About four regression lines	195	0.4961	0.002544
Additional reduction due to fitting individual regression lines	6	0.2409	0.040150

$$F_{6,195} = 15.79$$

The results of the tests are such that we conclude that a simple regression line will not do in either defect class.

There might be some reason to suppose that the regression of the logarithm of log value on the logarithm of log volume has a slope of unity. We test, then, by defect class this hypotheses:

$$\beta_{jk} = 1 \text{ for both k}$$

Source	df	Sum of squares	Mean square
Defect Class 1			
About parallel regression lines $\beta_{j1} = 1$	188	0.2361	
About individual regression lines	185	0.2156	0.00116
Additional reduction due to fitting individual regression lines	3	0.0206	0.00687

$$F_{3,185} = 5.92$$

Source	df	Sum of squares	Mean square
Defect Class 2			
About parallel regression lines $\beta_{j2} = 1$	199	0.7545	
About individual regression lines	195	0.4961	0.00254
Additional reduction due to fitting individual regression lines	4	0.2581	0.06453

$$F_{4,195} = 25.41$$

The magnitude of the F ratios is such that we conclude that separate, parallel regression lines of unit slope fit neither defect class very well. It might be, however, that separate parallel regressions not limited to unit slope might fit one or both sets of data. We test then

$$\beta_{jk} = \beta_k \quad \text{for both k.}$$

Source	df	Sum of squares	Mean square
Defect Class 1			
About parallel regression lines $\beta_{j1} = \beta$	187	0.2327	
About individual regression lines	185	0.2156	0.00116
Additional reduction due to fitting individual regression lines	2	0.0171	0.00855

$$F_{2,185} = 7.37$$

Source	df	Sum of squares	Mean square
Defect Class 2			
About parallel regression lines $\beta_{j2} = \beta_j$	198	0.5373	
About individual regression lines	195	0.4961	0.0025
Additional reduction due to fitting individual regression lines	3	0.0412	0.0138

$$F_{3,195} = 5.433$$

The F ratios are such that we conclude that i each defect group there are at least two grade whose regression slopes are not equal.

We have, now, selected the following form of th model:

$$Y_{ijk} = \mu_{jk} + \beta_{jk} X_{ijk} + \epsilon_{ijk}$$

$$\epsilon_{ijk} \rightarrow NID\,(0, \sigma_k^2)$$

That is, we have seven separate regression lines c logarithm of log value on logarithm of log volum with variance about the regression line constar for grades within defect classes, but different ove defect classes.

Further simple F tests, indicated that for grade : both defect classes, the slope of value on volume wa not different from unity.

The final regressions for each of the seven grad defect classes are presented in arithmetic form els where.

Summary

An analytical technique that may be used in evaluating log-grading systems is described. It provides answers to these questions:

1. Does the system separate logs into grades that are distinctly different in average value of end product?
2. Is the variation around average value for each grade reasonably small?
3. If value differences are not significant, are the end-product grade yields distinctly different?

The technique also provides means of comparing two or more grading systems, or a proposed change with the system from which it was developed, terms of the same three questions.

The total volume and computed value of lumb from each sample log are the basic data used. Fr them we computed quadratic logarithmic regressic of value on volume within each log grade. We us covariance techniques to evaluate the significance differences between log grades within a system, a between grading systems. We computed and co pared estimated values from the regressions to ev uate further the effectiveness of a system in s regating logs into distinct value groups.

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Appendix

Specifications for Log Grades

Grade 1 - Select. — Logs are at least 90 percent surface clear, and straight and generally smooth in appearance. Spiral grain does not exceed 1 in 5. Any one of the following is admitted:

1. One knot in the central zone larger than 3 inches in diameter.
2. Two scattered knots in the central zone less than 3 inches in diameter or four scattered pin knots.
3. Any number of knots of any size within a foot of one end.
4. Concentrated grouping of knots of any size or other defect or blemish affecting not more than one-fourth of the circumference for a length of 6 feet from one end (logs having fire scars covering a larger area should be graded as having been long butted).
5. A line of knots less than 3 inches in diameter for the full length of the log (one larger knot permitted) that affects a strip of the circumference not wider than three-tenths of the log diameter inside bark at the small end. A straight-grained frost crack would be permitted in an otherwise high grade log.

Grade 2 - Shop. — Logs are 50 percent surface clear in length or circumference. Also included are shop-type logs upon which the blemishes and knots are so distributed as to produce factory cuttings. On such shop-type logs, 50 percent or more of the surface should be in clear areas, at least 8 feet long, and 6 inches or more wide between knots and blemishes.

Grade 3 - High Common. — Logs are less than 50 percent surface clear, having any combination of knots or blemishes which are not permitted on the higher grades. Any number of knots not over 3 inches diameter inside bark are allowed.

Grade 4 - Low Common. — Logs do not qualify for grades 1, 2, or 3, but are considered merchantable by Forest Service regional standards.

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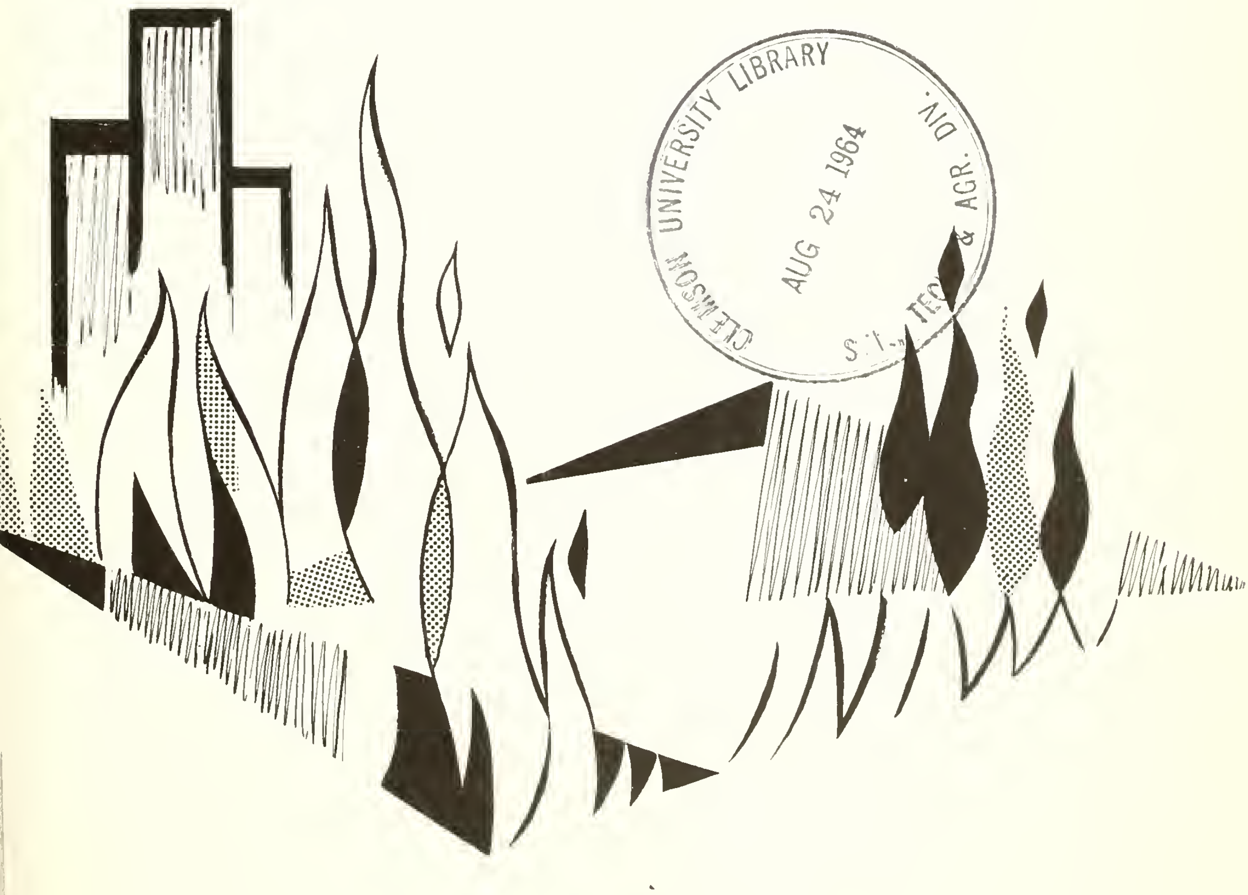
Prediction of Fire Spread Following Nuclear Explosions

Craig C. Chandler, Theodore G. Storey, and Charles D. Tangren



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Prediction of Fire Spread Following Nuclear Explosions

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Contents

The Authors

Craig C. Chandler is a fire behavior specialist with first-hand experience on more than 30 major fires. After graduating from the University of California with a B.S. degree in forestry (1951), he joined the Experiment Station in Berkeley, taught at the University of California School of Forestry (1953–1956), returned to the Forest Service, and became project leader of conflagration control research at the Pacific Southwest Station. He is the principal author of the sections on wildland fires in this report.

Theodore G. Storey has specialized in forest fire research since joining the Forest Service at Berkeley in 1949. In 1955, he transferred to the Southeastern Station, Asheville, N. C. He worked at the forest fire laboratory in Macon, Ga., for three years before returning to the Pacific Southwest Station in 1962. A forestry graduate of the University of California, he produced the sections on urban fires in this report.

Charles D. Tangren is a mathematician, and prepared the data analyses in this report. He was graduated from California State Polytechnic College in 1961 with a B.S. degree in mathematics. He began working for the Pacific Southwest Station as a research technician, and was promoted to his present position in 1962.

Experience during World War II proved that mass fires can produce casualties and physical damage equal to or greater than those caused by conventional high explosives *(16)*.[1] The atomic bombs dropped on Hiroshima and Nagasaki started fires that burned a total of more than 5 square miles in the two cities *(138, 139)*. With the development of multimegaton nuclear weapons, the area exposed to immediate ignition and subsequent burnout has been increased to between 450 and 1,200 square miles, depending largely on weapon yield and height of burst *(84)*. Furthermore, the area over which fire might ultimately spread from a single nuclear explosion has been estimated to be as great as 10,000 square miles for selected targets during selected times of year *(72)*. The problem of fire damage prediction has consequently been receiving greater attention.

The sequence of events following an incendiary attack is identical whether the incendiary devices are thermite bombs, atomic bombs, or hydrogen bombs. Numerous small fires are ignited to a greater or lesser distance around the selected target area. These small fires may or may not merge to form a single mass fire. If a mass fire forms, it may remain confined to the area initially ignited (firestorm), or it may develop a moving front (conflagration) and spread appreciably beyond the initial ignition area.

Much is known about the ignition of urban and wildland fuels following small nuclear detonations *(54)*. For weapons in the kiloton range, the distances to which fires can be expected to be ignited directly by the thermal flash are known relatively accurately *(101)*. But ignition radii become increasingly uncertain as weapon yield increases. This uncertainty arises primarily because of the questionable effect of atmospheric attenuation at distances approximating the optical visibility distance. For a 10-megaton air burst and a 15-mile visibility, the ignition radius can be variously calculated to be from 11 to 18 miles, and for a 100-megaton air burst, from 17 to 28 miles *(82)*.

The question of whether a mass fire will be produced within the area initially ignited has also been studied for both urban and wildland targets *(124)*. The formation of mass fires depends primarily upon the presence or absence of multiple ignitions in areas of high fuel concentration. This question is academic for multi-megaton weapons because susceptible locations will be found within nearly all possible target areas, and the development of several mass fires somewhere within the initial ignition area is virtually certain.

The problem of whether a mass fire from a particular nuclear attack will be of the stationary or moving variety has received only cursory attention, as has the question of how far and how fast such a fire might spread from the area of massive initial ignition. In 1957, as part of the rural fire damage assessment study, the Forest Service prepared a series of tables and maps for predicting the maximum extent of spread of mass fires occurring at various times of year in the continental United States *(129)*. This work was extended and the computational methods simplified in 1960 *(72)*.

As presently constituted, this method of assessing fire damage has two limitations: First, the predictions cover only the probable maximum final area of burnout, and the rate of burnout or the area burned at any particular time cannot be determined. Second, the mechanics of the system are incompatible with the damage assessment system currently used by civil defense planners to predict damage from blast, radiation, and fall-out. In addition, some assumptions used in developing the fire damage predictions have been questioned in recent testimony before Congressional committees *(61)*.

In 1962 the Office of Civil Defense, U.S. Department of Defense, contracted with the Forest Service, U.S. Department of Agriculture, and with United Research Services, Inc., Burlingame, California, to prepare a mathematical model of mass fire spread compatible with the damage assessment system. The Forest Service was to isolate and identify the specific parameters significant to the spread and intensity of mass fires, suggest methods of measuring and codifying these parameters, and collect specific input data to be used in testing a predictive model of fire spread. United Research Services was to develop the models to be tested. This is a terminal report covering the activities and results of the Forest Service part of these studies.

[1] Italic numbers in parentheses refer to Literature Cited, p. 33.

Scope and Assumptions

This study is confined solely to predicting the rate, duration, and extent of spread of mass fires from the area of initial ignitions that may occur following nuclear attack on the continental United States. The factors affecting the extent of primary and secondary ignitions from a nuclear explosion are beyond the scope of this paper. The factors governing the coalescence of small fires starting from these initial ignitions into a mass fire are of secondary importance to this study and are discussed only briefly.

Certain assumptions are implicit in our approach to the problem:

1. Small fires will occur as a consequence of a nuclear explosion.
2. Fire spread following nuclear attack will be controlled primarily by natural factors and will be relatively independent of firefighting efforts.
3. The rate of spread of mass fires following nuclear attack will be identical to the rate of spread of large area conflagrations that have occurred in the past in identical fuel, weather, and topographic situations.

The third assumption requires explanation since it has been widely asserted that the mass fires originating from nuclear explosions in the megaton range will cover hundreds of square miles, an area much greater than any fire before experienced. The argument further runs that such enormous fires will also show behavior characteristics and rates of spread never before experienced.

Admittedly, mass fires within the area initially ignited may be larger than any heretofore known. But we have reason to believe that the spread of such fires out from the area of initial ignition will be governed by the same factors, acting in the same way, that govern the spread of other large area fires. Single fires covering hundreds or even thousands of square miles have occurred many times in history. As recently as 1950, fire burned over almost 2 million acres (3,000 square miles) east of Fort Yukon, Alaska *(80)*. In 1923 an earthquake in Tokyo started at least 80 fires within a few minutes; the resulting conflagration burned out 12,000 acres of central Tokyo *(74)*. Data from such fires should be directly applicable to the problem of predicting the spread of mass fires resulting from nuclear explosions.

Theory also supports the assumption that fire behavior in mass fires resulting from nuclear attack will not differ essentially from the behavior of "normal" large-area fires. Calculations have shown that the violent indrafts so characteristic of a firestorm can penetrate only from about a quarter to a half mile into the fire area *(19)*. Inside these limits, mixing with the atmosphere comes from above rather than laterally. One of the primary characteristics of a mass fire is its ability to produce a convection column reaching thousands of feet into the atmosphere. Mass fire behavior is often controlled by characteristics of the upper atmosphere that have no influence on smaller fires without a well defined convection column. Active fires of 600 to 800 acres in heavy fuels often produce convection columns that rise 25,000 feet or higher. Since about 70 per cent of the mass of the atmosphere lies below this altitude, these fires are exposed to all the factors that are expected to affect fires, no matter how large. Thus, for fuels in the center of a mass fire a mile or so in diameter, the fire is already infinitely large and no new factors are expected to influence significantly the environment within the fire zone even were the fire ten or a hundred or even a thousand times larger.

There are numerous, documented examples of fire behavior in mass fires of this size. One example is the Stewart fire near the town of San Juan Capistrano, California, in December 1958 (fig. 1). At the time this picture was taken, the fire covered an area of slightly over 60,000 acres, or almost 100 square miles. The mass fire in the foreground scales 1.4 miles across and 0.6 miles deep, all actively burning at the same time. A second area of mass fire can be seen in the right background, 11 miles away from the nearer portion of the fire.

This situation — several mass fires scattered throughout a much larger burning area — will probably be more typical of the first 12 to 24 hours following nuclear attack than is the often postulated picture of hundreds of square miles going up in flames at once.

Within any likely ignition radius some areas will be free of kindling fuels, some areas will be shielded from thermal radiation by hills, and some areas will be protected from ignition by the screening effect of tree and brush foliage. Thus sizeable portions of the target area will not be ignited immediately. Even within the areas initially ignited, differences in fuel arrangement and ex

Figure 1.—Stewart Fire, Cleveland National Forest, California, December 17, 1958.

posure can be expected to affect the rate of fire buildup, and some areas likely will have burned out before fires in other areas have merged to form a mass fire.

Even under the most severe situation imaginable, in which hundreds of square miles of unbroken, homogenous fuels are ignited simultaneously, the period of active burning will not exceed a few hours. Once the central area has burned out, the remaining fire perimeter will spread in the same way as any other wildfire. Though there are obviously some uncertainties in predicting the rate of outward spread during the first few hours, it is unlikely that actual spread will differ from the predicted spread by more than a mile or two. Since there is at least a 4-mile uncertainty in predicting the radius of initial ignitions from weapons in the megaton range, errors in predictions of rate of spread will be well within the limits of error imposed by other components of the damage assessment model.

Determinants of Fire Behavior

Small Wildland Fires

Research into the mechanisms governing the ignition, spread, and intensity of forest fires in the United States was begun by the Army Signal Service in 1881 *(119)*. Investigations into the meteorological determinants of forest fire behavior were continued by the Weather Bureau after its establishment in 1891 and intensified with the organization of the Fire Weather Service in 1916. As early as 1915, the Forest Service began burning experimental fires under carefully measured conditions to determine the influence of various fuel, weather, and topographic factors on the rate of fire spread *(107)*. By 1939 serious attempts were being made to determine scaling laws for forest fires by burning idealized forest fuels under controlled conditions in wind tunnels *(41)*.

Considerable literature on the parameters that affect the spread of forest fires has been published, most of it listed in half a dozen bibliographies *(57, 76, 85, 122, 143)*.[2] Nearly all of it falls into one of these categories:

1. Statistical correlations between various fire characteristics and various parameters of fuels, weather, or topography.

During the past 50 years, analyses have been made correlating the occurrence and size of forest fires with every conceivable variable from sunspots *(21)* to ocean water temperatures.[3] Much of this work can be useful in determining which areas of the United States will be particularly vulnerable to fire damage following nuclear attack, and in predicting the most critical times of year for each area. But most of the results have been too gross to be useful for predicting the behavior of individual fires, and very few of the correlations have used synoptic parameters which are themselves predictable on a day-to-day basis *(102, 103)*.

2. Measurements of fire spread in model fires burned under controlled conditions.

Although modeling studies have been conducted sporadically since 1939, this work has been greatly intensified in the past few years following the establishment of forest fire laboratories in Macon, Georgia, and Missoula, Montana. Laboratory research of this type has done much to increase our understanding of the mechanics of combustion in cellulosic fuels, particularly in defining the properties of fuels that affect rate of fire spread *(7, 47)*. But as yet no scaling laws have been developed that will enable the accurate prediction of rate of spread of large area fires. In view of the extreme difficulties in modeling heterogeneous fuel mixtures and several of the important atmospheric variables, direct application of laboratory results to large-area fire behavior prediction appears several year away *(14)*.

3. Measurements of fire spread on test fires and naturally occurring fires burning under controlled conditions.

Most of the present knowledge concerning rates of spread of forest fires has come from the thousands of test fires and instrumented wildfires that have been studied since 1915. One would expect that such data would be directly applicable to the problem of predicting fire spread following nuclear

[2] Dietrich, J. H. A bibliography on fire behavior, fire danger, fire effects, and fire weather. 1952. (Unpublished master's thesis on file at Univ. Wash., Seattle.)

[3] Robinson, D.D. Relation of ocean-surface temperatures to fire hazard. 1942. (Unpublished master's thesis on file at State Univ. of New York, N. Y.)

ttack. Unfortunately, such is not the case.

Three criteria have been commonly used to ıeasure rate of spread in forest fires: (a) rate of rea growth (acres per hour); (b) rate of perim- :er increase (chains per hour); and (c) forward ıte of spread of the head, or fastest moving por- on of the fire (feet or chains per hour). Figures n area growth or perimeter increase cannot be onverted to linear radial rates of spread unless the ze and shape of the fire at the beginning and end f the selected time period are known. This prob- :m is not particularly serious for small fires when ɔread rates are measured from a point source, but ɔr larger fires over long time periods, geometry oses formidable difficulties in making realistic ɔread-rate conversions *(70)*.

Thus, although we have considerable data at ur disposal, we have little information that is di- :ctly applicable to the civil defense fire problem. Ve can use much of it indirectly, however, and ɔme of the data are useable if we bear in mind the ıistakes inherent in direct application. For exam- le, directly applying rate of forward spread to redict radial spread results automatically in over- stimating fire size, but we believe that forward ates are useful for establishing the effects of /eather, fuel, and topographic variables, and for etermining the maximum rates at which fires ould be expected to spread. To see if this would e useful to civil defense fire problems, however, /e first wanted to determine whether data from :st and small wildfires would be applicable to arger fires.

A comprehensive study on rates of spread of ıres in California was made by Abell in 1940 *(5)*. Ie analyzed data from more than 9,500 fires that ccurred between 1925 and 1937. These data show ıat the average rate of spread of fires burning in hamise and mixed chaparral (shrub vegetation ypes) in southern California was 0.13 miles per our; 10 percent of these fires spread faster than).34 miles per hour, and 5 percent spread faster ıan 0.52 miles per hour.

These data were obtained by determining the ate of spread from the time the fire was discovered o the time the fire was attacked by fire control orces, nearly always in less than 2 hours. We lecided to get similar data for larger fires that asted for some time because the fires studied by \bell were small and the time periods short. We letermined the forward rate of spread for 12-hour ɔeriods for 50 fires that burned in the same area ınd the same fuel type as the fires studied by Abell. Each fire covered more than 300 acres. We found an average spread of 0.133 miles per hour; five fires (10 percent) spread faster than 0.33 miles per hour, and two fires (4 percent) spread faster than 0.50 miles per hour. Evidently, fires in this fuel type are neither time-dependent nor size-dependent within the time and size limits of interest. Consequently, it is worthwhile to examine the factors that are known to affect the rate of spread of small forest fires.

Weather

Certain weather elements, particularly wind velocity and fuel moisture content, have been established as being the primary controls for the spread of small forest fires. Several systems of integrating the effects of these elements have been developed. The most common systems are described in various textbooks, such as that by Davis *(38)*, and the historical development of these systems has been reported.[4]

Fire Danger Rating

Schroeder *(104)* has given a particularly good account of the way in which a fire danger rating system is developed:

"The relationships between fire behavior and the factors that affect it are so complex that no system can take all of the factors, such as risk, fuels, topography, and weather, into account. Weather is the most variable and the most difficult to estimate. This system was based on weather variables and the resulting rating number called a 'burning index' so as not to imply that all factors were included. The burning index indicates the burning condition of the fuels due to weather variables.

"Since the relationship between the weather variables and fire behavior is so complex, it was necessary to make certain simplifying assumptions in order to develop a workable fire danger system.

"1. While there is an almost infinite number of dead fuel sizes, it was assumed that there were model fuels composed of only three sizes:

a. Fine fuels, whose moisture content changes quickly with changing weather conditions.

[4] Pirsko, A. R. The history, development and current use of forest fire danger meters in the United States and Canada. 1950. (Unpublished master's thesis on file at Univ. of Mich., Ann Arbor.)

b. Medium fuels, whose moisture content can be represented by the moisture content of ½-inch sticks.

c. Heavy fuels, such as logs, large limbs, and deep duff.

"2. While most natural fuels contain combinations of these fuel size classes, the fire is carried primarily in the fine fuels. Therefore, it was assumed that the rate of spread calculated for fine fuels applied to all fuel types.

"3. While the fire intensity in fine fuels certainly varies, the size of the control job is largely determined by the rate of spread. Therefore, it was assumed that for fine fuels the rate of spread is an adequate measure of the control job.

"4. Finally it was assumed that the change of fire intensity resulting from the involvement of more medium and heavy fuels in the fire is of such magnitude that it will affect the fire control job.

"With these assumptions, the development of a fire danger system based on rate of spread and intensity involved the following steps:

"1. Devising a method of estimating the moisture content of fine dead fuels.

"The moisture content of these fuels responds quickly to changing weather conditions. The relative humidity of the air gives a good indication of their equilibrium moisture content. Therefore satisfactory results could be obtained by combining relative humidity with ½-inch stick moisture content.

"2. Determining the effects of fine fuel moisture content and wind speed on the rate of fire spread and combining them into a spread factor.

"A rate of spread formula was developed from theoretical considerations. Data from previous wind tunnel fire tests were then used to obtain empirical values for some of the unknown factors in the formula. From the formula, a family of curves was obtained which represented the relationship between fuel moisture, wind speed, and rate of spread for fine fuels. The latter was changed to an index number, called the spread factor, and a table was constructed to compute it.

"3. Determining a method for estimating the moisture content of heavy fuels.

"Moisture content for medium fuels can be measured directly from ½-inch stick moisture content. Heavy fuel moisture and ½-inch stick moisture records were kept simultaneously and the relationship graphed. The resultant values were combined with precipitation records to give an estimate of heavy fuel moisture.

"4. Determining the effect of green plant material on the moisture content of the whole fuel complex.

"In grass fuels, Forest Service fine fuel moisture figures apply, with adjustments, for percentage of green versus cured content. In brush, it was found that the number of days since new growth can be used as a measure of the moisture content of new brush growth.

"5. Combining the effects of moisture contents of green material, medium fuels, and heavy fuels into intensity factors.

"The fire intensity will increase as medium and heavy fuels dry out. When these fuels are very wet, the effect is believed to be such that the fire intensity is actually less than it would be if only fine fuels were present. Therefore, the effects of the moisture content of medium and heavy fuels were combined in one table to give an intensity factor.

"6. Combining the spread factor and intensity factor into a burning index.

"The length and width of fireline were used to obtain a measure of the control job. The spread factor is the rate of perimeter increase and can be used as a measure of the length of line needed to contain a fire. The intensity factor is a measure of the width of line needed. The control job can be thought of as the number of square feet of line required, or the length of line multiplied by the width of line.

"The use of index numbers, rather than measures of the actual rate of spread, intensity, or control job allows for application to other than the model fuels originally assumed, provided that changes in the fire behavior of both natural fuels and model fuels have the same relationship to the index number."

Rates of fire spread and fire danger rating index numbers are correlated in most fire danger rating systems. Figure 2 shows the variation in rate of perimeter increase versus fire danger index for three commonly used fire danger rating systems.

Fuels

Fuel characteristics are known to be extremely important in controlling rate of spread in forest fires, but systems for integrating their effects have been largely unsuccessful.[5] Although laboratory

[5] Chandler, C. C. The classification of forest fuels. 1951. (Unpublished master's thesis on file Univ. Calif., Berkeley.)

udies have yielded much information about the nfluence of such fuel particle properties as moisıre content *(59)*, thermal absorptivity *(26)*, speific gravity *(46)*, and particle geometry *(42)*, the haracteristics of the fuel bed, rather than those f the individual particles, determine the behavior f an established fire *(145, p. 819)*. The associaon of living and dead woody materials of various izes and shapes that make up the fuel bed in a orest fire is extremely complex. Few techniques ave been developed to measure or even describe s properties. Consequently, studies on rate of pread in different fuel types have used only such ross descriptions as "grass", "brush", and "timer" to differentiate between fuels.

An additional difficulty in classifying fuels for valuating rate of spread arises from the fact that ifferences between fuels also are weather depenent. Because of the rapidity with which they abɔrb moisture, thin fuels, such as dried grass, will ot support combustion when the relative humidity ses much above 80 percent. But once fires in ırger-sized fuels in brush or forested areas are arted, they will continue to spread at significantly igher humidities. On the other hand, when humidies are low, grass fires spread significantly faster ıan brush or timber fires. Under extremely dry nd windy conditions, differences in rates of spread etween fuel types are minimized.

Nevertheless, under known weather conditions, ifferences between rates of spread of small fires in various fuel types appear consistent. Figure 3 shows the relative rates of spread of fires in various fuel types in California and in Idaho-Montana under "average bad" weather conditions. Similar comparisons have been made for typical fuel types of the Eastern and Southern United States, where the predominance of deciduous trees makes simple graphical representation more difficult *(125, 126)*.

Topography

Topography has a significant, though usually indirect, influence on the rate of spread of small fires. It controls the amount and timing of solar radiation reaching the surface of a particular area and thus profoundly affects the microclimate within which a fire will burn *(45)*. Microclimate also influences the species of plants that will grow on a particular site, and thus topography may exert an indirect control on fuel type. This influence of altitude and aspect on fire behavior has been studied exhaustively *(40, 60)*.

Slope has a direct effect on the rate of spread of small fires. For a fire climbing up slope, the rate of forward spread will approximately double for each 15-degree increase in slope *(131)*. For a fire moving down a steep slope, the relationship is not so simple. A fire will move more slowly downslope than on the level unless burning fuels, such as pine cones or logs, roll downslope ahead of the main flame front.

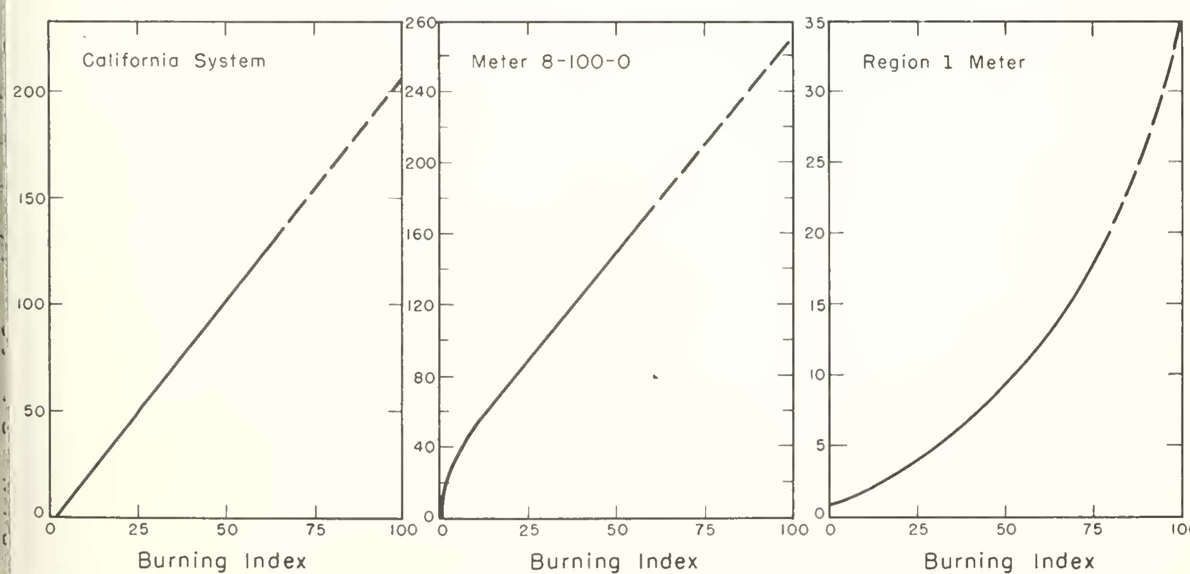

Figure 2.—Relative rate of fire spread, by burning index (all fuel types combined).

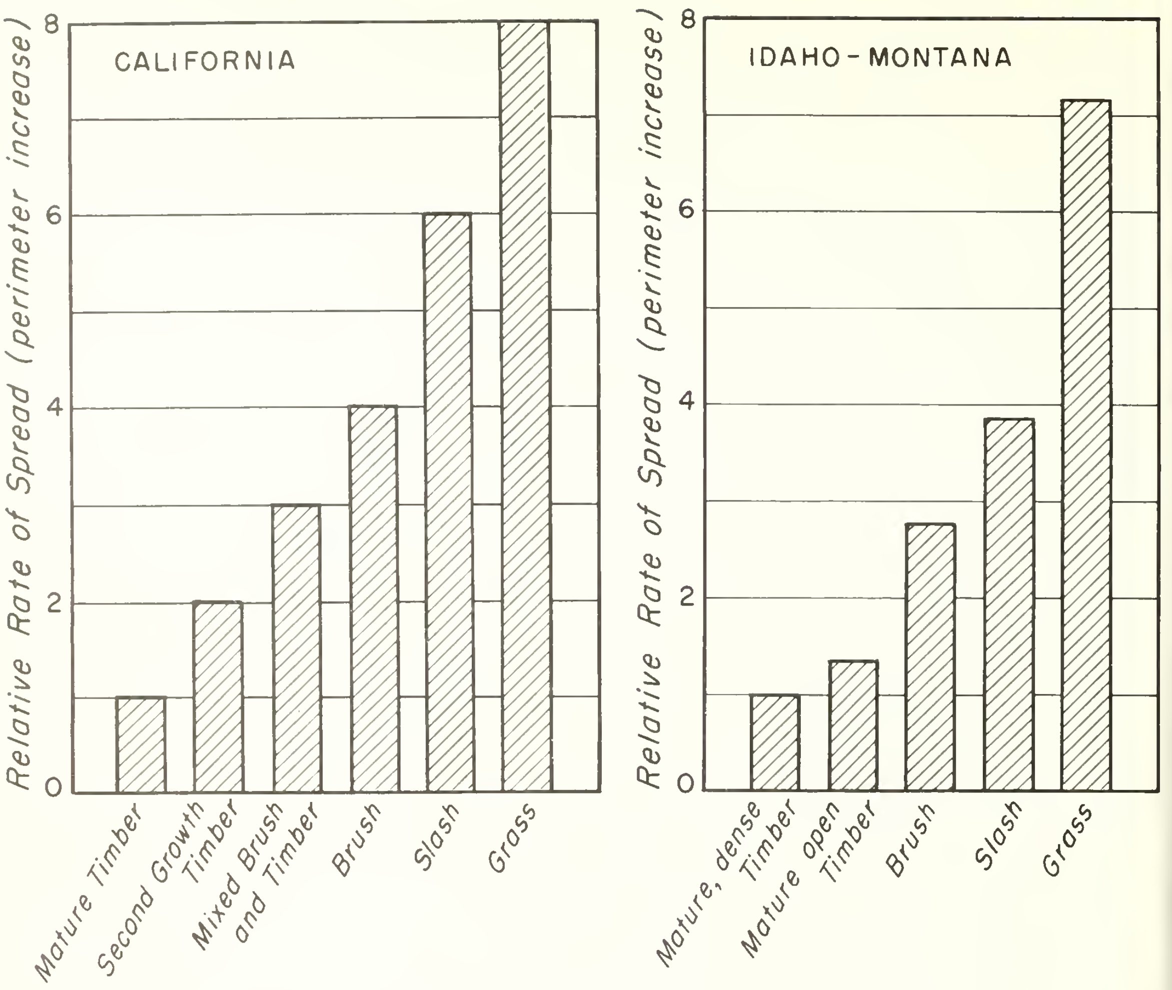

Figure 3.—Relative rate of fire spread, by fuel types.

Small Urban Fires

Research in urban fire behavior was begun by Suzuki in Japan in 1928 *(109)*. He studied the effect of weather factors on the occurrence of fires, spread of fires, and the rate of burning of hygroscopic incense sticks. Others also analyzed case histories of fires to determine the effect of weather factors *(111)*. This work was discontinued during World War II. After the war, some fire-modeling of convection *(148)* and flame shape *(94)* were started. The emphasis in Japan today, however, is still on the study of actual conflagrations for probable occurrence and spread in relation to the weather *(74)*.[6] Such studies are numerous *(6, 53, 58, 62, 65, 68, 73, 147, 149)*.

[6] Personal correspondence with Dr. Saburo Horiuchi, Fire Research Institute of Japan, Tokyo, April 25, 1963.

Urban fire behavior research in the United States probably began with the work of the National Fire Protection Association. This organization, founded in 1896 *(37)*, publishes tabulations of those weather and fuel factors which contribute to conflagrations *(37, 90, 91)*. These tabulations are based on case histories of hundreds of fires studied by the Association itself *(83, 88, 89, 90, 92)*, the National Board of Fire Underwriters *(99)* other organizations of underwriters *(30, 108)*, interested laymen *(8, 31, 49, 86)*, and the Weather Bureau *(35)*.

After World War II, the U.S. Strategic Bombing Survey (U.S.S.B.S.) studied the fire effects of the incendiary and nuclear attacks on Japan *(137, 138, 139)* and Germany *(136)*. These reports have been analyzed extensively for clues as to how fires might spread in any future war *(16, 17, 78, 116, 123)*. The British Mission to Japan also reported on the fire effects of the two atomic bombs in relation to possible similar fires in Britain *(1)*.

In 1950 British scientists began studying the ıread of fire from building to building *(2, 77)*. odel studies of fire spread inside buildings began ɔout 1960 with the work of Thomas *(112)*.

Since 1953 the Forest Service has done considable work on the ignitions of wildland and exrior and interior urban fuels by atomic attack *8, 100, 128)*. It has participated since 1957 in udies aimed at modeling areas of burnout after ıclear attack on wildland and urban targets *(129)*. ɔme pioneer work on a fire occurrence rating ʼstem for cities was done by Pirsko and Fons in 956 *(96)*. In 1961 Fons began fire model studies ʼ burning liquid hydrocarbons *(43)* and, later, ib fires *(48)*.

Thus, considerable literature has been published n the parameters affecting the ignition and spread f urban fires. Nearly all of these data fall, like ıose for wildland fires, into one of three cateɔries:

1. Statistical correlations between various fire haracteristics and various parameters of fuels, 'eather, topography, or location.

In Japan, several investigators have made corelation analyses of number and size of fires as ıfluenced by particular aspects of weather, fuel, r season *(58, 73, 109, 111, 147)*. Much of this 'ork has been useful in determining which areas re vulnerable to fire and in predicting the critical mes of the year for each area. But most of the esults have been too gross to be useful in predictıg the behavior of individual fires. Also, few corelations have used synoptic parameters which are ıemselves predictable from day to day. Of course, uantitative results of analyses such as these would ot necessarily be applicable in the United States.

In the United States, statistical analyses of urban res are confined almost exclusively to frequency istributions of number and size of fires by months, eason, cause, locality, or similar categories *(37, 0, 91)*. Such tabulations are satisfactory for their ıtended purpose but are of little use in predicting ate of spread. The most useful U.S. research of ıis type related frequency of building fires in elected cities to relative humidity in summer and ewpoint temperature in winter. It found no sigcant correlations with wind, rain, or snow *(96)*.

2. Measurements of fire spread of model fires urned under carefully controlled conditions.

As yet no complete urban fire spread model is eported in the literature. Some theoretical computations on behavior of fires in buildings have been eported *(113)*, and spread of fire in individual rooms *(112)* and model rooms *(114)* has been studied to a limited extent. Modeling studies of mass fires using gas jets have been made by Putnam and Speich *(98)*. Fons is now modeling fire spread in small wood cribs and determining the influence of weather and fuel *(44, 48)*. This type of laboratory research, like that for wildland fires, is still a long way from application.

3. Measurements of fire spread on test fires and naturally occurring fires burning under controlled conditions.

Only in Japan have radial rates of spread of actual city fires been related to the controlling variables of weather, fuels, and topography. The works of Hishida *(62)* and his successor, Hamada, are considered the most reliable.[7] Hishida found that wind speed was the most important factor in predicting forward rate of spread of city fires as well as spread to windward and the flanks.

Hishida also recognized the effect of synoptic weather conditions, climate, topography, and types of construction on rate of spread. Forward rate of spread in buildings of flimsy construction was computed as 40 percent greater than in buildings of ordinary construction. Hishida based an urban risk rating system on this data and proposed a tentative urban fuel classification system. Horiuchi developed a formula for estimating the capacity of the city fire department *(65)* based on Hishida's spread data.[8]

The U.S.S.B.S. reports for World War II contain no data on rate of fire spread. Some give the final fire perimeter or the limits of fire spread, but usually the ignition area is very uncertain. Fire researchers in Japan consider the data taken by their own people during the attacks and subsequent fires and the U.S.S.B.S. data so unreliable that they do not use these data in their own studies *(74)*.[9] However, the information has value to us in indicating limits to which fires in similar fuels and weather might be expected to spread.

Fire data in the U.S.S.B.S. reports for Germany are also incomplete and sometimes unreliable *(79)*.

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[7] See footnote 6.

[8] We might wonder why the Japanese are not studying urban fires and fire spread from the standpoint of defense against possible nuclear attack. The answer is that the thought of another nuclear experience is so repugnant to the public that research agencies cannot get support for such work even though it might be prudent to start such investigations. (See footnote 6.)

[9] See footnote 6.

The area ignited initially is usually poorly defined on the fire maps, although the final fire perimeter is sometimes distinct. Because the larger cities were partially burned on many successive raids, accurate fire maps were difficult to produce.

Ignition

Although one assumption of this study is that fires will be burning and will spread, a word on ignition of city fires is in order.

It is fairly well established that the number of urban fire starts depends heavily upon interior fine fuel dryness and that fuel dryness depends upon the humidity of the air in the building *(58, 96)*. Forest fire occurrence is also closely related to fine fuel dryness *(104)*, although fuels in these instances are in different forms. Pirsko *(96)* has found that in several American cities summer fine fuel moisture and fire occurrence are closely related to relative humidity, but that in the winter there is no correlation. Instead, during the winter, fine fuel moisture and fire occurrence are closely related to exterior dewpoint temperature. For these and other reasons, fire seasons in urban areas and forests do not usually coincide. There is no fire occurrence rating system for cities as there is for forests *(104)*.

According to the U.S.S.B.S. reports, the major influence of wet weather on fire raids on Japan and Germany was in reducing initial ignitions rather than impeding fire spread.

Spread

Once a fire has started, radiation and other factors determine how it spreads inside the room, from room to room, and from building to building *(106)*. From the work of Hishida *(62)*, we know that the forward rate of spread of fires in small Japanese cities of ordinary construction increases at a decreasing rate from origin to about 1 hour for all wind speeds. At wind speeds of 15 miles per hour or less, the rate of spread levels off at about 1 hour from origin. At wind speeds of about 40 miles per hour or greater, rate of spread continues to increase for more than 2 hours. Spread rate increases exponentially with increasing wind up to 55 miles per hour for all fire durations. Of course after 2 hours or longer, a fire burning under such conditions could no longer be classified as small. Rate of spread to windward and to the flanks is also known *(62)*, the former having the lowest rate of the three directions of spread. Rates of spread to windward and leeward level off after about 1 hour elapsed time from origin for all wind speeds. This result is expected because fire is less actively burning in these two directions. Hishida's results agree reasonably well with observations on both small and large urban fires in the United States.

Weather

Most investigators agree that surface wind speed is the most important weather factor influencing the spread of small urban fires *(62, 73, 111, 149)*. Once a fire in a building breaks through the roof or windows, its spread is largely wind controlled. The moisture content of the flammables in the building and the wetness or dryness of the exteriors of the building and adjacent buildings have some effect, but these are second-order determinants. Studies of the incendiary attacks on Japan during World War II *(16)* showed that precipitation had very little effect in reducing fire damage. As Nathans *(16, pp. 143-144)* put it: ". . . However, these factors (snow, rain, and generally moist conditions) did not offer the serious handicaps that had been supposed." Sanborn *(16, p. 178)* wrote: "When the weather had been damp or snowy prior to the attack, the attacks were found to be slightly less effective. When attacks were carried out during rain storms, the damage averaged 20 percent less than normal . . ."

Rain fell heavily for a week before the fire raid on Oita, Japan, and it was raining during the attack. Yet the fires spread, both from flames and from flying embers. Many other night raids on Japanese cities during wet or snowy weather caused vast spreading fires. In no case did rain, snow, or a wet target prevent the success of the bombing mission.

In the opinion of the fire chiefs of 17 large American cities interviewed during the present study, fires spreading from nuclear attack in their cities would be slowed down only slightly by wet weather or wet fuels in the absence of fire fighting. In their experience, high wind is the most important contributor to conflagrations. Wide spacing between buildings would be the most important factor in stopping fires, they suggested.

A counterpart to the fire spread index for forest fuels *(104)* that integrates the influence of wind, humidity, and other weather elements has not been developed for urban fuels.

Fuels

The characteristics that are important in determining the spread of fire in small groups of buildings are height, width, type of construction, window area, and separation from adjoining structures. In small fires, spread is by radiation, direct impingement of flames, and short distance spotting from firebrands. The fire is influenced only by surface weather phenomena. As the fire grows, flames from many burning buildings merge, a tall convection column forms, and a mass fire ensues.

Theoretical and experimental studies have been conducted in Japan to determine the flame characteristics of burning structures and ignition characteristics of exposed structures to determine safe clearances between buildings as a basis of fuel typing *(53)*. From analyses of fire raids on German cities, Bond *(16)* and U.S.S.B.S. investigators *(137)* constructed curves of probability of fire spread versus width of firebreak. Their work has not been checked experimentally.

Most of the 17 fire chiefs interviewed believe that a simple land use classification system, such as those already in use in some urban areas *(3, 4)* or that devised by Chandler and Arnold *(28)*, would indicate with reasonable accuracy the relative probability of fire spread. In general, such classifications reflect most of the factors recognized by the National Fire Protection Association as contributing to conflagrations *(37, 91)*. Important factors include flammable roofs, wind, extreme dryness, and flammable construction.

Topography

Among topographic factors, slope probably has the greatest influence on rate of spread of urban fires. Most larger cities usually lie on level areas or on gentle slopes. During the San Fancisco earthquake, the fire was observed to accelerate when it started up Russian Hill *(99)*. One account of the fire following the atomic bomb attack on Nagasaki mentions fires "sweeping up hillsides" *(139)*. In the Bel Air conflagration, fire accelerated up hillsides through residences and brush alike. We do not know if the increased spread of a forest fire moving up slope — doubling for each 15 degree increase in slope *(131)* — applies to cities. A forest fire will move more slowly downslope than along the level, and this relationship probably also applies to urban fires.

Topography controls the amount and timing of solar radiation reaching the surface of a given area, and thus exerts a significant effect on the climate near the ground within which a fire will burn. Aspect is important in determining how exposed forest fuels will burn, but it appears doubtful that it has much effect on protected urban fuels.

Large Wildland and Urban Fires

So far we have described only small fires burning for an hour or two after starting from a point source of ignition and influenced primarily by surface weather phenomena. Much less quantative information is available on the factors controlling the spread of large forest and urban fires.

As a fire increases in size and intensity, additional factors influence its rate of spread. Even the mechanism of spread may change if spotting, or the mass transfer of burning materials ahead of the main flame front, occurs.

Although we do not know enough about the factors affecting the spread of large fires to integrate their effects and thus prepare a "large-fire danger rating system," many of the factors have been studied more or less intensively. Merely understanding their qualitative effect on rate of spread can help in predicting the probable fire consequences of nuclear explosions.

Convection

Probably the most striking phenomenon of large forest and urban fires as contrasted with small ones is the increase in convective activity and development of a convection column of hot gasses, water vapor, and smoke reaching thousands of feet into the atmosphere. In fact, the extent of convective activity over a fire is a much better indicator of fire intensity than is the size or surface area of the fire itself. Figures 4, 5, 6, and 7 illustrate various types of convection columns.

Once a convection column has formed over a fire, characteristics of the upper atmosphere begin to influence the direction and speed of fire spread. Embers carried up into the column are transported by upper level winds which may differ drastically in both speed and direction from those at the surface *(144)*. In addition, the convection column itself, because of its difference in temperature and density from the surrounding air, acts as a semisolid barrier and causes mechanical turbulence in the wind field around the column. Byram *(25)* has

Figure 4.—Towering convection column typical of fires burning in an unstable atmosphere with light winds aloft. Jameson Fire, Cleveland National Forest, California, August 31, 1954.

Figure 5.—Flattened convection column typical of fires burning beneath an inversion. Haslett Fire, Sierra National Forest, California, October 15, 1961.

Figure 6.—Tilted convection column typical of fires burning in a conditionally stable atmosphere with moderate winds aloft. Los Angeles County, California, September 22, 1957.

Figure 7.—Tilted convection column typical of fires burning in a conditionally stable atmosphere with moderate winds aloft. San Francisco, California, April 20, 1906.

Figure 8.—Cumulonimbus cloud over Bussum, Netherlands, June 17, 1948. (Photo courtesy of Royal Netherlands Meteorological Institute.)

Figure 9.—Convection column of Basin Fire, Sierra National Forest, California, July 16, 1961.

eveloped a formula which shows that when

$$\frac{I}{C_p(T_o+459)} > \frac{\rho(v-r)^3}{2g}$$

ien the kinetic energy output of a fire is greater ıan the rate of flow of kinetic energy in the wind eld in a neutrally stable atmosphere. In this equaon, I is the fire intensity in BTU per foot per econd, C_p is the specific heat of air at constant ressure, T_o is the free air temperature, ρ is the ir density, v is the wind speed, r is the forward ate of spread of the fire, and g is the acceleration f gravity. Studies of large fires have shown that hen these conditions are met, rate of spread is ıdeed independent of surface wind speed. In ıeory, spread should then become dependent on inds aloft, but there are, at present, too few ıeasurements of upper winds in the immediate icinity of large forest fires to support fully this iew.

When high velocity winds occur within 1,500 eet of the surface, large fires will spread rapidly in ıe same direction as the winds *(23)*. However, ıis phenomenon can be explained by translation f momentum to the surface through turbulent ıixing in the lee of the convection column.

Evidence of effects of winds at higher levels, ıch as the jet stream effects postulated by Schaefer *102)* seems, as yet, unconvincing.

Although the convection column of a large fire oes affect fire spread mechanically, it does not ct as a chimney for the unimpeded flow of stack ases as has been popularly assumed. Convection olumns are similar to other atmospheric convecve cells, such as thunderstorms, whose dynamics re reasonably well understood *(22)*. Indeed, it is ften nearly impossible to distinguish between a re's convection column and a cumulus cloud figs. 8 and 9).

Work on air entrainment into fires by Grumer *55)* and studies of the firestorm at Hamburg by bert *(39)* both confirm that a massive convecon column is a result, not a cause, of increased onvective activity. Convection column formation epends simply upon the efficiency of the fire as heat source and upon the vertical distribution of mperature, moisture, and wind flow that deterıine all types of atmospheric convections.

Air Entrainment

Knowledge of air entrainment into fires is of vital importance for predicting whether a mass fire will be of the firestorm (stationary front with inflow from all directions) or the conflagration (moving fire front) type. Qualitatively, much can be deduced about air entrainment *(110)*. But quantitatively, results of extrapolation of convective flow from fire modeling experiments are highly dependent upon the assumptions one makes regarding the interaction of radiation and flow *(67)*. Results from test fires and wildfires have been inconsistent. Usually, light indrafts have been observed *(141)*, and wind speeds measured in the lee of the fire have been lighter than the wind speeds measured on the windward side or the flanks. This difference indicates a vectoral tendency for air entrainment from all sides of the fire. But occasionally outdrafts have been observed from both stationary *(117)* and moving *(33)* fires. These outdrafts tend most often to form on the lee side and are apparently uncorrelated with fire size or fire intensity. Strength of the outflow seems to be directly related to the free air wind speeds, but whether outdrafts will or will not occur appears to be independent of weather conditions.

Certain topographic features that produce natural wind channels also seem to produce fire outdrafts that can have a very pronounced effect on rate of spread. In one brush fire in southern California, wind speeds at ground level ahead of the fire were measured at 27 miles per hour while winds at the side and rear of the fire were 12 miles per hour or less.

Another fire, in timber, spread 10½ miles in 2 hours. Observers in front of the fire reported gale force winds blowing out of the fire, but winds measured at some distance from the fire zone never exceeded 7 miles per hour. Figure 10 pictures a wildfire in which outdrafts are evidently blowing from the head of the fire. The oak tree in the center of the picture is about 40 feet tall.

Although completely unpredictable at present, the phenomenon of increased airflow out of a fire may be a common feature of larger fires. Observations made directly in front of mass fires are understandably few, but nearly all eyewitness accounts mention high winds. Even during the fires following air raids on Leipzig and Hamburg (listed as classic firestorms), successful firefighting was possible at selected locations on the perimeter, and heavy smoke was reported outside the fire area in

Figure 10.—Nichol Fire, Cleveland National Forest, California, July 11, 1958.

some places. These circumstances indicate that hurricane indrafts could not have been uniform and continuous around the entire perimeter. Analysis of wartime fires leads to the conclusion that the stationary firestorm is virtually limited to situations of fuel and weather in which normal fire spread is impossible *(17)*. Under conditions in which ordinary fires would be expected to spread, mass fires will be of the conflagration type.

Atmospheric Stability

Atmospheric stability is the tendency of the air to resist or encourage vertical motion. It is known to be an important parameter affecting large forest fires[10] and has been postulated as critically important in firestorm formation *(39)* Under an unstable lapse rate, vertical motions are accelerated. Therefore the convection column transports more and larger pieces of burning material to higher levels. If an unstable lapse rate is combined with high wind shear, as occurs during the passage of a dry cold front, conditions are at the optimum for firebrands to be carried long distances *(24)*. Other combinations of stability and wind in the lower atmosphere are associated with particular

[10] Reifsnyder, W. E. Atmospheric stability and forest fire behavior. 1954. (Unpublished doctoral dissertation on file at Yale Univ., New Haven, Conn.)

fire behavior characteristics *(10)*. Because adequate three-dimensional maps of temperature and wind distribution are difficult to prepare, the most profitable method of developing prediction systems for these fire phenomena is by correlating them with predictable synoptic patterns *(69)*. Such an approach is being undertaken by the Forest Service and the Weather Bureau *(133)*.

Fuels

In high intensity mass fires, total weight of fuel becomes of greater relative importance than the factors of size, distribution, and arrangement that are so critical to the spread of small fires. As fire intensity increases, burning time for a particular piece of fuel decreases. Consequently, the rate of heat output per unit of fuel of a given size is greater; larger-sized fuels contribute a greater proportion of the total fire energy, and the percentage of fuel involved in active combustion at any given instant is much greater. The net result is an extremely rapid burnout and nearly total consumption of all combustible material.

Fuel classification systems based solely on fuel weight should give much more consistent results in predicting the behavior of large fires than of small ones. The urban fuel factor of "builtupness" (ratio of the area covered by buildings to total ground area) has been used as an expression of total fuel weight in cities. Although it ignores building height and construction type, this factor was mentioned by Bond *(16)* and, slightly modified, by others *(15)* as the most important factor in determining whether a firestorm can develop following nuclear attack.

Topography

Topogaphy, in its strict dictionary sense of surface configuration of "shape of the country," is undoubtedly an important factor in determining the rate of spread of large fires. Unfortunately, the subject has not yet been systematically researched, and it is difficult even to classify topographic types in a meaningful framework for fire behavior studies. There are strong indications, however, that for periods of 2 to 3 hours, rate of fire spread is greatest in mountainous or broken topography but, for periods of 12 to 24 hours, greatest on flat or gently rolling topography. The difference probably arises because mountainous country has more steep slopes which cause rapid fire spread, but also more breaks or barriers which retard spread for long periods.

Topography is particularly important in considering fire spread following nuclear attack since hills will provide shielding from thermal radiation and result in uneven ignition within the theoretical ignition radius. Fire spread in such instances will be affected by ignition pattern. The differences in behavior between the Nagasaki and Hiroshima fires have been attributed largely to shielding by the hilly country around Nagasaki *(61)*.

Requirements for Predictive Model of Fire Spread

Before attempting to specify the type of data that must be collected to predict fire spread following nuclear attack, we must know the output requirements of the proposed prediction system and the use to be made of the output information. Two general types of use and three levels of output detail have been established as having potential value for civil defense purposes *(95)*. Fire spread predictions are needed for pre-attack planning and for post-attack indirect damage assessment. For either purpose they may be needed on a national, regional, or local level.

Fo pre-attack planning, a broad base of historical records must be available for all variable factors so that plans can be made on the basis of calculated probabilities. Thus, the availability of data becomes a primary consideration in selecting parameters to be used as inputs in the predictive model.

For post-attack damage assessment, on the other hand, the greatest requirement is that accurate current information be obtainable. In either actual or simulated situations, totally new parameters can be considered — provided that the information can be collected quickly enough and at enough locations to give the desired degree of accuracy.

At a national level, the model output can give fairly gross information on fire spread and still be acceptable, if errors of prediction are unbiased. Inputs based on existing data on fuels, weather, and topography should be sufficient for adequate fire spread prediction on a national scale, either for planning or for post-attack assessment.

At a regional level, a somewhat greater degree of detail and accuracy is required for both input and output, particularly for critical areas within the region. But again, the predicted spread from any one nuclear explosion may have fairly wide limits of error, if fire spread predictions are accurate for the attack as a whole. For most regions of the United States, there is sufficient input data available for pre-attack planning. But additional comunications procedures for obtaining weather information and some extensive fuel surveys will probably be required for post-attack damage assessment.

Local use of a fire spread prediction system will require the most sophisticated modeling techniques. Input data must be very detailed, and the output must predict fire spread from an individual detonation with a high degree of accuracy. Very few areas of the country have made the intensive land-use and climatological surveys that would be required to provide input data *(120)*. In addition, it is questionable whether the current status of knowledge about fire behavior is sufficient for the construction of a useful model designed to predict the rate and extent of individual fires. For post-attack evaluation, fire behavior specialists could prepare detailed predictions based on their experience and available information by using regional fire spread predictions as guidelines. This approach has proved highly successful in predicting the behavior of large forest fires *(29)*.

Data: Availability and Needs

For any predictive model of fire spread, all input parameters can be assigned to one of three general classes: fuels, topography, or weather. Although this project collected only the data required for one specific model, we did survey the availability of other types of data within these three broad categories A generalized study of the availability of environmental data has been prepared by the U.S. Army Corps of Engineers *(118)*.

Fuels

Information on fuels, per se, is almost completely lacking except for the specialized coverage provided by the Sanborn Maps *(37, p. 617)* for certain urban areas and by the fuel-type maps prepared for selected National Forests *(66)*. Much of this coverage is badly out of date. However, when properly interpreted, data on land-use classification and vegetative distribution can be converted into broad but meaningful fuel classifications.

Several adequate sources of phytogeographic coverage are available for national use. On the broadest scale, "Major Land Uses in the United States," a map prepared by the Bureau of Agricultural Economics *(81)*, can be used to delineate cropland, arid and semiarid areas, alpine zones, and major conifer and hardwood forest types. Similar but more recent coverage is being prepared by the University of Kansas for publication in late 1963 or 1964.[11] The Atlas of American Agriculture *(121)* contains older but more detailed and larger-scaled maps of the natural vegetation.

Except for the largest cities, urban areas would show up only as small dots on even the largest phytogeographic maps of the United States *(121)*. If cities were important to civil defense only in proportion to their area in the United States, most cities could be ignored for predicting fire spread on a national scale and the broadest sort of land use classification would suffice for characterizing fuels in the large cities. However, cities are what we are most intererested in protecting. For national use, the small-scale, general land-use maps available *(64)* for most cities in the United States with 25,000 or more population, should suffice. Scales of these maps usually are larger than 1,000 feet per inch, and the map is contained on one or two page-sized sheets of paper. Usually there are 5 to 10 categories of land use. Most cities also have zoning maps; although these maps show desired or planned, rather than actual land use, they could be used with small loss in accuracy in cities lacking a land use map.

At the regional level, the soil-vegetation maps of the U. S. Department of Agriculture *(130)* and the timber type maps of the Forest Service[12] are excellent sources for fuel typing. In addition, agricultural and other special land-use maps are usually available from the appropriate department of the various states.

[11] Kuchler, A. W. Natural vegetation of the United States. (In preparation for publication, Dept. of Geography, Univ. of Kansas, Mo.)

[12] Vegetation type and forest condition maps. U. S. Forest Service, Washington, D.C.

Most cities of 25,000 population or more (of which there are about 480 in the United States) have a fairly large land-use map scaled to 1,000 feet or less per inch. These maps would provide satisfactory detail on a regional level. For heavily populated cities, such as New York, maps may be as large as 8 by 8 feet and have great detail and many use categories. Generally, however, map sizes and number of categories are very similar from city to city. Zoning maps generally are available and, though less accurate, can be used to classify fuels if land-use maps are quite dated or non-existent.

Large-scale aerial photos (that is, photos representing few feet on the ground per inch of photo) probably are not necessary for classifying fuels on a regional level. But in most cities of 25,000 population or more, prints of vertical or oblique aerial photos of the city, sometimes in color, taken by some professional or amateur photographer, can be obtained. Often they appear on large souvenir postcards. These photos can be useful for checking building characteristics, street widths, and other information as an aid to rating fuels.

To be useful on a local scale, fuel mapping must be intensive and should be repeated periodically in the rapidly changing urban complexes and newly developing suburbs. The most feasible method of type mapping in fine detail is through the use of aerial photographs (see Appendix A).

Sanborn Maps used in conjunction with vertical aerial photos probably would be the best source of data for typing or rating urban fuels on a local scale. Sanborn Maps are designed for the use of fire insurance underwriters. They show the location, physical characteristics, and use of most buildings in nearly all cities with populations of 2,000 or more. The maps of the larger cities are revised once a year. The maps are in the form of atlases, averaging four blocks per page, and available at scales of 50 feet and 100 feet per inch. Aerial photographs and photo mosaics have been made for all or part of many cities since World War II. Some urban areas, such as Metropolitan Dade County, Florida, have made enlargements of aerial photos into atlas form with one 30- by 30-inch page covering approximately a 4-city block-area.

Topography

Detailed, accurate topographic maps of most areas of the continental United States are easily obtained. The current status of both topographic mapping and aerial photography can be ascertained through the U. S. Geological Survey or through the National Atlas of the United States *(134, 135)*.

But unlike fuels, topography cannot easily be categorized into classes with both a quantitative and a universally recognized meaning. This problem is of concern to several agencies and recent work on terrain analysis by the U. S. Army *(75, 146)* may eventually result in an acceptable classification system.

In the meantime, such classifications as "broken" or "rolling" should be sufficient for fire spread models for national or regional use.

Topographic maps usually show enough features of the cities to give an idea of the land use. Unfortunately, most of them are rather old and the city features out of date. Most larger American cities are situated on relatively level land, so that topography would not be a factor in fire spread. However, some cities contain hills where topography could be a factor.

Weather

Climatological data on the important surface weather elements are available in almost embarrassing profusion. The Weather Bureau alone has more than 12,000 weather observation stations in its climatological station network *(140)*. Additional weather observations are taken regularly by the military services, by federal and state forestry agencies, by air pollution control districts, by universities, and by private industrial, agricultural, and aviation groups. Measurements of pressure, temperature, and humidity patterns in the upper air are available from 137 locations, 64 of them within the continental U. S. An additional 290 stations make routine measurements of upper air wind velocity and direction.

For national use, the 24-hour Climatic Network (consisting of 179 First Order Weather Bureau and U. S. Federal Aviation Agency stations) provides a well spaced grid of observing stations with uniform standards of observing, compiling, and reporting surface weather data. Hourly observations of precipitation, temperature, dewpoint, relative humidity, wind direction and speed, ceiling, and visibility are available either in published form or on punched cards. Upper air data are also available, both in published form and on punched cards.[13]

Additional weather coverage should be obtained for predicting fire spread at the regional level. Surface observations from military stations, FAA stations, and fire-danger rating stations operated by state or federal forestry agencies can provide an adequate data base. However, instrument exposure standards, observation times, and reporting procedures differ between agencies. The data should be standardized before being combined for use as inputs for predicting fire spread.

Existing upper air stations are adequate for regional use, except in the Western United States and mountainous regions of the East. In mountainous country, significant variations in upper air patterns have been noted over distances of 200 miles or less *(27)*. Most upper air observation stations are located near the large population centers of each region. Consequently upper air data will be more accurate for many civil defense purposes, particularly in urban areas, than might be expected from the relatively small number of stations.

For fire spread prediction on a local scale, intensive climatological surveys should be made for each area of interest. Rate and direction of fire spread for a particular fire often depend as much on local weather patterns as they do on synoptic weather features *(34)*. Accurate prediction of the behavior of an individual fire, wildland or urban, requires accurate data on these local weather patterns.

Fire Spread

Although fire spread data are the outputs, not the inputs, of the mathematical models, some independent measurements of fire spread are needed to test the models. The data presented in Appendices D and E were collected for another purpose: to determine the relationships between rate of spread and other variables. Consequently, the criteria used to select these data are probably more stringent than necessary for simply testing model output. For this and other purposes, data from several other sources are available.

For example, a fire report that includes the area of fire at specified time periods is prepared for every fire of 10 acres or larger burning on lands protected by the Forest Service *(132)*. Similar records are kept by other fire protection agencies. These records provide data on the rate of spread of small fires and the initial stages of larger fires. Data on the spread of large forest fires over longer time periods can be obtained only from the narrative fire reports that are filed in the local offices of the protection agencies concerned.

Occasionally, specific information on the rate of spread of historic forest conflagrations has been published *(11, 56, 97)*. A thorough study of the reports on early fires might be valuable in determining the upper limits of fire spread under the most unfavorable conditions.

Data on wildland fire spread may be available from other countries. Australia, Argentine, Chile, and parts of Africa have areas where the fuels, climate, and fire history are similar to those of parts of the United States. Australia is a particularly promising source of data. It has a serious forest fire problem and a long established fire control and fire research organization. Data from Australian records probably could be applied directly to American conditions.

In general, urban fires are not as well documented for rate of spread as are forest fires. Records of local fire departments usually show the time the fire started, when controlled, and the number of buildings involved, but they include no maps or other indication of the location of the fire front at specified time intervals. Urban fire reports stress cause, equipment used, and monetary damage. Very few fire departments keep their reports on punch cards, and it is therefore time consuming to summarize number of fires and fire characteristics for special studies.

The Fire Record Department of the National Fire Protection Association has a special 1-page Fire Report which it sends to the local fire chief whenever it hears that the city has had a large or unusual fire. Usually these are spreading fires. Space is provided on the form for sketching a fire map and recording weather conditions. Short case histories of most larger fires are published in the N.F.P.A. Quarterly, often with fire maps. How-

[13] Published surface weather data can be found in *Local Climatological Data and Local Climatological Data* (supplement), issued monthly for each reporting station, by U.S. Govt. Printing Office, Wash., D.C. Data contained on the surface weather cards are found in WBAN 1, hourly surface observations. See *Reference Manual 144 WBAN 1 1945*, Weather Bureau Climatological Services Div., National Weather Records Center, Asheville, N.C. Published upper air data are in *Climatological Data—National Summary*, issued monthly by U.S. Govt. Printing Office, Wash., D.C. Upper air data are kept on several card decks. See *Reference Manuals WBAN 535, 542, 544, 545, & 645*, Weather Bureau Climatological Services Div. National Weather Records Center, Asheville, N.C.

ever, only rarely do these accounts contain enough information on time and distances to compute rate of spread. They describe fuels in great detail, but usually do not include weather data. After very large conflagrations or very damaging smaller fires, either the N.F.P.A. or the National Board of Fire Underwriters, or sometimes both, will send a special team of investigators to study and prepare a detailed report on the fire. These reports are the best source of time and distance data for computing rates of spread *(9, 71, 83, 87,.99)*. Many excellent reports that contain enough information to compute rate of spread have been written by laymen and are available in libraries *(8, 53, 86)*.

Although the U.S.S.B.S. reports contain no information on rate of spread, their fire maps showing final area of burnout include data that can be useful for checking model output.

In recent years, many of the largest urban conflagrations in the Western Hemisphere have occurred in Canada *(105)*. Unfortunately, very few published reports are available on these fires.

Urban conflagrations continue to occur in the United States. Many of these could furnish valuable information on rate of spread if an effort were made to obtain these data. Urban fire reports could easily be extended or revised to require noting or mapping the fire perimeter or at least the position of the head at specified times. The N.F.P.A.'s Fire Report could be revised to make more specific requirements for times and distances for fire spread. Weather data during the fire usually is readily available at the local Weather Bureau Office—unless the office burns up as in the Great Chicago Fire and the San Francisco Earthquake Fire.

Data Collected for United Research Services

Wildland Fires

An objective of this project was to provide specific input data for one or more mathematical models of fire spread to be developed by United Research Services, Inc. U.R.S. personnel asked that we provide data on the length of time natural fuels might be expected to burn, weather conditions under which forest fires would be expected to exhibit no significant forward spread, weather conditions under which forest fires might be expected to be extinguished in the absence of effective fire-fighting action, and free rate of spread of large forest fires under known conditions of weather, fuel, and topography.

Burning Times

Burning times were determined by examining the records of experimental test fires in natural fuels where time-histories of temperature or radiation at locations adjacent to the fire were available. Although fires ranged widely in size (from plots 6 by 6 feet to plots 110 by 150 feet) and burned under varying weather conditions, all data seemed consistent in several respects. All plottings of radiation or temperature against time resembled "log normal" distributions; that is, a relatively rapid rise to peak, a slower decline to some value much below peak, but well above ambient, and a very long "tail" before reaching ambient values (fig. 11).

Accordingly, we selected, rather arbitrarily, two burning regimes:

- *Violent burning time* (representing the period of most active flaming): the period when radiation (or temperature) exceeds 50 percent of the maximum value recorded.
- *Residual burning time* (representing the period when glowing combustion is predominant, but flaming is still occurring on at least part of the area): the period after peak when radiation (or temperature) is between 50 percent and 10 percent of the maximum value.

The burning times defined above depend on both weather and fuels, and sufficient data were not available to estimate values for all weather and fuel conditions. As a result, we prepared a table for "average bad" weather conditions and five fuel types (table 1). The weather conditions were: relative humidity 15-25 percent, temperature 80-90°, and wind 5-10 miles per hour. Under drier or windier conditions, violent burning time would be approximately the same as the tabulated values and residual burning time would be shorter. Under damper conditions, all burning times would be materially longer, with a greater percentage increase in violent burning time. Table 1 values

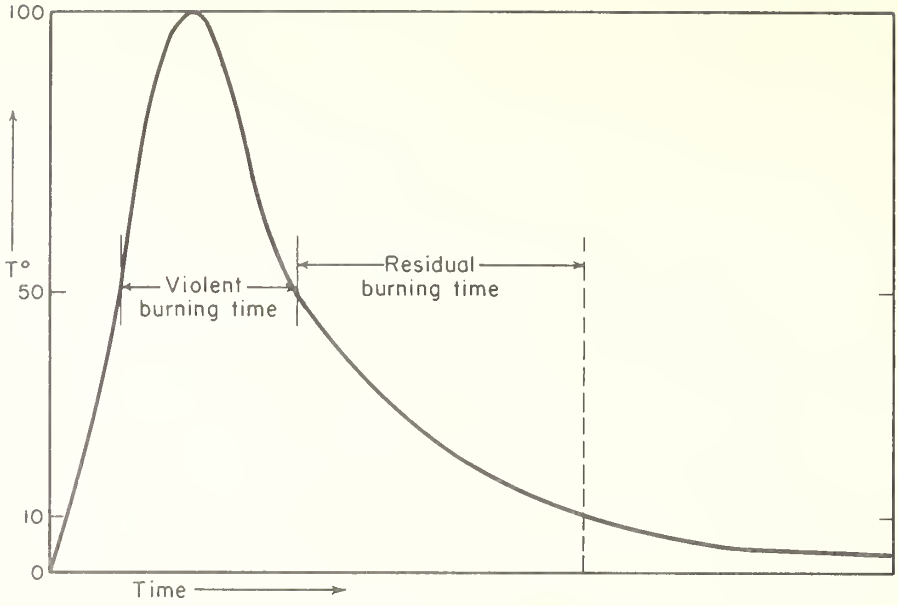

Figure 11.—Distribution of temperature in relation to burning time. T° represents percentage difference between initial temperature and maximum temperature.

were determined from the heat received at a single point adjacent to the fire area.

We were also asked to provide estimates of total burning time (the period during which a large fire might remain stationary yet be capable of resuming active spread if burning conditions changed for the worse). An accurate answer to this question would have to be given in statistical rather than in discrete terms, but such data are not available. Most fires will remain contained if their spread is completely stopped for a few hours. But occasionally a fire will resume spreading after days or weeks of dormancy. Forest fires have even been known to smolder all winter under a blanket of snow and become active the next summer when fuels dry out.

Table 1. Violent and residual burning times, by fuel type

Fuel type	Violent burning		Residual burning	
	Time	Total energy release	Time	Total energy release
	Minutes	*Percent*	*Minutes*	*Percent*
Grass	1½	>90	½	<10
Light brush (12 tons/ acre)	2	60	6	40
Medium brush (25 tons/ acre)	6	50	24	50
Heavy brush (40 tons/ acre)	10	40	70	60
Timber	24	17	157	83

Since there were no data available from which to determine the total burning time, we obtained the opinions of experienced fire control personnel in various parts of the country. The consensus was as follows:

Fuel type:	*Time*
Grass	30 minutes
Light brush	16 hours
Medium brush	36 hours
Heavy brush	72 hours
Timber	7 days

'No Spread' Criteria

To prepare a mathematical model of fire spread in which firefighting effort is assumed to be ineffective, it is necessary to provide "stopping rules," that is, the burning conditions under which fires could be expected to exhibit essentially no outward spread.

Ten of the various fire danger rating systems commonly used in the United States and Canada have as the starting point for the index number system "the weather conditions such that abandoned camp fires or debris burning fires will spread sufficiently to pose a threat requiring fire control action." When we examined the weather and fuel conditions specified for this point in each of the 10 systems, we found them remarkably consistent. Accordingly, we prepared the following list of "no spread" criteria.

Large fires in the following fuel types can be expected to show no measurable spread when the following conditions are met:

All fuels: over 1 inch of snow on the ground at the nearest weather reporting stations.

Grass: relative humidity above 80 percent.

Brush or Hardwoods: 0.1 inch of precipitation or more within the past 7 days *and*—

Wind 0-3 mph; relative humidity 60 percent or higher, or

Wind 4-10 mph; relative humidity 75 percent or higher, or

Wind 11-25 mph; relative humidity 85 percent or higher.

Conifer Timber: (a) 1 day or less since at least 0.25 inch of precipitation *and*—

Wind 0-3 mph; relative humidity 50 percent or higher, or

Wind 4-10 mph; relative humidity 75 percent or higher, or

Wind, 11-25 mph; relative humidity 85 percent or higher.

(b) Or, 2-3 days since at least 0.25 inch of precipitation *and*—

Wind 0-3 mph; relative humidity 60 percent or higher, or

Wind 4-10 mph; relative humidity 80 percent or higher, or

Wind 11-25 mph; relative humidity 90 percent or higher.

(c) Or, 4-5 days since at least 0.25 inch of precipitation *and*—

Wind 0-3 mph; relative humidity 80 percent or higher.

(d) Or, 6-7 days since at least 0.25 inch of precipitation *and*—

Wind 0-3 mph; relative humidity 90 percent or higher.

These criteria were tested against the records of 4,378 forest fires that burned for more than an hour before firefighters arrived and for which adequate spread and weather records were available. Fires were listed as "no spread" if their rate of free spread before the arrival of firefighting forces was 0.4 chains per hour (0.005 mph) or less.

Of the 134 fires that burned under conditions in which no spread would be predicted, 131—97.8 percent—did not spread. Closer examination of the three fires that did spread showed that rain had fallen at one or two but *not* at all of the three nearest weather stations. It is possible that all three failures of prediction were due to showers that wet the weather station, but not the fire area. Thus the criteria selected appear adequate for predicting the weather conditions when fires will not spread significantly.

But 2,537—59.8 percent—of the 4,244 fires that burned when the criteria predicted "will spread" did not spread at a rate of 0.005 mph or faster. Our criteria may have been too stringent, but there are other possible reasons for failure to spread as predicted:

1. Weather measurements were made at 3 p.m., the time of most severe burning conditions; 3 p.m. weather was assigned to the fires regardless of what time of day they were burning. Consequently, many fires were burning under damper and less

Figure 12.—Basic network of weather stations for which fire danger was computed daily during a 10-year period.

windy conditions than is shown by the weather records.

2. Many of the fires may have occurred in isolated patches of fuel where sustained spread was impossible.

3. Weather records were obtained from measuring stations in exposed locations that may have had drier and more windy conditions than those at the site of the fire.

An additional reason for accepting the criteria even though they appear too stringent is that the fires tested were predominantly small. Half of them covered less than 0.1 acre each. On larger fires some part of the fire will always be exposed to the sweep of the wind and the drying effect of the sun, and measurements from an exposed weather station will be more directly applicable.

In connection with another civil defense project *(133)*, daily fire danger was computed for a 10-year period for a basic network of weather stations (fig. 12).

Using data from this study, the average number of days per month when "no spread" conditions can be expected was checked for 18 selected stations (table 2). Since data on snow cover were not available, only the normally snow-free months are included.

'Fire Out' Criteria

We were also asked to decide the conditions under which fires would be extinguished without effective firefighting action. Since we could find no data on large forest fires that went out by themselves, we were forced to depend on the opinions of experienced fire personnel. The consensus was:

Grass: "No spread" conditions or measurable precipitation at the three nearest weather stations.

Brush or Hardwoods: 0.1 inch of precipitation or more at the three nearest weather stations or "no spread" conditions for three consecutive 12-hour periods.

Conifer Timber: (a) 0.5 inch of precipitation or more at the three nearest weather stations.

(b) Or 0.25 to 0.5 inch of precipitation at the three nearest weather stations and "no spead" conditions for the following two 12-hour periods.

(c) Or "no spread" conditions for eight consecutive 12-hour periods and measureable precipitation at the three nearest weather stations during any two 12-hour periods.

(d) Or "no spread" conditions for 14 consecutive 12-hour periods.

Fire Spread Data

The major time and effort on this project was spent in obtaining data on the spread of large fires burning under known conditions of fuel, topography, and weather. This was done by carefully examining 1,621 reports of forest fires 300 acres or larger in size. Spread rates were determined only if:

1. The spread was essentially "free", that is, unaffected by fire control action.

2. Free spread was maintained for 6 hours or longer. (This restriction was necessary because of a universal tendency for forest fires to spread in very rapid "runs" of relatively short duration [see figs. 13 and 14]. Rates of spread measured during such runs are not representative of spread over periods of a day or more.)

3. Linear spread rates could be determined between two known points and two known times.

4. Weather measurements were obtainable either from measurements made at the fire scene or from weather stations located sufficiently near the fire to have representative readings.

5. Fuel types were known.

6. Topographic maps of the fire area were available.

Of the 1,621 fire reports examined, 924 were rejected on the basis of the last three criteria. For

Table 2. Number of 'no spread' days at selected weather stations, by months

Station	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
orthern:												
Olympia, Wash.	--	--	24	16	15	16	9	8	15	26	28	31
Boise, Idaho	--	--	--	7	7	3	0	0	1	4	--	--
Casper, Wyoming	--	--	--	9	7	4	2	1	2	4	--	--
Minneapolis, Minn.	--	--	--	9	9	9	9	10	9	11	--	--
Grand Rapids, Mich.	--	--	--	12	10	9	9	10	8	13	--	--
Albany, N. Y.	--	--	--	13	13	11	10	11	14	15	--	--
Washington, D. C.	--	--	12	10	10	8	9	11	10	12	14	--
entral:												
Oakland, Calif.	28	20	13	10	6	3	1	2	2	6	13	22
Cedar City, Utah	--	--	8	3	3	1	1	1	1	3	7	--
Springfield, Mo.	--	--	14	10	10	10	10	7	7	10	12	17
Charleston, W. Va.	--	--	12	12	12	13	12	16	10	14	17	23
uthern:												
Los Angeles, Calif.	16	13	12	13	9	5	1	2	3	6	8	12
Roswell, N. Mexico	4	4	2	1	1	0	1	1	1	3	2	4
San Antonio, Texas	11	10	7	7	8	4	2	2	5	8	10	11
Shreveport, La.	16	13	12	10	10	8	9	7	7	8	12	14
Memphis, Tenn.	21	15	13	9	9	9	10	8	8	9	11	18
Columbia, S. C.	16	13	12	8	7	7	10	11	11	10	11	17
Tallahassee, Fla.	16	12	11	10	11	15	22	19	17	13	14	18

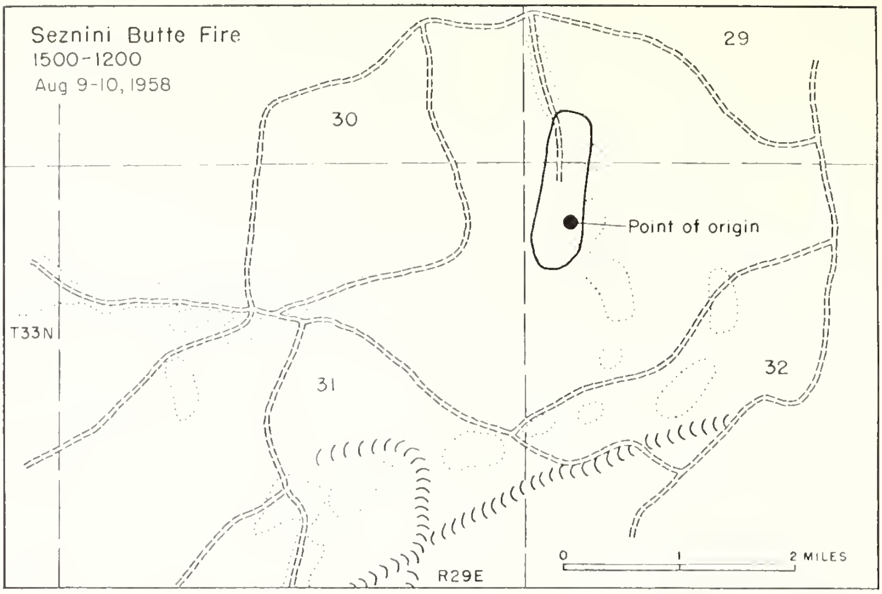

Figure 13.—Extent of fire spread in the Seznini Butte Fire, California, during the first 21 hours.

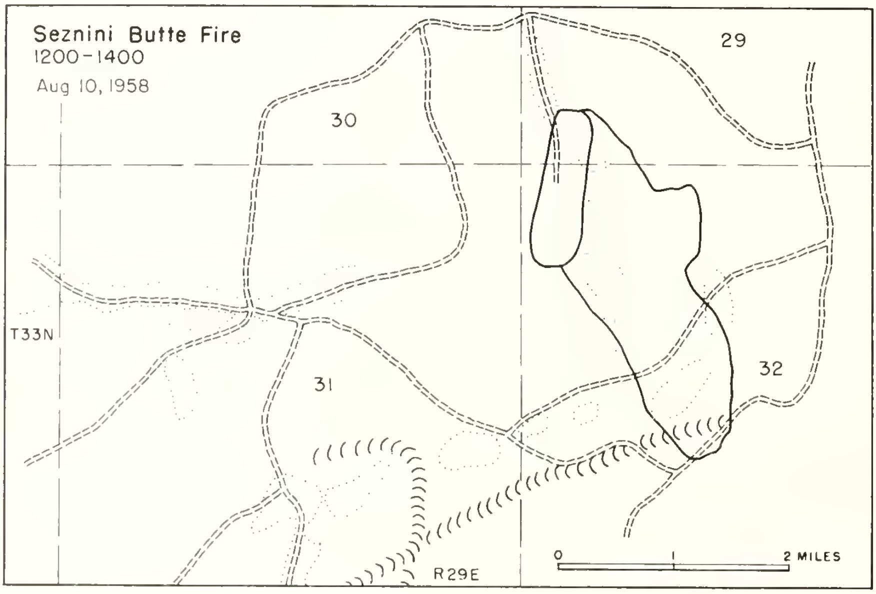

Figure 14.—Extent of fire spread in the Seznini Butte Fire, California, during the next 2 hours.

the remaining 697 fires, we obtained complete narrative reports of the fire behavior and fire control action throughout the history of the fire. A sample report is given as Appendix B. From these reports, we attempted to select areas of fire spread which met the first three criteria. In questionable cases we interviewed, personally or by mail, fire control personnel familiar with the particular fire. We ended up with 333 burning periods on 110 fires from which we were able to obtain 1,614 linear spread rates.

The fires that survived this weeding-out process are not the fastest spreading, nor the most dramatic forest fires of record. On such fires as the Tillamook, which reportedly spread 24 air line miles in one afternoon, we found it impossible to establish accurately known distances and times. In some cases, we obtained known locations and times, but could not establish the path followed by the fire in arriving at a given point. In many other cases, the period of free fire spread was too short for consideration.

But if these fires are not the fastest of record, neither are they to be considered unusually slow. The 110 fires from which data were obtained burned a total of 1,243,284 acres or 17.7 square miles per fire. Any fire that manages to maintain free spread for 6 hours or longer is probably burning under conditions that are unusually favorable for fire spread. The data included in Appendix D are probably representative of the rate of spread of large forest fires under any but the most extreme burning conditions.

Once a fire had been selected for analysis, the fire perimeter at each known time was drawn on a topographic map. The direction and rate of spread were calculated by determining the direct distance between established related points on successive fire perimeters, measuring the distance of spread, and dividing the distance by the time. A profile of the topography across which the fire spread was then drawn to scale. If the narrative report showed that the fire did not spread in a straight line between the two points, the profile was drawn along the path of the fire, but the direction and rate were still calculated from the shortest distance between the points.

Since one model under consideration by U.R.S. involved prediction of spread rates normal to the fire perimeter, perpendicular lines were also drawn from each perimeter point and the direction and distance to the intersection with the succeeding perimeter were recorded. In cases where the perpendicular line from either perimeter failed to intersect the other perimeter because of peculiarities of shape, neither perpendicular line was recorded.

For example, figure 15 shows the perimeters of two fires; one fire spread from point A to point B in a straight line, A B; the other fire changed directions, following the path A E B. The dashed lines A C and B D were drawn perpendicular to the perimeters at points A and B, respectively. For both fires, the rate of spread was calculated from the straight line A B. The topography was profiled for line A E B on the irregularly spreading fire. Since the perpendicular line B D failed to intersect the inner perimeter on the irregular fire, no perpendicular lines were recorded for this fire.

Information on the fuels along the line of fire spread was obtained either from the narrative report or from interviews with fire control personnel. A fuel type was recorded only if it occupied more than one-fourth of the line along which spread was measured.

Weather information was obtained from 3 p.m. and midnight readings whenever possible. The 3 p.m. weather readings were recorded for all spread periods occurring between 6 a.m. and 6 p.m. Midnight weather readings were recorded for spread periods between 6 p.m. and 6 a.m. Weather readings at 3 p.m. were recorded for all 24-hour spread periods. We chose 3 p.m. because this was closest to the time at which most fire-danger rating systems measure weather for fire planning purposes. It represents the period of the day when burning conditions are most severe and fire spread most rapid. Midnight was selected arbitrarily as being most representative of the night period. Often burning conditions are marginal at night, and the selection of a time closer to minimum tempera-

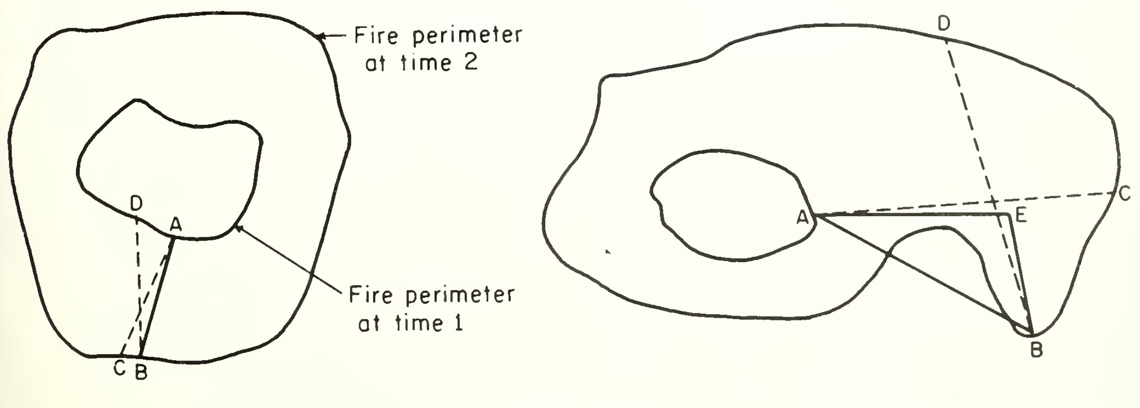

Figure 15.—Geometry of rate of spread calculations between perimeters on two typical fires.

FOREST	FIRE	SECTOR	DATE	TIME FROM	TIME TO	WIND VELOC (mph)	WIND DIRECTION	TEMP.	REL. HUM.	STICK	B. I.	FUEL CHARACTERISTIC	SPREAD AND RATE (mph) ORIGIN Az.	ORIGIN Rate	END Az.	END Rate	MEAN Az.	MEAN Rate	ACTUAL Az.	ACTUAL Rate
Plumas	Mosquito	1A	8 13 60	0200	1800	7	225	85	14	6.0	12	Oak, brush							004	.0650
(Calif)		1B	8 13 60	0200	1800	7	225	86	14	6 0	12	Oak, brush							022	.0625
		1C	8 13 60	0200	1800	7	225	88	13	6.0	12	Oak, brush							046	.0350
		2A	8 13 60	1800	0600	0		62	34	6.5	5	Mixed conifer	304	.0117	304	.0117	304	.0117	304	.0117
		2B	8 13 60	1800	0600	0		62	34	6 5	5	Mixed conifer	098	.0082	125	.0082	111	.0082	120	.0082
		3A	8 14 60	0600	1800	6	225	83	14	4.0	18	Mixed conifer	3/0	.0184	3/0	.0184	3/0	.0184	3/0	.0184
		3B	8 14 60	0600	1800	6	225	81	15	4.0	18	Mixed conifer							008	.0283
		4A	8 14 60	1800	0600	5	225	59	37	6 0	7	Mixed conifer	319	.0266	319	0266	319	.0266	319	0266
		4B	8 14 60	1800	0600	5	225	59	37	6 0	7	Mixed conifer	337	.0301	329	.0250	341	.0216	351	0285
Yosemite	Mt	2A	9 4 60	2400	2400	5	270	69	42	8 5	5	Red fir	116	0025	114	0017	115	0021	067	.0025
Nat Park	Gibson	3A	9 5 60	2400	2400	10	225	77	32	5.5	13	Brush	115	0050	116	0058	116	0054	081	.0067
(Calif)		4A	9 6 60	2400	2400	8	180	77	20	5.5	13	Red fir	121	0025	121	0025	121	.0025	121	0025
		5A	9 7 60	2400	2400	7	270	73	21	4.5	11	Red fir	123	0133	083	0142	103	.0138	073	.0150
BLM	Murphy	1B	7 3 58	0930	2000	3	338	77	28	5 5	8	Timber							097	.0420
(Alaska)	Dome	1C	7 3 58	0930	2000	3	338	77	28	5.5	8	Timber							100	.1160
		1D	7 3 58	0930	2000	3	338	78	27	5.5	8	Timber							109	.1820
		1E	7 3 58	0930	2000	3	338	79	27	5.5	8	Timber							112	.2260
		1F	7 3 58	0930	2000	3	338	79	27	5.5	8	Timber							117	.2460
Private Land	Pungo	1A	4 8 59	1100	2400	10	202	80	50	6 5	5	Brush - timber							032	.7240
(North Carolina)		2A	4 9 59	0600	1800	17	202	83	67	8 0	12	Brush - timber							015	.8600
Private Land	West Marsh-	1E	5 1 59	1230	2030	23	225	89	23	8 0	39	Jack Pine & Scrub Oak							024	.9600
(Wisconsin)	land	1F	5 1 59	1230	0900	23	225	89	23	8.0	39	Jack Pine & Scrub Oak							010	4229
BLM (Idaho)	Horse-shoe	4A	8 7 61	0000	2400	5	270	84	21	6	9	Timber	030	0125	344	0113	007	.0119	023	.0108

Figure 16.—Data as sent to United Research Services, Inc.

tures and maximum humidities might be misleading.

Weather data were obtained from one of three sources. We used weather measurements made at the fire scene when available, and provided that they were taken within 2 hours of the selected times. If weather was not measured at the fire, we used data from the nearest fire danger rating station if available. If fire danger rating stations were not in use, we obtained data from the nearest Weather Bureau reporting station.

Daytime temperatures and humidities were corrected for differences between weather station and fireline elevations by standard methods *(36)*. In nearly all cases the stations were within 1,500 ft., and corrections were minimal. No corrections were made for nighttime weather readings. The burning index as measured by the Wildland Fire Danger Rating System *(127)* was calculated and recorded.

All data and profiles were copied on a standard form as shown in figures 16 and 17 and sent to United Research Services. Appendix D gives a complete listing of all data in more simplified form.

Urban Fires

In general, less is known concerning burning times, "fire out" conditions, and rates of spread for urban fires than for wildland fires.

Burning Times

Burning times were determined by examining the records of experimental test fires in actual buildings of various sizes where time histories of radiation or temperature had been made at locations adjacent to the fire *(32, 50, 51, 52, 65, 106)*.

Although the buildings burned ranged in size from 1-room wooden bungalows to multi-story solid brick or concrete buildings with heavy fuel loading and the weather conditions under which they burned varied, all data seemed consistent in

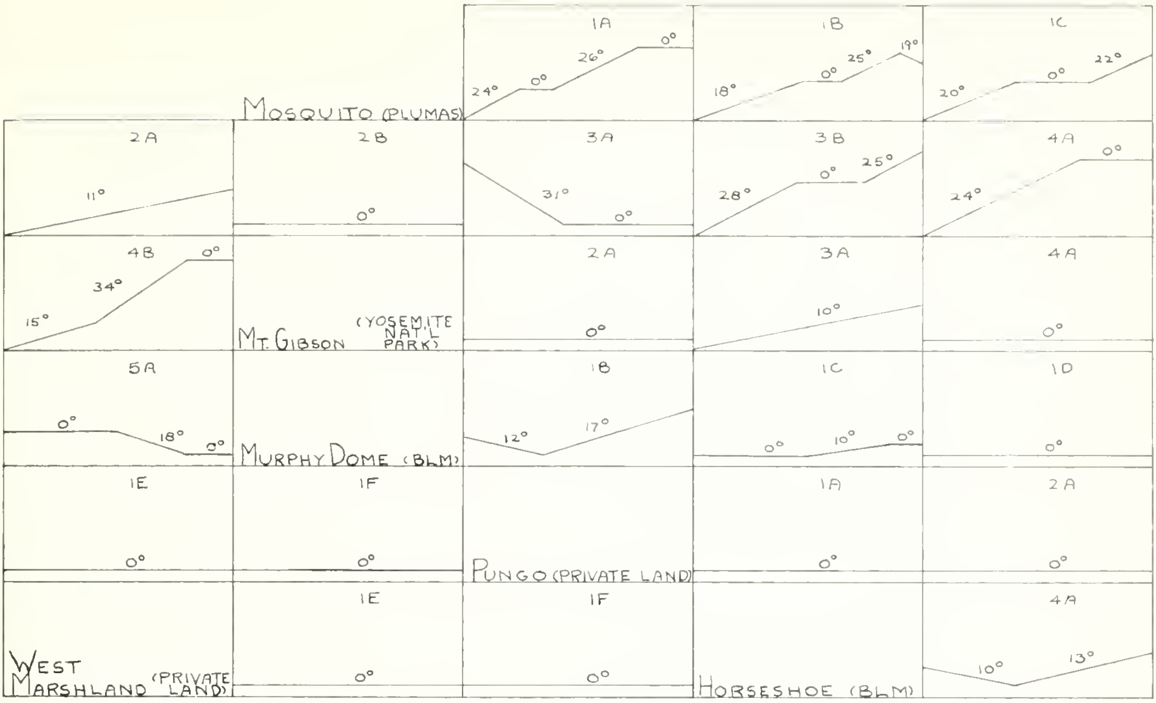

Figure 17.—Profiles as sent to United Research Services, Inc.

several respects. All plottings of radiation or temperature against time also followed a "log-normal" pattern. But the temperature-time curve was displaced to the right of the radiation-time curve for most types of building, particularly those with noncombustible exteriors. Flame, the primary thermal radiator early in a fire, peaks relatively rapidly and then decays rapidly. Most of the radiation from this source emerges through the window and door openings. Temperature, however, remains high after flaming subsides, and high temperatures may persist for long periods. Since radiation from a burning building, particularly from flames, is the principal source of ignition of adjoining buildings, the radiation-time curve was used as a basis for determining burning regimes. Two burning regimes were selected similar to those used for wildland fires:

- *Violent burning time* (representing the period of most active flaming): the period in which radiation exceeds 50 percent of the maximum value recorded. This period coincides fairly well with the "period of maximum flaming" or "second period of burning" described by

Table 3. Violent and residual burning times of urban fuels

Construction type	Violent burning: Time	Violent burning: Total energy release	Residual burning: Time	Residual burning: Total energy release
	Minutes	*Percent*	*Minutes*	*Percent*
Light residential	10	80	12	20
Heavy residential	13	70	20	30
Commercial	25	60	60	40
City center and massive manufacturing	55	30	120	70

Thomas *(114)*. This period starts at about the time of flash-over. During this period, most of the combustibles are consumed *(114)*.

- *Residual burning time* (representing the period when glowing combustion is predominant, but flaming is still occurring on at least part of the area): the period after peak when radiation is between 50 percent and 10 percent of the maximum value. In frame residences, this period often starts about the time of structural collapse.

The burning times defined above depend most heavily on fuel loading and to a small extent on weather. Since urban fuels normally are roofed and protected from the extremes of weather, such as rain, snow, and direct solar radiation, only one weather condition is recognized, that is, average weather. Four types were recognized (table 3). The weather conditions were: relative humidity—40-60 percent; temperature—70-80°; and wind—5-10 miles per hour. Under drier or more windy conditions violent burning times would be approximately the same as the tabulated values and residual burning times would be shorter. For less wind all burning times would be materially longer with a greater percentage increase in violent burning time. Accounts of the Hamburg firestorm indicate that the fire had run its course in about 3 hours. Much of the Hamburg area would be equivalent to the Centy Center and Massive Manufacturing fuel type. The largest buildings studied in the St. Lawrence Burns *(106)* were consumed in less than 2 hours.[14] These buildings were equivalent to the Commercial fuel type in the present study.

The values in table 3 were determined from the heat received at a single point adjacent to the fire area. Again, we were asked to provide estimates of total burning time (the period during which a large urban fire might remain stationary yet be capable of resuming active burning if conditions changed for the worse). Most urban fires will remain contained if their spread is completely stopped for a few hours. But occasionally a fire will resume spreading after days or weeks of dormancy. Rekindling fires were a problem for a month after the Hamburg fire of July 1943; some rekindles occurred as late as October of that year *(16)*.

Since few data were available from which to determine the total burning time, we obtained the opinions of experienced city fire department personnel in various part of the United States. The concensus was as follows:

Fuel type:	*Total burning time*
Light residential	36 hours
Heavy residential	72 hours
Commercial	7 days
City center and massive mfg.	2 months

'No Spread' Criteria

The problem of providing stopping rules for city fires is extremely complex. Because buildings are roofed, most of the fuel is effectively protected from the gross effects of the weather elements. Fire can spread even when it is raining or snowing. Many such cases have been recorded both during wartime and peacetime. A large increase in relative humidity that might exert a powerful influence on slowing or stopping a wildland fire in a light fuel type probably would have almost no effect on an urban fire. Nevertheless, fires in cities eventually do stop.

Factors that have been mentioned as affecting fire spread and, presumably, stopping are builtupness, spacing between buildings (width of fire break), type of construction, and weather changes. Of the 23 large urban fires studied for this report, 14 were eventually stopped by factors other than direct suppression action or else suppression action played only a small part. In these 14 cases, lack of fuel (low builtupness or wide spacing) was the factor most frequently mentioned as responsible for stopping spread. Change in weather, usually reduction in wind speed or change in direction, was also frequently mentioned.

The four urban fuel types—Light Residential, Heavy Residential, Commercial, and City Center and Massive Manufacturing — reflect different builtupness from low to high in the order given as well as increased amount of fuel loading. In the absence of any better data on which to base stopping criteria for urban fires, for this study the probability-of-spread curves developed by Sanborn *(16)* were suggested with modifications as shown in figure 18. These curves were drawn from a study of fire spread in Hachioji, Japan, following an incendiary attack. Experts believe that Japanese cities are representative of American cities in many respects *(123, 124)*.

The curves show that the probability of fire spreading across a given distance is greater in a fuel type with heavy fire loading (and high built-

[14] Personal correspondence with J. H. McGuire, Division of Building Research, National Research Council, Ottawa, Canada, Sept. 20, 1962.

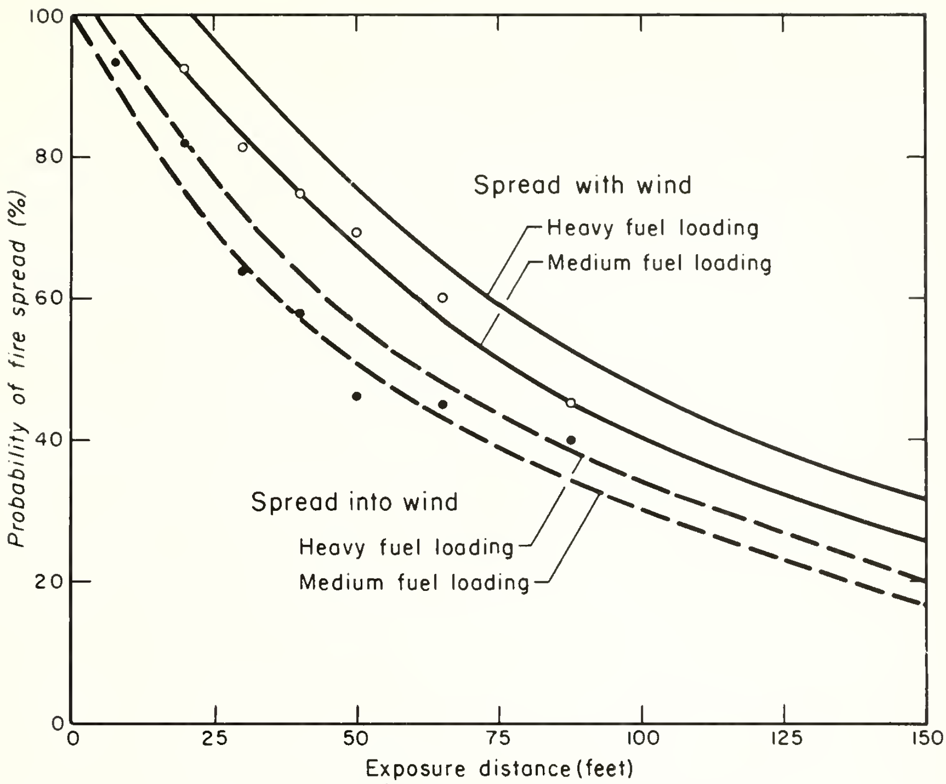

Figure 18.—Probability of urban fire spread across various exposure distances, by type and wind direction.

upness) than in a fuel with light fire loading (low builtupness). Probability of spread is less to windward than it is to leeward in any given fuel type. The curves could be extrapolated toward zero probability of spread. This would give an indication of width of break for stopping or "no spread" in the absence of very long distance spotting.

'Fire Out' Criteria

In addition to determining the fuel and weather conditions under which fires might be expected to remain stationary, we were asked to decide the conditions under which fires would be extinguished without effective firefighting action. The only data available on fires that essentially went out by themselves are the accounts of certain incendiary raids on Japan and Germany during World War II *(16, 17, 136, 137, 138, 139)*. The following "fire out" criteria are based on these data and the opinions of experienced fire chiefs.

- Light residential: 1.0 inch of precipitation at the Weather Bureau Station and "no spread" conditions for 36 consecutive hours or "no spread" conditions for 48 consecutive hours.
- Heavy Residential: 1.5 inches of precipitation at the city Weather Bureau Station and "no spread" conditions for 72 consecutive hours or "no spread" conditions for 100 consecutive hours.
- Commercial: 2.0 inches of precipitation at the city Weather Bureau Station and "no spread" conditions for 7 consecutive days or "no spread" conditions for 10 consecutive days.
- City Center or Massive Manufacturing: 2.0 inches of precipitation at the city Weather Bureau Station and "no spread" conditions for 2 consecutive months or "no spread" conditions for 3 consecutive months.

Fire Spread Data

To obtain data on the spread of large city fires burning under known conditions of fuel, topography, and weather, we examined 254 fire reports or case histories on spreading fires involving one or more city blocks. Spread rates were determined only if:

1. The spread was essentially "free," that is, unaffected by fire control action.
2. Linear spread rates could be determined between two known points and two known times.
3. Weather measurements were obtainable either from measurements made at the fire scene or from weather stations located sufficiently near the fire to have representative readings. Usually these were Weather Bureau offices located in the downtown section of the city.
4. Building (fuel) types were known.
5. Topographic maps or accurate descriptions of topography of the fire area were available.

Of the 254 case histories examined, 195 were rejected on the basis of the first three criteria. In questionable cases we interviewed, personally or by mail, fire control personnel familiar with the particular fire. Whenever possible, we tried to obtain more than one account of the same fire as a check. As many as four different accounts of a single fire were found. We ended up with 73 linear rates of spread on 23 fires.

The fires that survived this weeding out process include most of the largest and fastest spreading city fires of record in the United States. Only one Canadian city fire, Ottawa-Hull, 1900 *(105)*, is included, although some of the largest city fires in the Western Hemisphere in recent years have been in Canada. Time and distance data from which rates of spread could be computed and weather records were not available for most of these fires.

By no means did all of these large fires burn under unusually severe burning conditions. There were cases of snow on the ground, low wind speed, and buildings wet from recent rains. The 23 fires from which data were obtained burned a total of about 12,000 acres, or 20 square miles, and more than 100,000 buildings. The data included in this report are probably representative of the rate of spread of large urban fires under a complete range of burning conditions. Fires from almost every section of the United States are included.

Once a fire had been selected for analysis, locations of the fire front and times extracted from the narrative were plotted on the fire map. Usually a city street map showing the final fire perimeter was included in one or more of the case histories. Occasionally the map scale was not given and had to be obtained by writing the city engineer. All but a few fires were in cities on relatively level sites. Whenever topography was a factor in fire spread, topographic maps were obtained and slopes determined.

Information on the fuels along the line of spread was obtained either from the narrative report, photographs in the case history, or from interviews with local fire chiefs or engineering departments. A fuel type was recorded only if it occupied more than one-fourth of the line along which spread was measured.

Weather information was recorded for the start of the particular run or period of spread or for a time close thereto.

The direction and rate of spread was calculated by determining the direct distance between established points at the midpoint of the fire's head, measuring the distance of spread, and dividing the distance by the time. Many of the city fires studied lasted only a few hours and position of the front was noted at random times, or when a particularly big or historic building started to burn. Consequently, it was not possible to list rates of spread for set periods such as the 12-hour burning period used for recording rate of spread on wildland fires. Rates of spread for two or more consecutive shorter runs can be averaged, however. Sometimes averages for longer periods are more representative because of the tendency of fires to spread in spurts with relative lulls in between. Urban fires appear to spread about equally well night and day. So the day-night distinction used for analyzing wildland fire spread is not so important for city fires.

All data were copied on a standard form as shown in Appendix E. A complete listing of all data is presented.

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Appendix A

Estimators of Fire Modeling Parameters Obtainable from Aerial Photographs[15]

The success of a predictive fire model depends on the adequacy of the selected parameters for predicting fire spread in a given set of circumstances and on the ability to assemble, on a massive scale, data concerning the parameters. If either condition is unsatisfied, use of the model is impractical. Collecting all sample data on the ground over the entire United States would be prohibitively costly, but aerial photogrammetry and photo interpretation have proved particularly reliable aids in collecting geodetic, topographic, and vegetative data over large areas with maximum speed and minimum cost.

This report discusses the various parameters which can be feasibly obtained from aerial photographs consistently and accurately for use in predictive fire modeling. The present availability of sample data is also discussed. Further, we wish to know the kinds of new data which can be obtained by trained personnel with available equipment, and the kinds of data which could feasibly be collected with available or prospective automated equipment.

Four main factors to be considered in defining fire spread parameters are: (a) geographical location, (b) topography, (c) fuels, and (d) weather. We will consider only the first three; each includes several parameters for which unbiased estimators are desired as well as their variances.

Parameters Obtainable from Aerial Photographs

Geographical Location

X and Y coordinates of any point on the land area, standardized to a map projection, can be obtained to a high degree of accuracy when photogrammetric control is maintained with plotting instruments. The accuracy of location depends on the precision of the camera and plotting systems, the skill of those using the equipment, the scale of photography, the amount of tip and tilt at the time of exposure, the type of control used, and the specifications of the photographic materials used. The range of average error would run from about 10 feet to 300 feet, depending on the combination of the above factors present on a given project.

If photogrammetric control is not used but good maps are available, the coordinate position of a spot on the ground can usually be estimated within one-fourth mile of its true plan position at the photo center and within one-half mile at the photo edges on 1/20,000 scale photographs taken through an 8¼-inch focal length lens.

Topography

Three main topographic parameters concerning a point on the land surface can be consistently determined from controlled aerial photographs: elevation, steepness of slope, and aspect. The obtainable limits of error in absolute elevation are affected more by the type of control used than are horizontal measurements. However, the average error can be maintained somewhere between 5 feet and 100 feet, depending on the project specifications.

The accuracy of slope determination is, of course, dependent on the accuracy of the relative horizontal and vertical differential between the reference points used in determining the slope. In general, we can obtain good slope estimates if we can see the ground surface at both ends of the reference line.

Aspect (direction of slope) can be accurately determined within a wide range of project control specifications.

If no photogrammetric control is used, the elevation of a point can best be determined from topographic maps. The limits of error will depend on the accuracy of the map itself and on the horrizontal accuracy maintained in point location. In this situation, the topographic parameters of elevation, slope, and aspect should probably be estimated strictly from maps without regard to the image position on a photograph.

Fuels

The fuel type classifications desired for predictive fire modeling which can be obtained from aerial photographs are best determined if one begins with the following broad groups of classification: (a) urban areas, (b) agricultural areas, (c) wildland areas, and (d) water areas.

Urban areas.—These can easily be subdivided into industrial, commercial, and residential groups. Within each group, photo interpreters can easily distinguish buildings, streets, parking lots, vacant lots, lawns, shrubs, trees, swimming pools, canals, harbors and other features. The parameters which can be measured for each item, where applicable, are length, width, height, and the distance between items. From these measurements, other indexing parameters, such as size, distribution, and density, can be determined.

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Vegetation characteristics within urban areas will vary according to the season of the year because of winter defoliation of trees and shrubs and other physiological changes. Therefore, summer and winter data on the area of ground covered by foliage would be desirable.

Agricultural areas.—These can be subdivided into fallow, orchards, vineyards, row crops, close-grown crops, and pasture if photo scales of about 1:5,000 are used. On smaller scale photography, fallow ground and orchards will each be discernible; vineyards will merge with tall row crops; small row crops, close-grown crops, and pasture will merge into a single discernible group. Row crops include corn, milo maize, beans, peas, cabbage, tomatoes, and carrots. Close-grown crops include rice, wheat, oats, barley, rye, alfalfa, and hay.

Parameters which can be measured in agricultural areas are length and width of fields, roads, buildings, and the distance between these items. Heights of trees (orchards) and their crown width can also be measured. The heights of taller row crops can be measured on aerial photos if good plotting instruments are used, provided the height of the camera station is no greater than approximately 6,000 feet (independent of photo scale). However, it would probably be more feasible to dichotomize these items into "tall" or "short" groups. Other indexing parameters such as vegetative density and crop spacing can be determined with varying degree of reliability. Special filtering can be used at the time of photography to maximize the tone contrast between crop types if the spectral characteristics of each is known (Colwell 1956). This information can be read and interpreted electronically (Langley 1961).

Crops on agricultural land usually vary a great deal owing to the seasonal nature of many agricultural crops and to the practice of crop rotation on specific areas. Consequently, any information concerning crop parameters for a specific time period will be quickly outdated.

Wildland areas.—These can be classified as bare ground, grass, brush, or trees fairly consistently on existing photographs. Hardwood trees taller than 40 feet can usually be distinguished from conifers of the same height or taller by using photographs from 1:18,000 scale or larger with good image resolution. The interpreter's ability to distinguish between hardwoods and conifers is also affected by the season of the year and the film-filter combination used. It is very difficult to consistently separate hardwoods from conifers of a height less than 40 feet unless photographs taken under rigid specifications are used.

The accuracy of height measurements on vegetation also depends on the photo specifications. Generally, height measurements are less reliable when made in heavily forested areas than when made in open forest stands or in urban or agricultural areas because the foliage in tree crowns, deep shadows, and understory vegetation obscure the ground surface. Height measurements can generally be maintained to within about 40 feet in dense, old-growth redwood or Douglas-fir stands and to within about 20 feet in other forest types. It is not practical to measure the height of vegetation less than about 20 feet tall on available photographs taken from a height of 15,000 or more feet above the ground.

The percent of crown closure on a small area (1 acre) around a ground point can be ocularly estimated within about 10 percent. Crown diameters of prominent trees can be measured to close tolerances on photographs of any workable scale if the image resolution is good. Other indexing parameters concerning size, spacing, or distribution can be formulated from height, crown closure, crown diameter, and the distance between trees, stands, or other unit designations.

Parameters concerning vegetation in wildland areas are, of course, subject to seasonal variations, particularly in deciduous forest.

Water areas.—These can be distinguished on nearly all photography taken under a variety of conditions.

Methods of Data Collection

Method Versus Estimator Bias

To determine the usefulness of existing data and the optimum method of collecting new data for use in predictive fire modeling, some consideration should be given to the possible bias inherent in the estimators.

Measurements taken from uncontrolled photographs result in errors of estimate owing to relief displacement and distortion in the plane of the stereo model. These errors may or may not result in bias when estimating the desired parameters for fire modeling. For instance, estimates of land area vary inversely with the flight height above the terrain. The estimates of land areas which lie above and below the datum plane of a photo project can average out if the distribution of the samples happens to balance around the mean datum.

Other errors in area estimates can be caused by the varying tilt of the ground surface with respect to the position of the camera station. These errors can result in considerable bias (100 percent) if the flight lines happen to parallel high ridges or canyons. Moessner (1957) reported that no significant bias occurred in area estimates with dot sampling from uncontrolled aerial photographs in the Rocky Mountain, whereas Wilson (1949) reported earlier that bias does show up when making dot count estimates for "small" areas.

Bias in height measurements, when using uncontrolled photographs, can also be caused by varying flight above the terrain. This bias can amount to as much as 30 percent between the extreme flight height difference under normal photographic conditions.

Therefore, one must weigh the possible effects of random error in measurement encountered when using uncontrolled photography against those encountered when using controlled photography as well as the relative cost of each method.

Method Versus Variance

The usefulness of the estimated variance around each parametric mean will depend on the data mode. For example, it is rarely possible to calculate a valid estimate of the variance from any data extracted from a forest type map because no information is collected on the "within group" variation, but only on the "between group" variation. It can be shown that the "within group" variation of vegetative type, size, and density as shown on a type map, is of sizable magnitude and is often as great as the "between group" variation.

As another example, a true picture of the terrain form is not realized simply from the variance around the mean elevation. The variance around the mean elevation in plateau country can be exactly the same as the variance in very broken country with many changes in slope. Therefore, some other parameter must be used, such as the difference in elevation between adjacent points in a systematic grid, or the distance between slope changes and the steepness of the intervening slope as measured from a line transect.

Availability of Existing Data

An extensive study would be required to learn exactly the kinds and amounts of useful data available for predictive fire modeling. My personal knowledge of data concerning the types, amounts, and distribution of fuels in urban or agricultural areas is limited. But much relative information has been collected in wildland areas for forest, range, and soil surveys.

Some of the existing data concerning vegetative fuel types in wildland areas of California exist in the form of forest type maps or soil-vegetation maps. Area estimates made from these maps contain little bias owing to relief displacement because the maps were generally compiled through plotting instruments of some type. These maps usually contain no information concerning terrain characteristics, but such information can be obtained from topographic maps and tied into the type maps. The maps usually contain information on the vegetative density of an area, but often have no direct figures on vegetative heights. Some type maps made in the Pacific Northwest, however, do contain height and density information. The forest survey maps and the soil-vegetation maps made in California before 1961 contain age-density classifications from which height can be approximated.

In addition to the survey type maps, the Forest Service has made similar maps for management purposes on the National Forests. The extent of this mapping work would have to be determined by further inquiry.

Most, if not all, of the large area forest surveys have now departed from type mapping as a means of data collection from aerial photographs. Photo-point sampling of some form is now used to collect this data. However, the kinds of data collected in different regions of the United States differ considerably.

The photo classification system presently used in California collects data on general location, productivity class (commercial forest, noncommercial forest, or nonforest), major forest type, timber size class, and volume class. The survey has collected photo information on elevation, aspect, and topographic situation only in Mendocino and western Siskiyou counties. Some of the other regions collect similar data; some only separate out the area of commercial forest land. All the photo-point information presently collected is gathered without photogrammetric control, and the information cannot be directly correlated to topographic information by point-to-point correspondence without a considerable amount of control work.

The intensity of photo-point sampling in California varies from about one point per 150 acres to one point per 320 acres. The sampling intensity in other regions goes as high as one point per 75 acres.

Collection of New Data

The methods used for collecting new data concerning the estimators of the selected parameters will depend on the short- and long-term requirements of intensity, accuracy, timeliness, and cost.

Use of uncontrolled photography.—If only a single reference value along with an estimated variance is required for each parameter within a 5½-mile square area, photopoint sampling using uncontrolled photographs would probably be speedier than any other system, provided few measurements are required. However, it should be recognized that data of unknown accuracy and statistical validity will result, regardless of whether or not special purpose photography is used. Also, this method of approach would nearly preclude the possibility of later intensification of the data for use in instantaneous fire-spread predictions on going fires when using electronic computers.

Use of controlled photography.—Controlled photography offers many technical advantages, but may increase time and cost of data collection. However, I believe that the advantages of using controlled photography can be gained without substantially increasing the time or long-term cost if a reasonable complement of equipment is assembled for use with special-purpose photography. If the U. S. Air Force could be persuaded to furnish civil defense offices with high altitude precision photography, taken to specifications, controlled data, with known limits of accuracy and statistical validity, could be obtained from existing plotting and data-recording equipment costing between $10,000 and $20,000. The Air Force RC-130A aircraft equipped with the HYRAN mapping system (Walls 1960) or similar systems are reported to be fully capable of producing radar-controlled precision photography from which the information could be taken. Aerial photographs of high resolution in 9- by 9-inch format and taken at a scale of 1:60,000 through a 6-inch focal length lens would cover approximately 22 square miles per stereo model. From these photos, an interpreter could measure well defined horizontal lines, such as street widths, to an approximate accuracy of plus or minus 5 feet. Vertical measurements of well defined objects could be obtained to plus or minus 15 feet under optimum conditions. Over-all geodetic control of ground points could be maintained to an average error of plus or minus 60 feet horizontally and plus or minus 20 feet vertically if necessary, and some relaxation of these requirements would allow considerable increase in speed.

Virtually all parameters mentioned at the beginning of this report could be collected and placed on EDP magnetic tapes for use in predictive fire modeling with the equipment complement referred to above. If data were collected with sufficient intensity, they could be effectively used in terrain analysis problems and in research on behavior of going fires.

Prospective Use of Automated PI Equipment

Much interest has been generated in recent years concerning the possibilities for obtaining PI information from aerial photographs automatically. Some pieces of automation equipment are now available for special use and more will be available in the near future. However, to use this equipment effectively for predictive fire modeling, some modifications would be needed to assemble an integrated interpretation system which would record all pertinent data and convert to an optimum form for processing. These modifications will require imagination, but much progress has already been made in their development.

Recently developed electronic scanning instruments will record line profiles and compile topographic maps automatically. Both the Benson-Lehner "stereomat" system and the Ramo-Woolridge stereo mapping system have been developed to a high degree. A third digital automatic map-compilation system now under development appears to offer much promise toward the solution of automatic interpretation problems and EDP.

Researchers have demonstrated the usefulness of taking photographs through selected filters to detect crop diseases (Colwell 1956) and to differentiate between tree species (Colwell 1960, Olson 1961). At least one researcher has made preliminary statistical analyses of reflectance data of field crops and has demonstrated that a number of crop types and other objects can be "read" and identified electronically from special-purpose photography and that the probability of detection can be determined (Langley 1961, 1962). Others have studied methods of terrain recognition through multiband sensing techniques using radar magnetometers and infrared (Frost 1960; Hoffman 1960; Newbry 1960; Scheps 1960; Olson 1960; Lyytikainen 1960). A relatively new and promising technique using digitized contrast frequencies was explored by Rosenfeld (1962) for the purpose of developing a method of automatic land-use classification from aerial photographs.

Even though much of this equipment is still in the developmental stage, enough progress has been made to indicate that the application of automated instruments to photo interpretation problems is definitely on the horizon. Consequently, in selecting a method of data collection used in the beginning for predictive fire modeling, a method that will yield data compatible with data obtained from automated equipment should be preferred. I can visualize how, by using an integrated complex of interpretation instruments, it will be possible to locate, identify, and measure nearly all required parameters and record the results in digitized form—all automatically. Interrogation of the data can then be made for many purposes depending on the particular computer model used at a given time.

Summary

Aerial photographs are useful for gathering geodetic, topographic, and vegetative data because they permit coverage of large areas of land much more rapidly than ground methods. Data concerning the defined parameters to be extracted from photographs should be restricted to that which can be measured with instruments or directly estimated from visible features. Subjective estimates should be avoided. The reliability of the data depends on the photo specifications and on the interpretation equipment used. Geodetic control can be maintained in the X, Y, and Z directions with plotting instruments, and the dimensions of visible features in three dimensions can be similarly obtained. Information on land use and vegetative types can be effectively measured, particularly if the photo specifications are prescribed to fit the job. Seasonal variations in vegetative manifestations should be taken into account.

The validity of the variances concerning the defined parameters depends on the method of data collection. Some methods of collection, as from type maps, will ignore some components of variance, while others will be ineffective for use in predictive fire modeling. The form of the data should be consistent with that which may be obtained with automated PI procedures so that the inevitable change-over will take place smoothly and efficiently. A digital system, based on photo-point sampling, will probably best lend itself to later intensification and to high-speed data collection, processing, and retrieval. Minimum photogrammetric control or no control can be tolerated if it is only necessary to collect information concerning the parametric means on areas approximately 5½ miles square.

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Appendix B

Example of a Wildland Fire Case History

(Note: This is an abridgement of a typical narrative fire report. In determining rates of spread from such a report, the fire action was plotted on large scale contour maps and the weather data were supplemented from adjacent Fire Danger Rating and Weather Bureau stations.)

The Lyons Peak Fire of Sept. 30 – Oct. 4, 1945

Control Action—September 30, 1945.

8:00 a.m. Lyons Peak weather: T° 71—Humidity 19—Wind ESE 8.

8:22 a.m. Fire start.

8:24 a.m. Fire reported on Lyons Valley Road ¼ mile west of Lyons Valley Suppression Station by Lyons Peak Lookout.

8:25 a.m. Called California Division of Forestry.

8:28 a.m. Lyons Peak reports smoke picking up.

8:30 a.m. Alpine Tank Truck crew was dispatched to fire. Suppression foreman, tank truck operator, and three crew men. Lyons reported fire going good.

8:33 a.m. F. C. A. Davis, Descanso Tank Truck crew, consisting of foreman and four men, were dispatched to fire.

9:07 a.m. La Mesa Tanker dispatched.

9:24 a.m. Davis arrived at fire (51 minutes travel). Fire approximately 5 acres, burning up hill to north and east. On arrival at fire, Davis found five local men standing on road watching fire burn; these men had no tools, Davis equipped them with all available tools from his pick-up and placed them along road to keep fire from spotting over road. After sizing up the fire, Davis placed an order for two tractors and I.R.C. crew (16 men Laguna).

9:31 a.m. Descanso Tanker arrived via Japatul Barrat, Davis instructed Foreman Brown to work east line of fire north from road, using water as far as possible, then continue along line with hand tools. This line constructed about 500 feet, when fire spotted over road. Foreman Brown pulled his crew off line to try and pick up spot-over. At this stage the fire seemed to blow up all over and was too hot to work with tools.

9:40 a.m. Alpine Tanker arrived via Sweetwater and pulled off road in front of fire; running out two hose lines, crew succeeded in knocking down north flank of slop-over. At the same time the C.D.F. Tanker from La Mesa arrived and started working south line from road east. Fire was traveling too fast for this crew to work flank to head off fire. The Descanso Tanker ran out of water and had gone to Lyons Valley Station for refill. This crew working hand line up south flank, aided by C.D.F. Tanker crew.

9:50 a.m. Second C.D.F. Tanker arrived from La Mesa.

10:14 a.m. Davis sized the situation up and decided the one remaining try was to fire the road from Lyons Valley Road to switch-back one-third way up Lyons Peak road. Sent the C.D.F. Tanker around back of ranch north of road to fire from open field south and tie into Lyons Valley road, near station. Davis started Foreman Austin with Alpine Tanker and crew, firing Lyons Peak road from County road up hill. Davis took Descanso Tanker, crew, and the locals to switchback and began firing down hill to meet Austin. His plan was to control the head of the fire south of the County road and the past line on the north of road.

10:14 a.m. Davis reached the switchback in time to check the head of the fire. As the two crews fired towards each other, the fire continued to gain headway and backfire had to be carried too fast to give adequate patrol behind Descanso Tanker. The fire spotted over road—all but two men were started to work picking up this slop-over, while tanker and two men carried backfire on down road to tie in with Austin. As soon as the backfiring tied in both tanker crews and pickups were left to tie in slop-over, which by this time was approximately 3 acres burning in heavy brush in steep rugged country.

10:52 a.m. Cleveland team dispatched including 60 Firefly.

12:00 m. Lyons Peak weather: T° 84—Humidity 10—Wind NW 4.

12:10 p.m. Davis left Foreman Austin in charge of the above line and proceeded to line north of county road. Opon arrival at the county road he contacted State Ranger Miller. Miller informed Davis he had just sent the Sampo tanker crew of four men around to aid the La Mesa Tanker crew in carrying a line south from open field along west side of fire which was cool enough to work with hand tools. Also, the State's Woodson crew was coming in as well as the I.R.C. crew and another larger tanker.

2:15 p.m. State Ranger E. M. Miller, J. Ewing, and Davis met at the Lyons Valley State Guard Station. Miller asked that the U.S. Forest Service take charge of the fire and use Forest Service forces to fight it since most of his forces were already on other state fires. Ewing agreed to take the fire over and use Forest Service force since the fire was a definite threat to the National Forest.

Plan of Action—Day Shift—September 30, 1945:

2:15 p.m. Forces on the fire:

2 Forest Service tank trucks and crews, 11 men.

2 State Division of Forestry tank trucks and crews, 8 men.

8 Pick-up Fire Fighters

Forces ordered to arrive within a short time:

1 State Division of Forestry Tanker

16 Men—County Prison crew

15 Men—Woodson crew, State Division of Forestry

Also several Forest Service and State Guards.

This was about all of the manpower and equipment that could be expected to arrive on the fire before 6 p.m. The plan for the remainder of the afternoon was: Continue to use two Forest Service tankers and crews with 8-man pick-up crew on road from Lyons Valley to Lyons Peak. Try to keep fire from crossing the road to the east side.

Two State Division of Forestry tankers and crews to continue to north on east side of fire from Lyons Valley road, cut off head of fire if possible.

To use two crews coming in on west side of fire, one crew to work southeast from Lyons Valley Road and cold trail line, the other crew to work north from Lyons Valley Road and cold trail line.

Action and Accomplishment: All crews worked as planned. None of the crews was able to flank or pinch in the head of the fire.

Plan of Action–Night Shift–September 30, 1945:

4 p.m. Status of fire:

Size: 291 acres

Fire line controlled: 1.25 miles

Fire line uncontrolled: 2.6 miles

Weather: See Weather record attached.

Fire still spreading rapidly to both north and south, running up slope on both heads.

Manpower requested for night shift·

50 Firefly from San Diego

200 Military, Navy, from San Diego

2 tractors, one from Oak Grove, one from Descanso

3 tankers in addition to four already on fire.

Forest Service and State Division of Forestry overhead was ordered to handle above manpower.

4 p.m. Lyons Peak weather: T° 70 — Humidity 22 — Wind WNW 19

Organization and Strategy: Fire would probably go to ridges both to north and south. Was lying down some on all flanks and could be worked by hand crews.

Strategy was to control fire with night crews. The fire had been scouted by Davis, Miller, and Ewing and it was believed that sufficient equipment and manpower were available and ordered to accomplish control.

The Cleveland fire team took charge of the fires. Fire camp and headquarters were set up at Lyons Valley State Suppression Station.

Division I. 35 Firefly Troops to go out Lyons Peak road to head of fire, divide crew, and work two directions, cold trail line.

Division II, Sector A. 100 to start work from Lyons Valley Road and cold trail fire line North to top of ridge or tie in with Sec. 8.

Section B. To go out through burn (old road and trail) from Fire Camp to top of ridge and work north, cold trail northeast to tie in with tractor working from skyline truck trail to meet them. One tractor to go out skyline truck trail, cut line from road to fire line and cold trail line southwest to meet hand crews. One tractor to go into west end of Division 2, Sector B, and work all line possible.

Division III. To use tanker crews and go out skyline truck trail to west end of fire, to back fire from that point to Lyons Valley road. South line of fire north of Lyons Valley road backing in to open fields.

Action and Accomplishment: Division I, Sector A. Firefly crew 20 men cold-trailed fire line down ridge west from Lyons Peak. Area very rough and steep. Cold trail not completed. All line hot-spotted through entire sector.

Sector B. Firefly Crew men cold-trailed fire line to bluffs north of Lyons Peak, too rough and steep to work. Went around bluff area and worked line from where day crew left cold trail in to north end of bluff area, hot-spotting only.

Division II, Sector A. Completed cold trail over entire sector.

Sector B. Completed cold trail over entire sector. Tractor worked about 0.4 mile of this line. Also constructed secondary line 0.3 mile in around spot fire on north side of road in Division 3. Too rocky to work on fire line at night. Tractor did not arrive on fire line until 3:15 a.m. October 1, due to breakdown of contract truck hired to transport it from Descanso.

Forest Service Tractor from Oak Grove did not arrive on fire until 6 a.m., owing to breakdown of Forest Service Transport truck.

Division III. Line was completed, backfired as planned along roads. Some mop-up left to do on entire line. No cold trail around spot fire on north side of skyline truck trail. Secondary tractor line around it only.

Slopover. Plan was to burn out the slopover. In the morning, Rockwell, in charge, with three tankers and crews and one cat tried burning; unsuccessful and so decided to let fire burn out.

Rockwell and Ranger Miller optimistic about this piece. Rockwell did not want to use tanker or cold trail. He wanted to let it burn out. His objective was to get this area burned out clean. Forty-five minutes later (10:45 a.m.) fire broke.

Plan of Action- -Day Shift—October 1, 1945:

12:01 a.m., October 1: Fire scouted by Ewing, Davis, Sindel. Fire had stopped running.

Size: 760 acres

Fire line controlled: 8.9 miles

Fire line uncontrolled: .4 mile

Fire line to be mopped up: 9.3 miles

Action and Accomplishment: Division I. Men assigned to line and placed as planned. Line was completed around entire Division. Some mop-up still needed in vicinity of bluffs north of Lyons Peak. Three Navy tractors arrived on fire about 6 a.m. Due to condition of lines in bluffs north of Lyons Peak, these tractors were dispatched to construct a secondary fire line from the Lyons Valley Road ½ mile east of the Fire Camp. To work south to main ridge and as near to Lyons Peak as possible. This line was completed to within 0.3 mile of Lyons Peak. Cats were then pulled back to Lyons Valley Fire Camp.

Division II. Men were assigned to the division as planned, except 12 who were pulled back on the slopover on Div. III, because 50 men ordered from the 11th Naval District had not arrived on the fire. This entire line held and was reported completed at 10 a.m. and before the break on Div. III.

Division III. Three hundred men ordered from the 11th Naval District. Arrivals were assigned and dispatched to other Divisions first since Div. III was more accessible. This left Div. III without any hand labor. As soon as this became apparent, about 9 a.m., 12 men were shifted from Division II to the slopover on Division III for the backfire job. Men were shifted all along the line on Division II to fill in where men were taken for Division III.

One additional tank truck and crew were assigned.

Division Boss Rockwell decided not to backfire the slopover but to let it burn out.

10 a.m. Lyons Peak weather: T° 75 — Humidity 12 — Wind ESE 14

10 a.m. Gowen, Ewing, and Miller had gone over slopover line and decided it should be mopped-up. Two tractors, two tankers and 12 men were assigned to concentrate on this job.

10:45 a.m. Fire jumped the line on the west end of the slopover. Crews on hand at the slopover were unable to control the spots. Fire made a 3-mile run west by 2 p.m. and 5½ miles by 6 p.m.

One tractor was started to work east line of break and accomplished about ¾ mile of cold trail. All men on Divisions I, II, III remained on their respective lines and held them except Sector B, Division II. All available overhead and tanker equipment were dispatched to the skyline road to try to hold fire on north side of road. This attempt failed.

The next attempt was made to hold the head of the fire east of Lawson Valley road and the Lyons Valley road in the vicinity of the Junction of these two roads and the skyline truck trail. This attempt also failed.

Plan of Action—Night Shift—October 1, 1945:

4 p.m. Status of fire:

Size: 5,600 acres

Fire line controlled: 7.4 miles. Died out in old burn 2.2 miles.

Fire line uncontrolled: 11.2 miles.

Fire spreading on all uncontrolled sections of fire line.

4 p.m. Lyons Peak weather: T° 76 — Humidity 13 — Wind ESE 19

Fire was still running on all lines that had not been worked. Uncontrolled line was 11.2 miles (map miles) which would mean 15 to 17 ground miles. Approximately 4.6 (map miles) or 7 ground miles could probably be worked with tractors. Two miles could be backfired from the Lyons Valley Road with tank truck crews. This left 7 to 8 miles to be cold-trailed by hand.

Five hundred men were needed and possibly could control the line. However, overhead was available for only 230 men. Strategy was planned to control the fire from the original lines to the west as far as possible with crews available.

Special effort to be made to control Divisions II and IV, Division III to be controlled from east to west as far as possible, and Division I to be patrolled and held.

Action and Accomplishment: Northern fire team arrived and took charge of fire at 9:00 p.m. Division I line held with no breaks through night shift. Division II, Sector A, tractor worked secondary line into fire from Lawson Valley Road, worked fire line east as far as possible. Tractor then went back to secondary line and worked fire line west into Canyon and could go no further. Thirty-five men worked from end of tractor line on SE end of Division II, to end of tractor line at NW end of Sector. Line was hot spotted and dangerous spots cold-trailed. (All line on Division II, Sector A held until flanked from the west on afternoon of October 2.)

Division II, Sector B. Tractor and crew of 50 went into line and worked as assigned but accomplished little. Tractor was roaded from Sector A, Division II, over skyline road to Wood Valley, arriving on line at about 11 p.m. Navy crews arrived on fire at about 8 p.m. Division bosses were taken to their divisions by daylight and shown their assignments and were later sent to their starting points. One crew of 50 men got lost in the burn after being on their line and did not again get lined up until 3 a.m. by Willingham. Accomplishments were not as good as expected. Line was not completed. All sections of sector remained very hot all night and although it was not a running fire, it was very hot but not too hot for working trained hand crews.

One cat broke down near Wood Valley which also contributed to failure to mopup this sector completely during night.

Division III, Sector A. One hundred men arrived on fire line at about 7 p.m., worked line as assigned. Material heavy, fire line was hot all night. Crews did not accomplish as much as was expected. Line was not tied into Sector B, Division II. ¼ mile of cold trail and ½ mile of hot spot line was constructed west of Lawson Valley Road on this Sector.

Division III, Sector B. Two tractors continued to work until dark. One tractor had no lights, other tractor operated until line was constructed to canyon bottom, approximately 1 mile from starting point.

Section of line in last year's burn Honey Spring fire died out in light material and went out.

Division IV. Two tank trucks continued backfire along road. Fifty-man crew arrived on fire at about 11 p.m. and did mopup work on line. This section of line was not entirely completed as planned. Approximately ½ mile remaincd to be backfired on east end of line. Crews continued to backfire until line was completed, at about 9 a.m.

Summary: Not all work planned on Divisions II and IV was completed. On Division IV, this was not serious since the fire was not crowding the backfire line in the area not fired. Crews were slowed up because of spot fires occurring on south side of road that had to be picked up. On Division II, Sector B, and Division III, Sector A, the fire boss underestimated thc length and difficulty of line to be worked and misjudged the amount of work that could be accomplished by crews assigned.

Plan of Action—Day Shift—October 2, 1945:

11 p.m., October 1, 1945

Plans were completed to divide the fire into two zones. The Lyons Valley camp to continue to operate. All lines east of the Lawson Valley road to be handled by this camp. A new camp was planned to be established in the vicinity of Jamul, all line west of Lawson Valley road to be taken over by this camp.

4 a.m., October 2, 1945. Status of fire:

Two scouts reported fire had changed very little during night. Fire lines on Divisions II and III remained hot during night. Fire spread some along these lines, no runs occurred to materially change the size of the fire or line location.

Size of fire: 5,600 acres

Fire line controlled: 14.3 miles.

Fire line uncontrolled: 6.5 miles.

It was decided to divide the fire into two zones. All of fire line east of Lawson Valley road to be Zone A. All fire line west of Lawson Valley to be Zone B. The new fire camp for Zone B to be set up in the vicinity of Jamul. This zone to be handled by Ewing. The Lyons Valley Camp to remain intact for Zone A. Zone to be handled by Sindel. A second fire team had been requested for Zone B. The Modoc Team would take over Zone A. This would free the Cleveland Team to assist the two off-Forest teams and to coordinate work between the two zones.

Action and Accomplishment: Division I. Other than a small spot outside the line in early morning that was controlled very quickly, there was no real activity on this division of the fire. The entire division was completely mopped up during the day.

Division II. This division east of Wood Valley held. Some mopup was done. However, crews were pushed through to Wood Valley area to try to catch up hot fire line in that area. One tractor tried to work from the east (secondary line) in to Wood Valley. This tractor broke down (transmission went out). Operator got it into burn and was later pulled out to road by the other tractor. Line was not tied into Wood Valley. Fire started to make run west where line was not worked at about 10 a.m. One tractor in Wood Valley started line west and south, was not able to tie into hand line to west. At this same time crews that had started in to try to work line from Division III Lawson Valley road east and south had to bc pulled out. Crews were late (about 8:30) getting out, really never got on line to start work except to hot spot. Crew on Sector A did effective work. Men were pulled back to Beaver Hollow Junction on Division III.

Division III, Sector A. Crews were late getting out to fire line. Arrived at Jamul at 7 a.m. on fire line, about 8 a.m. at Beaver Hollow Junction. Had to be fed, organized, and gotten on the fire line.

One crew dispatched to try to tie line in east to Division II. See above. Other hand crews and tractors started line down ridge from Lawson Valley road west. Tried to work backfire line ½ mile down ridge, then into Beaver Hollow road. Reason for working line instead of using road for backfire was to bypass a large number of cabins (homes) along the south side of Beaver Hollow road in this area. Approximately 0.7 mile of line was successfully held. Tractors were trying to work line down slope into Beaver Hollow road when fire started run from the east behind them. Line was not completed into road. One tractor, a Navy D-8, became stuck on steep ground, had to be abandoned by crews and later burned up. From 10 to 11 a.m. the fire started making run over this entire sector.

Division III, Sector B. Eighty men were spread out over this line. Line was completed from where fire crossed Lyons Valley Road west to southwest corner of fire, from there north almost to Main Ridge southeast of McGinty Peak. Most of this line was in light material all held with very little patrol or mopup.

Division IV. Crews and tankers mopped up this entire division as planned.

Summary: Two hundred men ordered to arrive on fire at noon did not arrive until after fire on Divisions II and III had started to run. It was not possible to place them on the fire and do any really effective work during the afternoon.

After the break in the lines on Divisions II and III, it looked as though the fire would go to the Sweetwater River north. Wind changing to southeast and south. It was decided that an attempt to hold the north side of the fire would be made, starting at the Junction of Beaver Hollow and Sweetwater River, east to Sloan Ranch, southeast up Lawson Creek. To attempt to cut the east (head) of the fire off in the vicinity of the Lawson Valley Road. With this in mind instructions were issued changing the location of the new fire camp from Jamul to the Sweetwater Dam. This was accomplished and the Sweetwater Camp was established in time to get night overhead and crews out from that side of the fire.

Day crews and tractors were shifted from Divisions II and III to the Lawson Valley area and some work was accomplished East from where the fire crossed the Lawson Valley Road near the junction of the Sloan Ranch Road.

Plan of Action—Night Shift—October 2, 1945:

11 a.m., October 2, 1945. A check of the fire had shown that the south line of the fire could be held, the west side would probably hold owing to light cover and in most places fire would be backing down slope, and the north side of the fire was probably all lost from McGinty Peak east to the Lawson Valley Road. With this information, plans were made to shift the division of fire zones. The north side of the fire to be one zone with a camp in the vicinity of the Sweetwater Dam. The south side of the fire to be handled as a zone from Lyons Valley Fire Camp.

The camp equipment already ordered for a camp at Jamul was sent to Sweetwater Dam. All incoming overhead was dispatched to Sweetwater Dam. Overhead was already in Lyons Valley Camp from previous shifts.

4 p.m. Fire still running to north and east in Beaver Hollow area, was near top of Sequan Peak, had crossed Lawson Valley road northeast of Wood Valley; head of fire burning east in South Fork of Lawson Creek; wind shifts to west-northwest.

Size of fire: 7,000 acres
Fire line controlled: 14.5 miles
Fire line uncontrolled: 7 miles
Lyons Peak weather, October 2:
8 a.m., T° 77 — Humidity 15 — Wind ESE 12
12 noon, T° 84 — Humidity 10 — Wind SSE 17
4 p.m., T° 74 — Humidity 17 — Wind W 15

Organization and Strategy: To hold all line already constructed on southside of the fire from point south of McGinty Peak to the head of the fire in the vicinity of the junction of the Skyline truck trail and Lawson Valley-Lyons Valley truck trail. Continue cold trail line on west flank of fire in the vicinity of McGinty Peak and work this line north toward Sweetwater River. To start crews to cut the head of the fire off from Skyline truck trail north into Lawson Valley. To also start crews in Lawson Valley to work southeast on fire line to cut head of fire off. To work a crew from junction off Lawson Valley road and Sloan Ranch road to backfire Lawson Creek and keep ahead of main fire. To do no work on the fire line between Sloan Ranch and Beaver Hollow road.

If fire should back into Sweetwater River, tank trucks from State Division of Forestry and Navy to be called to backfire and hold fire along the Sweetwater River. The Sweetwater is an excellent natural barrier consisting of a wide flat gravel bed, several hundred feet wide in most narrow places. A good stream of water flowing down the canyon at all times. The northeast end of the fire now the dangerous threat.

Action and Accomplishment: Zone A. Only 88 of 100 men arrived; one unit got lost and returned to Camp Elliott.

Zone A, Division I. Crew worked as assigned. Backfire successful with one dangerous slopover, which was caught up and cold-trailed. Tractor arrived on line at 2 a.m. and completed ½ mile of line down canyon beyond backfire crews. Backfire successful to point where main fire had burned almost into canyon. From that point on backfire impossible to make burn and clean up.

Zone A, Division II. Crews started and worked as assigned; were not able to tie line through to head of fire. Fire burned quite hot through night. Tractors did not arrive on fire line until daylight, they then started secondary line on Lawson Valley Road.

Zone B. Only 56 of 100 men requested arrived on fire. Other men became lost and turned back to their base camp.

Zone B, Division I. Twenty-man crew went into McGinty Peak area as assigned. Were able to cold trail fire and keep up with west flank. Remainder of Division all held without mishap.

Zone B, Division II. Entire Division held as planned.

Zone B, Division III. Crews went to line and started work as assigned. Fire burned very hot on the east end of Division all night. Crews were not able to establish themselves on cold trail line and hold it. Fire jumped skyline road early in the afternoon on lower end, early in night on upper end. Was picked up and cold-trailed before morning. Tractors started work from skyline road and worked north on head of fire. Due to rough area, they could not get completely around the head of the fire. One tractor started work in Lawson Valley to work southeast to meet crews from above. Due to rough area, this piece of equipment accomplished very little.

Summary. More manpower could have been used on this shift and possibly could have cut the head of the fire off. However, due to the rough area in which the fire was burning and to the heat of the fire in very heavy oak brush, it is quite doubtful whether they could have accomplished much unless trained crews were available.

In the afternoon when manpower was ordered and organization worked out, a W-NW wind had not been anticipated. This W-NW wind did occur about 6 p.m. and continued until around midnight.

Plan of Action—Day Shift—October 3, 1945:

4 p.m., October 2. The head of the fire had crossed the Lawson Valley Road to the east. Wind was shifting to the west. Overhead would probably not be adequate to handle enough men to control the fire by 10 a.m., October 3. All available overhead on Zone B, Lyons Peak Camp, would be needed on that Zone to handle their lines at the head of the fire and patrol held line.

Overhead already dispatched to Sweetwater Camp would be able to handle 100 men on the night shift and enough more would arrive to handle 300 on day shift on October 3. A tentative order was placed for 300 men for day shift at the Sweetwater Camp and 125 men for the Lyons Valley Camp. The 6 p.m. weather forecast was favorable for control with rising humidity predicted. However, west winds on the head of the fire could be very troublesome, especially in the very rough country and heavy brush in the upper Lawson Creek area.

4 a.m., October 3, 1945. Status of fire:

Fire still burning quite hot on entire north line, except for an area of about two miles in the vicinity of the Junction of the Lawson Valley and Sloan Ranch roads. All control lines from McGinty Peak around the south line of the fire to the Skyline truck trail on the east line of the fire holding in good shape.

Size of fire: 8,000 acres
Fire line controlled: 17 miles
Fire line uncontrolled: 6 miles

Zone A. Strategy was to allow the section of line from Heaver Hollow Road east to the Sloan Ranch to continue to back into the Sweetwater River. To call in Navy and State tank trucks to backfire along the Sweetwater River Road if necessary. To continue to work lines from the junction of the Lawson Valley and Sloan Ranch roads as already started by night shift. Backfiring down Lawson Creek to Sloan Ranch ahead of main fire which was backing down slowly. To continue cold trail with men and tractors east to head of fire. To build secondary lines with tractors along roads to which to backup to and backfire if necessary.

Zone B. Strategy was to hold all line already constructed. Send a small crew to the west of the fire to continue cold trail from ridge SE of McGinty Peak north. To place the bulk of all manpower and equipment on the east end of the fire to work down from the Skyline truck trail north to cut off head of the fire. This Zone had also taken over the Gaskell Peak fire. One tanker and 10 men to attempt to cold trail the fire.

Action and Accomplishment: Zone A, Division I. Crews were successful in holding all line assigned. Completed and backfired to end of spur road south of Sloan Ranch. Some cleanup needed along entire line. From this point to Sweetwater River proper the Canyon bottom is flat and wide, orchards and plowed field over most of the distance. Little danger of even a running fire crossing it. Accessible to tank trucks. Backfire was ahead of main fire backing down so no further firing was necessary. On the west end of the Division the fire made a small run north in the afternoon. State tankers had gone to Tecate fire. Crew from Zone B accomplished some cold trail on west side of run. This crew picked up the slop-over.

Zone A, Division II. Line already constructed in Lawson Creek from road junction, Lawson Valley and Sloan Ranch roads, east, was held. Fire from that point east was too hot to cold trail. Crews started backfire from bottom of Lawson Creek east. Tied the west end of backfire to night shift cold trail by cold trailing along fire line. A parallel line, constructed east with tractors and hand crews, was successfully backfired. Crews were able to keep abreast of the head of the fire but were not able to cut off the head to the south.

Zone B, Division I. Division held all day with the exception of the area in Beaver Hollow where a break occurred. This was caught up and cold trailed to the end of the division successfully.

Zone B, Division II. Held through the day with no line-breaks reported.

Zone B, Division III. Several lines were started from Carveacre truck trail north to try to cut off the head of the fire. All attempts were unsuccessful. Tractors and crews were used to widen the clearing along the Carveacre truck trail and the truck trail was backfired. The backfire was carried along as the head of the fire made runs up to it. Crews were successful in keeping it from crossing the road.

Zone B, Division IV. The crew on Gaskel Peak was unsuccessful in cold trailing the north and west lines of that fire. Fire creeping down over very steep rock bluffs. Men were unable to work the line.

Summary. All fire lines constructed previous to this shift were held. Weather conditions were less favorable for burning through the day than on previous days. Crews working on the head of the fire could not cut a cold trail or line ahead of the fire because of the very rough steep area in which the fire was burning. However, crews on both flanks were able to keep secondary lines well ahead of the head of the fire and were able to backfire and hold these lines.

A change in strategy during the day was made approximately 2 p.m. The new strategy was to backfire the Carveacre truck trail to the Gaskell Peak fire, including that fire in the Lyons Peak fire burn, construct a line from the Smiley Ranch to the north line of the Gaskell Peak fire and backfire. Due to weather conditions in the lower elevation in Sweetwater River, the loss of the small section of line in lower Beaver Hollow was not serious.

Plan of Action—Night Shift—October 3, 1945:

11:30 a.m., October 3. Conditions on the fire indicated that control would not be accomplished during the day. Manpower order for the night shift was placed. Manpower orders were based on the overhead available to handle men on the line.

4 p.m. Status of fire:

Some overhead had been shifted to Descanso fire. All lines previously constructed were holding. Head of fire in vicinity of Lawson Peak was making small runs, but crews were well ahead of main fire with backfire on road, possibility of completing backfire to Gaskell Peak fire very favorable. Tractor line from Smiley Ranch to Gaskell Peak fire progressing favorably. West end of fire near Beaver Hollow completely laid down, little or no spread occurring. North line of fire from Beaver Hollow to Sloan Ranch doing very little, backing down very slowly in draws leading into Sweetwater, large part of line appears to be out.

Size of fire: 10,300 acres
Fire line controlled: 24.4 miles
Fire line uncontrolled: 6.7 miles
Lyons Peak weather, October 3:
8 a.m. T° 78 — Humidity 28 — Wind SSE 21
12 noon T° 82 — Humidity 27 — Wind W 8
4 p.m. T° 77 — Humidity 28 — Wind W 3

Organization and Strategy: Strategy was to patrol and hold all line already constructed. To continue to allow the section of line between Beaver Hollow and Sloan Ranch go unworked. To work the west line from end of present cold trail line into Sweetwater River and mop it up. To complete backfire on south line in vicinity of Lawson Peak to tie in with Gaskell Peak fire and mop-up this line. To complete line from Smiley Ranch to Gaskell Peak fire and backfire line.

Zone A, Division I, Sector A. Fifty men assigned to west line of fire. To cut cold trail, from end of present cold trail, around west line of fire. To cut a wide fire-break from NW corner of fire to Sweetwater Road. To continue cold trail east on north line of fire. Division I, Sector B, to be patrolled by tanker crew only.

Zone A, Division II. Seventy-five men and one tank truck assigned. Complete and mop-up all line on the division. Mop-up needed over entire line from junction of Lawson Valley and Sloan Ranch roads to Smiley Ranch.

Zone A, Division III. Seventy-five men and 4 tractors assigned. Continue backfire line already started from Smiley Ranch to tie in with crew working down from Gaskell Peak fire. When line is completed backfire from Gaskell Peak fire down and tie in line.

Zone B, Divisions I and II. No crews assigned.

Zone B, Division III, Sector A. Eighty men, one tank truck, four tractors assigned. Continue to mop-up line. Backfire all line that did not burn out completely, leave no islands, mop all line up completely along Wisecarver Truck Trail.

Zone B, Division III, Sector B. Continue to cut secondary line from northeast end of Gaskell Peak fire west to meet crew working from Smiley Ranch. As soon as line is completed start backfire from top down. Do not backfire until line is completed unless necessary.

Action and Accomplishment: Zone A, Division I. All fire line previously constructed held. Cold trail along west side of fire in Beaver Hollow area completed. Secondary line from northwest corner of fire completed to Sweetwater road. Fire line from secondary line east to Beaver Hollow road hot spotted.

Zone A, Division II. All line patrolled, partially mopped up. No break in line during shift.

Zone A, Division III. Tractors completed backfire as far as possible for them to go. Short section 0.2 miles to be worked by hand not completed. Tractors worked on secondary line from open field near Smiley Ranch east to tie in with line worked down from Gaskell Peak fire. This line was completed.

Zone B, Division I and II. All lines held, appear dead out.

Zone B, Division III. All line completed along Carveacre truck trail to Gaskell Peak fire. Some islands between Lawson Peak and Gaskell Peak did not burn out good. More firing out and mop-up needed. Backfire would not burn after midnight. Tractors moved to east of Gaskell Peak and secondary line started northwest into upper Lawson Creek.

Summary. All lines worked as planned. Crews assigned were not able to complete backfire line from Smiley Ranch to Gaskell Peak because of burning conditions. Very rough and steep area, difficult for night crews to work. Backfiring was very slow and did not clean up well because of rising humidities.

(The fire continued to spread sporadically for the next two days, when control was completed, but its behavior was such that no useful data on rates of spread could be ascertained.)

Appendix C

Example of an Urban Fire Case History

(Note: The following case history is based on Williams' (1954) book *Baltimore Afire,* published and copyrighted by Schneidereith & Sons, Baltimore, Maryland. Excerpts and illustrations are reproduced with permission of the copyright owners.)

The Baltimore Fire of February 7–8, 1904

The fire started at 10:48 a.m., Sunday, February 7, 1904, in a 6-story brick building occupied by a drygoods firm. Between this time and 5 p.m. the next day—a period of 30 hours—the fire burned out 77 blocks. It swept through 139 acres in the heart of downtown Baltimore (figs. 19, 20, 21) and destroyed 1,526 large buildings.

Heavy "builtupness" and moderate wind speed were the factors favorable for fire spread. Other conditions were generally unfavorable. The sky was overcast. Snow lay on the ground and muddy slush at intersections. Relative humidity ranged in the 80's and 90's, and the temperature ranged in the 50's and 60's. Yet flying brands set fires up to 5½ blocks ahead of the main fire front.

Although the fire occurred more than half a century ago, the buildings destroyed were substantial skyscrapers, even by present day standards. Many were rated

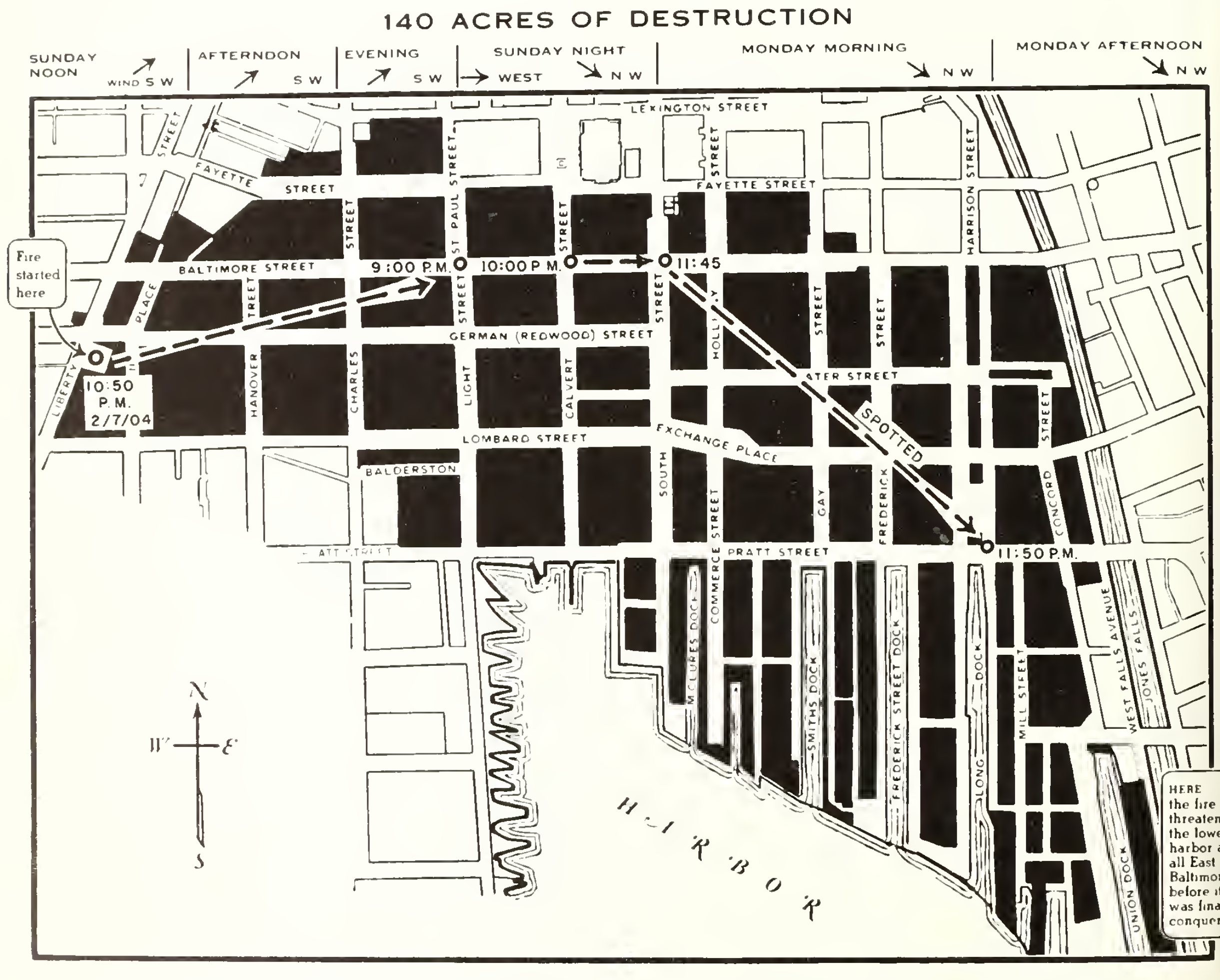

Figure 19.—Map of the Baltimore Fire, showing the approximate midpoint of the fire front at various times and final burned out area. (Reproduced from *Baltimore Afire,* published and copyrighted by Schneidereith & Sons, Baltimore, Maryland.)

Figure 20.—Baltimore after the fire, looking down Lombard Street. Brick buildings crumbled. Fireproof buildings were gutted. The Continental Trust Building is behind the large structure at left center. (Reproduced from *Baltimore Afire*, published and copyrighted by Schneidereith & Sons, Baltimore, Maryland.)

Figure 21.—Baltimore after the fire, looking southwest. The street to the right is Charles. Smoke was still rising from the ruins. (Reproduced from *Baltimore Afire*, published and copyrighted by Schneidereith & Sons, Baltimore, Maryland.)

"completely fireproof." In Williams' words: ". . . The sixteen-story completely fireproof Continental (Trust Building), tallest in Baltimore, burned like a torch. . . ." Another "fireproof" skyscraper burned "as if it had been made of matchwood and drenched with gasoline. . . ." The burned portion of the city probably is representative of large sections of many American cities today.

Relatively little influence was exerted by fire suppression action since the fire was so large that it overwhelmed nearly all efforts to control the flames. The fire was finally stopped by the water edge of the harbor; Jones Falls, a slough 75 feet wide; more favorable weather conditions; and some effective fire control action along the Falls.

Weather Conditions.—Weather data during the period of the fire were taken by the U.S. Weather Bureau office, near the fire area in downtown Baltimore:

Date and time	Wind speed	Wind dir.	Rel. humid.	Temp.	Sky
	M. p.h.		*Percent*	°*F.*	
Feb. 7, 1904:					
8 a.m.	1	SW	96	41	--
10 a.m.	2	S	--	48	overcast
12 noon	20	SW	--	64	--
2 p.m.	16	SW	--	60	--
4 p.m.	18	SW	--	60	--
6 p.m.	11	SW	--	58	--
8 p.m.	14	W	84	58	--
10 p.m.	22	W	--	60	--
12 p.m.	22	NW	--	53	--
Feb. 8, 1904:					
Morning	brisk	NW	--	[1]30	clear
Afternoon	brisk	NW	--	[1]30	--

[1] *Estimated.*

Mild weather February 6, the day before the fire, had melted most recent snow, but some snow and slush remained on the ground. The wind, which appeared to shift direction frequently, contributed to the difficulty of fighting the fire. Thousands of wind-carried firebrands spread the fire more than five blocks ahead of the main fire front.

Fire spread.—The rate of spread was computed from times given in the narrative account and distances scaled from the fire map. Locations of the fire front at various times as given in the narrative were plotted on the fire map to determine distances.

Significant excerpts from the narrative account follow:

". . . The fire started (at 10:48 a.m.) in the Hurst Building which stood on the south side of German Street at Liberty. Smoke explosions flared it west and south, but fresh winds from the southwest carried the broad front of the blaze to the northeast. By 5 p.m. much of the area between Fayette and German Streets and west of Charles was in flames or already burned. At 7:30 p.m. the wind changed to the west, hurrying the ragged eastern edges of the fire toward St. Paul Street where buildings caught fire by 9 o'clock. . . .

"At 9 o'clock the Bank of Baltimore, on the northeast corner of Baltimore and St. Paul Streets, caught fire. From there the flames ate through the Exchange Building of the Calvert Building, the first of the fireproof skyscrapers to catch. . . .

"By 10 o'clock the solid Baltimore and Ohio Railroad Building, on the northwest corner of Baltimore and Calvert, was burning. At 10:15 the 16-story 'completely fireproof' Continental Trust Company Building, the tallest one in town, was afire. . . .

"The flames in the area bounded by Fayette, Calvert, German, Light and St. Paul Streets were unusually intense. Firemen estimated that the blaze here developed 2,500 degrees of heat. When the Carrollton Hotel, on the southeast corner of Light and German, was blazing from top to bottom firemen could not get within a block of it because of the terrific heat and the flying sparks which swept the area like hail. . . .

"Shortly after 11:30 o'clock a cornice of the old Sun Iron Building on the southeast corner of South and Baltimore Streets was struck by falling brands. The first blaze was quickly put out. Fifteen minutes later (at 11:45 p.m.) the American Building, directly across South Street, caught fire and burned fast. More brands fell on the Iron Building.

"Five blocks to the east, sparks set fire to the roof of the old and historic Maryland Institute, scene of many political conventions, in Centre Market Space at Baltimore Street. The building burned for three-quarters of an hour before a stream of water was played on it. . . .

"At 11 p.m. the wind changed to the northwest and reached a maximum velocity of 30 miles an hour. At that time flames were racing down Baltimore Street as far as South Street and cutting through the financial district in a southeasterly direction toward the waterfront.

"At 3 a.m. on Monday, the southern edge of the fire, which had been checked along Lombard Street, finally crossed Charles and moved down to Pratt Street. By 4 a.m. the north side of Pratt was blazing almost to Jones Falls. By some quirk of wind, one tip of the fire turned at the Falls and went rushing back to the west almost to Cheapside through the dock area.

"A last-ditch fight was made along the Falls with thirty-seven fire engines. By 11 a.m. fire had destroyed practically everything to the Falls from Baltimore Street to the tip of Union Dock. Carried by the northwest wind, sparks started dangerous blazes on the *east side of the stream* in the vicinity of Union Dock but these were contained and conquered. The Great Fire was under control by 5 p.m. Monday."

The last documented spread, by spotting terminating at the corner of Harrison and Pratt Street, was obtained from another case history of this fire.

Appendix D

Wildland Fire Spread Data

The following tables contain rate-of-spread and associated data for large wildland fires. They have been separated into four groups according to the length of time over which the rate of spread was calculated. They were grouped because the rates of spread show a strong tendency towards time dependence and also because the weather data are related to each group in a different way.

Group I—6–11 hours: Weather measurements taken at 3 p.m. or midnight if the period includes either of those times. Otherwise, weather measurements taken at the hour nearest to 3 p.m. or midnight. Examples: fire spread measured from 6 a.m. to noon, weather measured at noon; fire spread from 4 p.m. to 10 p.m., weather measured at 4 p.m.

Group II—12 hours: Weather measurements taken at 3 p.m. or midnight.

Group III—13–23 hours: Weather measurements taken at 3 p.m. or midnight, whichever time was most representative of the period of active fire spread as established from the narrative report.

Group IV—24 hours: Weather measurements taken at 3 p.m.

Explanation of Table Headings

FIRE

Fire No.: An identifying number assigned to each fire.

Line No.: A number-letter combination identifying the burning period and the location where fire spread was measured.

Time of start: The time when the rate of spread measurement was started.

Hours of spread: The length of time over which spread was measured.

WEATHER

Wind vel.: Measured wind velocity, in miles per hour.

Temp.: Dry bulb temperature, in degrees Fahrenheit.

RH: Relative humidity, in percent.

Stick: Moisture content of ½-inch pine dowels, in percent.

BI: Burning index as measured by the Wildland Fire Danger Rating System.

FUEL

Predominant fuel types along the line of fire spread. G is grass, B is brush, T is conifer timber, and H is hardwood timber.

TOPOGRAPHY

SLOPE:

UP:

%: The proportion of the line of fire spread where the fire was traveling upslope.

Aver. deg.: The average steepness in degrees of the upslope portion of the line of fire spread.

DOWN: Same as UP

Percent Flat: The proportion of the line of fire spread where the fire was traveling across level ground.

Sketch: A vertical profile of the path of the fire, which is always moving from left to right.

SPREAD

Rate: Rate of fire spread in miles per hour.

Angle to wind: Direction of fire spread in degrees relative to the wind direction. O is fire spreading directly with the wind; 180 is fire spreading directly against the wind. All angles less than 90 are with the wind; all angles between 90 and 180 are against the wind.

Type: The manner in which the fire was spreading in the area where the rate of spread was measured. Determined from the original reports. H is a head fire, R is a rear or backing fire, F is a flank, and O is a circular fire or indeterminate.

GROUP I—6-11-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
3	1A	1300	6	18	82	29	4.5	35	B	80	14			20		.0630	179	R
	1B	1300	6	18	82	29	4.5	35	B	30	15	50	18	20		.0396	102	F
	1C	1300	6	18	82	29	4.5	35	B	10	10	50	10	40		.4440	11	H
	1D	1300	6	18	82	29	4.5	35	B			80	10	20		.1270	17	H
	2A	1900	11	14	67	43	6.0	16	B			100	12			.0219	6	H
	2B	1900	11	14	67	43	6.0	16	B	40	28	45	20	15		.0520	0	H
4	1A	1145	6¼	30	96.9	12.7	2.8	24	TB	100	22					.0683	13	H
	1B	1145	6¼	30	95.8	12.9	2.8	24	TB	70	20	30	11			.1207	25	H
	1C	1145	6¼	30	95.1	13.2	2.8	24	TB	70	18	30	19			.1428	40	H
	1D	1145	6¼	30	99.3	11.5	2.8	24	B			80	14	20		.0856	82	F
	2A	1800	6	30	73.4	17.0	2.2	24	T			100	35			.0159	103	R
	2B	1800	6	30	66.8	18.1	2.2	24	B	100	17					.0159	105	F
	2C	1800	6	30	66.4	17.9	2.2	24	B	75	19	25	6			.0587	22	H
	2D	1800	6	30	70.0	16.4	2.2	24	B	45	16	20	24	35		.0508	11	F
	2E	1800	6	30	69.6	16.5	2.2	24	B	65	10			35		.0430	5	H
	2F	1800	6	30	69.6	16.6	2.2	24	B	65	10			35		.0430	1	H
	2G	1800	6	30	70.1	16.4	2.2	24	B	70	12	30	8			.0540	41	H
	2H	1800	6	30	71.7	15.7	2.2	24	B	65	25	35	32			.0713	78	H
	3A	2400	6	20	66.9	14.1	2.2	25	B	75	18	25	34			.0253	30	H
	3B	2400	6	20	70.5	12.6	2.2	25	B	10	27	35	28	55		.0747	27	H
	3C	2400	6	20	72.9	11.6	2.2	25	B			65	18	35		.1667	16	H
	3D	2400	6	20	72.3	11.9	2.2	25	B	30	12	40	34	30		.0920	0	H
	3E	2400	6	20	72.1	11.9	2.2	25	B	20	6	80	28			.0778	16	H
	3F	2400	6	20	73.3	11.5	2.2	25	B			100	21			.0667	24	H
	4A	0600	11	10	89.4	14.7	2.0	25	B			100	28			.0135	4	H
	4B	0600	11	10	98.3	11.1	2.0	25	B	25	29	75	14			.0786	66	F
	4C	0600	11	10	98.3	11.1	2.0	25	B	65	30	35	33			.0477	103	H
	4D	0600	11	10	97.5	11.2	2.0	25	B	55	23	45	11			.0941	135	H
	4E	0600	11	10	93.2	13.1	2.0	25	B	80	24	10	17	10		.1410	160	H
	4F	0600	11	10	93.7	12.9	2.0	25	TB	65	16	20	36	15		.1350	137	H
	4G	0600	11	10	95.0	12.4	2.0	25	TB	100	22					.1111	150	H
	4H	0600	11	10	97.3	11.5	2.0	25	TB	100	24					.0508	165	F
	4I	0600	11	10	93.0	10.8	2.0	25	TB	100	14					.0461	135	F
	8A	0800	10	2	95.2	14.7	1.1	13	T			100	60			.0088	140	R
	8B	0800	10	2	98.6	13.4	1.1	13	TB			45	23	55		.0191	120	F

GROUP I—6-11-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
4	8C	0800	10	2	97.8	13.7	1.1	13	TB	70	18	30	31			.0381	135	F
5	1A	1200	6	8-15	107	8	2	40	GB	100	17					.1250		H
6	1B	1000	6	6	99	13	1.5	18	GB	45	11			55		.3583	46	H
7	1A	1000	8	18	97	35	4.5	31	GB	55	12	35	12	10		.2875	58	H
8	1A	1000	6	12	73	45	6.5	11	B	65	14	20	16	15		.1667	13	H
9	1A	1400	6	11	77	33	2.5	18	GB	20	10	20	21	60		.2025	24	H
	1B	1400	6	11	79	34	2.5	18	B	25	10	40	16	35		.2500	12	H
	1C	1400	6	11	79	34	2.5	18	B	55	16			45		.1360	21	F
10	1A	1100	6	23	94	20	3.0	65	B	35	12			65		.5170	2	H
12	1A	0930	8½	4	73	30	8.5	7	TGH	75	23	25	31			.0588	125	H
	1B	0930	8½	14	72	30	8.5	21	TGH	100	19					.0824	172	H
13	1A	1200	6	12	85	25	3.5	29	GBH	15	24			85		.2333	23	H
14	1A	2200	8	6	68	22	4.5	13	B	100	16					.0550	9	H
	1B	2200	8	6	68	22	4.5	13	B	100	11					.0600	14	H
15	1A	1130	6½	7	90	25	6	8	G			65	10	35		.0433	166	R
	1B	1130	6½	7	88	26	6	8	G	45	15	55	10			.0433	117	H
22	1A	1130	6½	8	99	17	5	16	BG	50	11	30	10	20		.2000	123	H
23	1A	1445	6¼	9	62	29	9.5	16	T			100	10			.0490	49	H
	1B	1445	6¼	9	62	29	9.5	16	T			100	10			.0502	1	H
25	1A	1440	6	14-17	100	20	5.0	26	B	55	11	45	14			.1555	10	H
	1B	1440	6	14-17	100	20	5.0	26	B			80	13	20		.1000	37	H
	1C	1440	6	14-17	100	20	5.0	26	B	15	11	85	13			.1445	76	H
28	1A	1230	6	12	81	16	4.0	25	B	20	10			80		.2580	5	H
	1B	1230	6	12	81	16	4.0	25	B	25	16			75		.2270	5	H
29	1A	1830	11½	20	59	32	4.0	57	G					100		.0533	12	H
	1B	1830	11½	20	59	32	4.0	57	G					100		.0561	8	H
30	1A	1100	6	20-25	74	32	5.0	43	T	75	16	25	10			.2500	0	[illegible]
	1B	1100	6	20-25	74	32	5.0	43	T	55	20	30	10	15		.1585	13	[illegible]
31	1A	1400	6	5	90	32	5.0	8	BT	85	12			15		.2580	29	[illegible]
	1B	1400	6	5	90	32	5.0	8	BT	85	12			15		.2620	23	[illegible]
	1C	1400	6	5	90	32	5.0	8	BT	100	10					.1945	12	[illegible]
32	1A	1530	6	7	90	26	5.0	18	B	80	22	20	26			.0861	140	[illegible]
	1B	1530	6	7	90	26	5.0	18	B	100	25					.1305	179	[illegible]
	1C	1530	6	7	90	26	5.0	18	B	100	16					.0694	135	F
33	1A	0950	6	4	83	23	5.5	9	BGT			100	27			.0389	173	[illegible]

GROUP I--6-11-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
3	1B	0950	6	4	83	23	5.5	9	BGT	50	14	50	23			.0444	120	H
	1C	0950	6	4	83	23	5.5	9	BGT	40	23	40	25	20		.0553	87	H
5	1A	1400	6	15	67	18	2.5	40	BT	15	10	15	17	70		.1470	20	H
7	1A	1230	6	8	86	15	3	25	B	60	13			40		.5200	48	H
	1B	1230	6	8	89	13	3	25	B	60	10			40		.2000	14	H
8	1A	1245	6	14	83	15	3	42	BT					100		.3333	5	H
9	1A	1150	6 1/6	10	88	15	6	18	B	25	19	10	29	65		.3440	12	H
2	1A	1240	6 1/3	16	87	29	4	35	G	80	10			20		.5375	34	H
3	1A	0400	6	3	69	51	6	7	BG	100	30					.0223	152	R
	1B	0400	6	3	69	51	6	7	BG			65	26	35		.0400	21	H
	1C	0400	6	3	69	51	6	7	BG	85	20	15	18			.0633	61	H
4	1A	1400	9	12	86	18	5	18	B	50	9	50	5			.1510	22	H
	1B	1400	9	12	86	18	5	18	B	70	6	30	13			.0378	49	F
9	1A	0913	8 3/4	13	88	29	5.5	18	B	45	10			55		.6419	1	H
	1B	0913	8 3/4	13	90	28	5.5	18	B	40	8	15	8	45		.7367	12	H
	1C	0913	8 3/4	13	90	28	5.5	18	B	30	8			70		.6943	28	H
	4A	0800	10	7	85	13	5	13	BT	35	11	20	10	45		.4500	9	H
	4B	0800	10	7	84	14	5	13	BT	55	11	15	10	30		.5150	8	H
	4C	0800	10	7	87	12	5	13	BT	50	16	20	10	30		.1150	70	F
	4D	0800	10	7	87	12	5	13	BT	100	27					.0450	51	F
	4E	0800	10	7	89	11	5	13	BT	15	8	60	8	25		.1820	122	H
	6A	0800	10	8	76	34	5.5	10	BT	100	13					.0280	134	R
	6B	0800	10	8	74	35	5.5	10	BT	100	16					.0259	103	R
	6C	0800	10	8	77	34	5.5	10	BT	100	7					.0250	90	R
	8A	0800	10	4	85	25	5	9	BT	100	11					.0380	167	R
	8B	0800	10	4	78	28	5	9	BT	100	14					.0180	131	R
6	1A	1300	9	5	87	26	5	10	T			100	10			.0267	10	H
	1B	1300	9	5	87	26	5	10	T			100	15			.0067	42	H
	1C	1300	9	5	87	26	5	10	T	100	14					.0222	54	H
	1D	1300	9	5	87	26	5	10	T	100	11					.0089	33	H
	1E	1300	9	5	85	27	5	10	T	85	17			15		.1578	46	H
[illegible]	1A	1400	8	6	94	10	3.5	18	BT	85	14	15	28			.1625	20	H
3	1A	1230	8 1/2	10	90	13	4	31	T	65	12			35		.2081	13	H
	1B	1230	8 1/2	10	90	13	4	31	T	60	11			40		.2409	9	H
	1C	1230	8 1/2	10	88	14	4	31	T	55	11	25	5	20		.2605	3	H

GROUP I—6-11-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD	
										SLOPE							
										UP		DOWN					
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind
62	1A	0900	9	7	80	22	3.5	11	BT	40	18	40	18	20		.0422	83
	1B	0900	9	7	79	23	3.5	11	BT	70	13	30	14			.0533	59
	1C	0900	9	7	78	23	3.5	11	BT	50	14	50	10			.0888	48
	1D	0900	9	7	78	23	3.5	11	BT	45	15	40	14	15		.1045	41
	1E	0900	9	7	77	24	3.5	11	BT	35	18	55	10	10		.1490	33
	1F	0900	9	7	78	23	3.5	11	BT	55	13	45	12			.1578	28
	1G	0900	9	7	76	25	3.5	11	BT	45	14	15	14	40		.1441	16
	1H	0900	9	7	78	23	3.5	11	BT	50	17	50	11			.1440	7
	1I	0900	9	7	78	23	3.5	11	BT	55	16	25	16	20		.1200	1
	1J	0900	9	7	77	24	3.5	11	BT	65	14	15	12	20		.1089	9
	1K	0900	9	7	76	25	3.5	11	BT	80	14			20		.0688	14
	1L	0900	9	7	77	24	3.5	11	BT	80	10			20		.0511	25
	1M	0900	9	7	77	24	3.5	11	BT	100	10					.0423	40
63	1A	1400	6	4	101	9	4.5	15	B	100	26					.0300	10
	1B	1400	6	4	101	9	4.5	15	B	60	21	40	10			.0867	18
	1C	1400	6	4	100	9	4.5	15	B	80	19			20		.1248	30
	1D	1400	6	4	99	9	4.5	15	B	100	17					.1499	41
	1E	1400	6	4	98	10	4.5	15	B	75	20			25		.1667	49
	1F	1400	6	4	100	9	4.5	15	B	100	19					.1300	58
64	1A	1300	6	8	61	45	10	7	B	70	20	10	23	20		.1561	34
	1B	1300	6	8	59	46	10	7	B	75	23	25	24			.2040	29
	1C	1300	6	8	57	47	10	7	B	70	25			30		.2265	20
	1D	1300	6	8	57	47	10	7	B	90	22			10		.2000	11
65	1A	1300	10	15	89	41	9	18	B	25	23	10	14	65		.2087	23
	1B	1300	10	15	87	42	9	18	B	30	21	10	12	60		.2279	19
	1C	1300	10	15	88	42	9	18	B	20	18	10	15	70		.2450	16
	1D	1300	10	15	89	41	9	18	B	20	18	10	11	70		.2660	13
	1E	1300	10	15	90	41	9	18	B	10	15			90		.2660	9
	1F	1300	10	15	86	42	9	18	B	20	16			80		.3421	8
67	1A	0730	6½	6	83	14	5.5	13	B			50	16	50		.1908	2
68	3A	1100	7	20	76	21	3.5	48	T	10	19	15	12	75		.4000	9
	3B	1100	7	20	74	22	3.5	48	TG	20	19	15	12	65		.4680	5
	3C	1100	7	20	76	22	3.5	48	TG	10	13	10	12	80		.5030	1
69	1A	0900	6	10	78	20	3.5	25	B					100		.4230	29
	1B	0900	6	10	78	20	3.5	25	B					100		.4470	24

GROUP I—6-11-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPEED		
										SLOPE								
										UP		DOWN						
re o.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
9	1C	0900	6	10	79	20	3.5	25	B					100		.4660	14	H
	1D	0900	6	10	79	20	3.5	25	B					100		.4600	9	H
	1E	0900	6	10	76	22	3.5	25	B					100		.4430	5	H
1	1E	1100	7	10	80	50	6.5	5	BT					100		.2380	35	H
	1G	1100	7	10	80	50	6.5	5	BT					100		.2030	40	H
	1H	1100	7	10	80	50	6.5	5	BT					100		.1680	47	F
2	1A	0930	10½	3	78	27	5.5	8	T	50	18	50	10			.0380	96	F
	1B	0930	10½	3	77	28	5.5	8	T	55	17	45	12			.0420	61	F
	1C	0930	10½	3	77	28	5.5	8	T	35	10			65		.1160	58	H
	1D	0930	10½	3	78	27	5.5	8	T					100		.1820	49	H
	1E	0930	10½	3	79	27	5.5	8	T					100		.2260	46	H
	1F	0930	10½	3	79	27	5.5	8	T					100		.2460	41	H
	1G	0930	10½	3	79	27	5.5	8	T					100		.2800	36	H
	1H	0930	10½	3	79	27	5.5	8	T			25	10	75		.1860	29	H
	1I	0930	10½	3	79	27	5.5	8	T			100	10			.1320	20	H
	1J	0930	10½	3	79	27	5.5	8	T			100	10			.1340	10	H
	1K	0930	10½	3	79	27	5.5	8	T			30	10	70		.1080	5	H
	1L	0930	10½	3	78	27	5.5	8	T					100		.1080	19	H
	1M	0930	10½	3	78	28	5.5	8	T			50	10	50		.1000	43	F
	1N	0930	10½	3	77	28	5.5	8	T			20	10	80		.0740	60	F
	1O	0930	10½	3	77	28	5.5	8	T	60	10			40		.0560	80	F
	1P	0930	10½	3	77	28	5.5	8	T	70	10	30	10			.0520	102	F
	1Q	0930	10½	3	76	28	5.5	8	T	100	10					.0500	129	R
	1R	0930	10½	3	76	28	5.5	8	T	100	12					.0420	146	R
	1S	0930	10½	3	77	28	5.5	8	T	100	14					.0300	171	R
4	1A	1930	10½	10	70	70	13	3	BT					100		.2413	4	H
	1B	1930	10½	10	70	70	13	3	BT					100		.5710	15	H
	1C	1930	10½	10	70	70	13	3	BT					100		.2410	36	H
	1D	1930	10½	10	70	70	13	3	BT					100		.4050	35	H
5	1A	2200	11	10	53	58	9	5	BTH			100	10			.0127	120	F
	1B	2200	11	10	53	58	9	5	BTH					100		.0328	80	F
	1C	2200	11	10	51	59	9	5	BTH	80	17			20		.0854	14	H
	1D	2200	11	10	52	58	9	5	BTH	100	18					.0309	4	H
	2A	0900	9	20	57	35	65	27	BTH	10	11	65	11	25		.1400	57	O
	2B	0900	9	20	55	36	6.5	27	BTH					100		.1555	36	O

GROUP I—6-11-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
75	2C	0900	9	20	53	37	6.5	27	BTH			25	10	75		.1556	33	O
	2D	0900	9	20	55	36	6.5	27	BTH			100	16			.0911	28	O
	2E	0900	9	20	55	36	6.5	27	BTH			100	17			.0889	40	O
	2F	0900	9	20	53	36	6.5	27	BTH			100	16			.0511	92	O
	2G	0900	9	20	53	37	6.5	27	BTH	20	22			80		.0444	142	O
	2H	0900	9	20	58	35	6.5	27	BTH	70	10			30		.0400	90	O
	2I	0900	9	20	59	34	6.5	27	BTH	10	10	60	10	30		.0555	152	O
76	2A	1200	6	13	77	24	4	29	B			100	10			.0800	22	F
	2B	1200	6	13	77	24	4	29	B			100	10			.1200	5	F
	2C	1200	6	13	77	24	4	29	B			80	10	20		.1600	5	H
	2D	1200	6	13	77	24	4	29	B			80	10	20		.1800	15	H
	2E	1200	6	13	77	24	4	29	B			85	10	15		.2100	20	H
	2F	1200	6	13	78	24	4	29	BT			90	10	10		.3300	24	H
	2G	1200	6	13	78	24	4	29	BT			100	10			.3770	32	H
	2H	1200	6	13	79	24	4	29	BT			65	13	35		.3639	25	H
	2I	1200	6	13	79	24	4	29	BT			75	11	25		.4248	26	H
	2J	1200	6	13	79	24	4	29	BT			90	10	10		.4440	28	H
	2K	1200	6	13	80	23	4	29	BT			100	13			.5570	29	H
	2L	1200	6	13	79	24	4	29	BT	10	18	65	10	25		.8550	36	H
	2M	1200	6	13	80	23	4	29	BT	15	13	60	12	25		.7150	40	H
	2N	1200	6	13	78	24	4	29	BT	30	11	50	13	20		.8675	38	H
	2O	1200	6	13	78	24	4	29	BT	30	13	45	12	25		.8850	46	H
	2P	1200	6	13	78	24	4	29	BT	25	14	50	12	25		.9160	50	H
	2Q	1200	6	13	78	24	4	29	BT	10	13	40	16	50		1.480	53	H
	2R	1200	6	13	78	24	4	29	BT	10	19	50	12	40		.9350	57	H
	2S	1200	6	13	79	24	4	29	BT	10	22	45	14	45		.7900	62	H
	2T	1200	6	13	77	24	4	29	BT			55	16	45		.3900	65	H
	2U	1200	6	13	74	26	4	29	B			100	20			.2000	74	H
	2V	1200	6	13	74	25	4	29	B			60	10	40		.1200	81	H
	2W	1200	6	13	75	25	4	29	B			100	10			.0467	38	F
77	3A	1200	8	15	92	20	8	20	BG	50	13	25	13	25		.0760	45	H
	3B	1200	8	15	92	20	8	20	BG	20	19	35	12	45		.0800	30	H
	3C	1200	8	15	92	20	8	20	BG	30	21	50	21	20		.0940	19	H
	3D	1200	8	15	92	20	8	20	BG	20	11	40	18	40		.1100	13	H
	3E	1200	8	15	92	20	8	20	BG	15	18	30	22	55		.1260	8	H

GROUP I--6-11 Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
[Fir]e [N]o.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
7	3F	1200	8	15	92	20	8	20	BG	10	22	60	15	30		.1420	2	H
	3G	1200	8	15	95	19	8	20	BG	20	15	70	15	10		.1300	11	H
	3H	1200	8	15	95	19	8	20	BG			60	16	40		.1000	18	H
	3I	1200	8	15	95	19	8	20	BG			100	20			.0200	38	H
	3J	1200	8	15	95	19	8	20	BG			100	20			.0140	64	H
	3K	1200	8	15	93	18	8	20	BG			100	14			.0100	102	H
	3L	1200	8	15	93	18	8	20	BG			100	10			.0100	103	H
0	4A	1200	6	13	90	14	6	31	G	25	14	45	28	30		.0666	50	H
	4B	1200	6	13	88	15	6	31	G	40	22	60	17			.0700	39	H
1	2A	1030	8½	18	72	14	5	38	GB					100		.3741	12	H
	2B	1030	8½	18	72	14	5	38	TG					100		.4235	7	H
	2C	1030	8½	18	72	14	5	38	TG					100		.4376	1	H
5	1A	1430	7.5	7	81	24	5.5	10	T					100		.0720	55	H
	1B	1430	7.5	7	81	24	5.5	10	T					100		.2580	46	H
	1C	1430	7.5	7	81	24	5.5	10	T					100		.2960	37	H
	1D	1430	7.5	7	81	24	5.5	10	T			100	8			.2080	24	H
	1E	1430	7.5	7	81	24	5.5	10	T					100		.1572	79	H
	2A	2200	8	5	63	43	6.5	5	T					100		.0275	70	F
	2B	2200	8	5	63	43	6.5	5	T					100		.0388	80	F
	2C	2200	8	5	63	43	6.5	5	T					100		.0575	75	F
	2D	2200	8	5	63	43	6.5	5	T					100		.0388	4	F
	2E	2200	8	5	63	43	6.5	5	T	30	8	70	18			.0825	22	F
	2F	2200	8	5	63	43	6.5	5	T	100	14					.0325	45	F
	3A	0600	10	15	78	16	5	28	T					100		.0400	96	F
	3B	0600	10	15	78	16	5	28	T					100		.0780	90	F
	3C	0600	10	15	79	15	5	28	T	20	21	25	35	55		.5500	20	H
	3D	0600	10	15	78	16	5	28	T	55	10	25	12	20		.3260	6	H
	3E	0600	10	15	78	16	5	28	T					100		.2800	6	H
	6A	2100	9	14	52	59	7	9	T					100		.1730	7	H
	6B	2100	9	14	52	59	7	9	T					100		.0910	7	H
	6C	2100	9	14	52	59	7	9	T					100		.1975	4	H
	6D	2100	9	14	52	59	7	9	T					100		.0356	14	H
	6E	2100	9	14	52	59	7	9	T					100		.0333	21	H
8	1A	1200	6	12	78	27	7.5	18	T					100		.7410	6	H
8	1A	1730	6.5	8	86	30	5	12	T	66⅔	18	33⅓	36			.0038	7	H

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
88	1B	1730	6.5	8	86	30	5	12	T	100	17					.0050	45	H
	1C	1730	6.5	8	86	30	5	12	T	100	14					.0075	77	H
	1D	1730	6.5	8	86	30	5	12	T	100	23					.0029	95	F
	1E	1730	6.5	8	86	30	5	12	T			100	19			.0025	153	F
89	1A	0900	6	12	94	27	5	18	B	45	24	15	13	40		.0330	52	H
	1B	0900	6	12	95	26	5	18	B					100		.1495	54	H
	1C	0900	6	12	94	27	5	18	B	45	17	30	9	25		.1567	68	H
	1D	0900	6	12	93	27	5	18	B	60	15	40	3			.1865	77	H
	1E	0900	6	12	92	28	5	18	B	60	18			40		.2162	89	H
	1F	0900	6	12	92	27	5	18	B	100	21					.1500	95	H
93	1A	2100	9	3	68	34	6.0	7	B	25	14	75	20			.0490	113	O
	1B	2100	9	3	68	34	6	7	B	45	19	55	27			.0312	93	O
	1C	2100	9	3	68	34	6	7	B			65	31	35		.0466	34	O
	1D	2100	9	3	68	34	6	7	B			40	28	60		.0423	121	O
	1E	2100	9	3	68	34	6	7	B			20	22	80		.0445	146	O
	1F	2100	9	3	68	34	6	7	B					100		.0623	170	O
	1G	2100	9	3	68	34	6	7	B			15	13	85		.0576	174	O
94	2A	0600	11	10	87	23	5.5	18	T	35	15	10	19	55		.1310	84	H
	2B	0600	11	10	88	22	5.5	18	T	100	9					.1071	50	H
	2C	0600	11	10	88	22	5.5	18	T	65	16			35		.0763	51	F
	2D	0600	11	10	88	23	5.5	18	T	55	7			45		.0781	43	H
	2E	0600	11	10	90	21	5.5	18	T					100		.0728	37	H
95	1A	0600	7	39	80	11	4.5	92	G	25	16	20	12	55		.7540	2	H
	1B	0600	7	39	80	11	4.5	92	G	40	16	35	21	25		.7770	10	H
97	1A	1230	8	23	89	23	8	39	TB					100		1.1100	25	H
	1B	1230	8	23	89	23	8	39	TB					100		1.1040	22	H
	1C	1230	8	23	89	23	8	39	TB					100		1.0880	23	H
	1D	1230	8	23	89	23	8	39	TB					100		1.0680	19	H
	1E	1230	8	23	89	23	8	39	TB					100		.9600	21	H
98	2A	0800	10	15	91	40	8	13	B					100		.2222	19	H
	2B	0800	10	15	91	40	8	13	B					100		.3400	18	H
	2C	0800	10	15	91	40	8	13	B					100		.5800	4	H
	2D	0800	10	15	91	40	8	13	B					100		.3600	8	H
	2E	0800	10	15	91	40	8	13	B					100		.1000	29	H
100	1A	1030	7.5	13	104	14	3.5	32	B					100		.1920	70	F

GROUP I—6-11-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
re o.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
00	1B	1030	7.5	13	104	13	3.5	32	B	80	10	20	10			.2110	60	F
	1C	1030	7.5	13	104	14	3.5	32	B	70	10	30	10			.2400	57	F
	1D	1030	7.5	13	103	14	3.5	32	B	50	10			50		.2290	48	F
	1E	1030	7.5	13	103	14	3.5	32	B	50	10			50		.2370	110	F
	1F	1030	7.5	13	104	14	3.5	32	B	60	10			40		.3340	47	H
	1G	1030	7.5	13	104	14	3.5	32	B	65	10			35		.3470	32	H
	1H	1030	7.5	13	105	13	3.5	32	B	35	10	35	10	30		.3230	24	H
	1I	1030	7.5	13	106	13	3.5	32	B	50	10	50	10			.2400	19	H
	1J	1030	7.5	13	106	13	3.5	32	B	50	10	50	10			.2270	12	H
	1K	1030	7.5	13	105	13	3.5	32	B	50	10	50	10			.2110	3	H
	1L	1030	7.5	13	105	13	3.5	32	B	40	10			60		.2080	6	H
	1M	1030	7.5	13	106	13	3.5	32	B	35	10	65	10			.2130	16	H
	1N	1030	7.5	13	106	13	3.5	32	B	35	10	30	16	35		.2210	23	H
	1O	1030	7.5	13	106	13	3.5	32	B	60	10	40	11			.2080	31	F
	1P	1030	7.5	13	105	13	3.5	32	B	60	10	40	10			.1730	31	F
	1Q	1030	7.5	13	106	13	3.5	32	B	70	10	30	10			.1650	49	F
04	1A	1630	7.5	15	85	6	3	48	B					100		.3578	50	H
	1B	1630	7.5	15	86	6	3	48	B					100		.4451	40	H
	1C	1630	7.5	15	86	6	3	48	B					100		.2880	31	H
	1D	1630	7.5	15	86	6	3	48	B					100		.3020	81	H
	1E	1630	7.5	15	86	6	3	48	B					100		.4960	73	H
	1F	1630	7.5	16	86	6	3	48	B					100		.6350	67	H
06	1A	1300	11	0	94	17	3.5	11	TG	50	12			50		.1909	179	H
	1B	1300	11	0	96	16	3.5	11	TG	50	12	50	10			.1909	172	H
	1C	1300	11	0	97	16	3.5	11	TG	50	10	35	9	15		.1909	164	H
	1D	1300	11	0	97	16	3.5	11	TG	75	7	25	19			.1909	159	H
	1E	1300	11	0	98	15	3.5	11	TG			25	11	75		.1682	148	H
	1F	1300	11	0	98	15	3.5	11	TG					100		.1682	135	H
	1G	1300	11	0	98	15	3.5	11	TG	25	7			75		.2273	128	H
	1H	1300	11	0	97	16	3.5	11	TG					100		.2864	119	H
	1I	1300	11	0	97	16	3.5	11	TG					100		.2818	113	H
	1J	1300	11	0	97	16	3.5	11	TG					100		.2636	107	H
0	1A	1245	6¼	6	86	19	4.5	15	T	100	14					.1439	5	H
	1B	1245	6¼	6	86	19	4.5	15	T	80	23			20		.1439	2	H
	1C	1245	6¼	6	86	19	4.5	15	T	100	15					.0080	16	H

GROUP I—6 11-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI		%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
110	1D	1245	6 1/4	6	86	19	4.5	15	T	90	13			10		.1730	22	H
	1E	1245	6 1/4	6	86	19	4.5	15	T			60	10	40		.0054	38	F

GROUP II—12-Hour Periods

FIRE			WEATHER						TOPOGRAPHY						SPREAD		
									SLOPE								
									UP		DOWN						
Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
2A	0600	12	10	94	20	4.0	24	B	80	25			20		.0417	60	F
2B	0600	12	10	90	22	4.5	24	B	100	26					.0354	15	H
2C	0600	12	10	90	22	4.5	24	B	45	15	30	16	25		.1500	20	H
2D	0600	12	10	98	19	4.0	24	B	60	30	40	25			.0450	66	F
3A	1800	12	0	56	47	6.5	5	B			95	27	5		.0104	—	R
3B	1800	12	0	58	48	6.5	5	B			100	11			.0312	—	R
3C	1800	12	0	57	48	6.5	5	B			100	24			.0250	—	R
3D	1800	12	0	63	46	6.5	5	B			70	14	30		.0375	—	R
3E	1800	12	0	67	44	6.5	5	GH			100	11			.0312	—	R
4A	0600	12	10	93	20	4.0	33	B	50	9			50		.0563	59	R
5A	1800	12	3	63	37	6.0	8	B			30	24	70		.0584	66	R
5B	1800	12	3	63	36	6.0	8	B			100	23			.0292	128	R
5C	1800	12	0	58	38	5.0	7	B	45	33			55		.0500	—	R
6A	0600	12	10	86	28	3.5	24	BT	100	19					.1851	2	H
6B	0600	12	10	87	27	3.5	24	BT	100	20					.1812	10	H
6C	0600	12	10	90	26	3.5	24	BT	80	23	20	11			2082	0	H
6D	0600	12	10	90	26	3.5	24	T	90	13			10		2979	73	F
6E	0600	12	10	93	25	3.5	24	T	75	8			25		.2643	4	H
6F	0600	12	10	88	27	4.5	24	B	100	12					.2200	137	F
7A	1800	12	3	54	45	5.5	7	T	100	22					.0563	135	O
7B	1800	12	3	51	45	5.5	7	T	100	26					.0417	159	O
7C	1800	12	3	48	45	5.5	7	T	15	17			85		.0312	116	O
7D	1800	12	3	54	44	5.5	7	B			70	34	30		.0375	94	O
7E	1800	12	0	55	43	5.0	5	B			100	14			.0167	—	O
8A	0600	12	10	78	27	4.0	24	T	15	23	15	10	70		.1200	123	H
8B	0600	12	10	84	26	4.0	24	BT					100		.0208	74	F
8C	0600	12	10	83	26	4.0	24	T	30	24			70		.0563	70	F
4A	0600	12	14	84	35	5.5	22	B	50	10	15	17	35		.0146	133	R
4B	0600	12	14	84	35	5.5	22	B			70	11	30		.0208	123	R
4C	0600	12	14	84	35	5.5	22	B			100	15			.0219	170	R
4D	0600	12	14	84	35	5.5	22	B			100	11			.0104	154	R
5A	1800	12	14	67	46	6.5	15	B			80	11	20		.0656	163	R
3B-2C	1800	12	25	71.4	12.3	2.2	25	B	40	22	20	31	40		.0658	27	H
3C-2D	1800	12	25	73.1	11.5	2.2	25	B	10	16	80	19	10		.1083	16	H
3D-2E	1800	12	25	72.5	11.8	2.2	25	B	35	11	40	33	25		.0675	0	H

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Ty
4	3E-2F	1800	12	25	72.7	11.7	2.2	25	B	40	8	45	30	15		.0595	16	
5	2A	1800	12	5	73	31	3.5	10	B					100		0167	100	
	2B	1800	12	5	73	31	3.5	10	B			40	18	60		.0417	96	
6	2A	1600	12	2	79	25	3.0	8	B			25	49	75		.0292	9	
	2B	1600	12	2	79	25	3.0	8	B	55	21	45	13			.0667	87	
7	2A	1800	12	5	66	65	6	4	B	45	15			55		.0917	4	
	2B	1800	12	5	66	65	6	4	B	50	22			50		.0583	21	
9	2A	2000	12	8	61	58	4	9	B	40	21	60	11			.0333	136	
	2B	2000	12	8	61	58	4	9	B			45	16	55		.0625	69	
	2C	2000	12	8	61	58	4	9	B			20	18	80		.0500	101	
	2D	2000	12	8	61	58	4	9	B	80	17	25	20	45		.1458	24	
	2E	2000	12	8	61	58	4	9	B	10	12	25	17	65		.2500	7	
	2F	2000	12	8	61	58	4	9	B	80	22	20	24			.1250	49	
	3A	0800	12	7	80	9	3	21	B	50	27	25	16	25		.1332	43	
	4A	2000	12	10	57	20	3.5	22	B	55	15	25	24	20		.2540	31	
	5A	0800	12	8	79	24	4	16	B			45	30	55		.1041	24	
10	2A	1700	12	14	79	34	4.5	24	B	100	10					0125	19	
11	2A	1800	12	18	88	32	5	32	G	70	12	30	19			.0666	171	
12	2A	1800	12	3	65	42	9.0	6	TGH	35	31			65		.0250	172	
	2B	1800	12	3	65	42	9.0	6	TGH	35	27	65	19			.0458	165	
	3A	0600	12	8	86	22	6.5	15	TGH	65	12			30		.0250	110	
	4A	1800	12	4	65	45	8.0	6	TGH	10	27	65	16	25		.0750	9	
	4B	1800	12	4	62	51	8.5	7	TGH			55	11	45		.0500	164	
	4C	1800	12	0	65	45	8.0	4	TGH			15	14	85		.0418		
	5A	0600	12	8	83	27	6.5	15	TGH	40	34			60		.0250	38	
	5B	0600	12	8	81	28	6.5	15	TGH	100	10					.0292	91	
	5C	0600	12	14	80	28	6.5	28	GH	90	19			10		.1583	22	
	6A	1800	12	4	62	54	8.5	4	GH	100	12					.0477	150	
	6C	1800	12	2	62	54	8.5	4	GH			100	15			.0167	19	
	7B	0600	12	10	78	27	6	18	GH	55	18			45		.0417	163	
	8A	1800	12	0	62	54	8.5	2	GH	100	35					0083		
	8B	1800	12	0	62	54	8.5	2	GH	40	27			60		.0083		
	10A	0600	12	8	83	15	5.5	18	GH			50	18	50		.0250	102	
	12A	0600	12	8	78	34	5.5	12	H	100	18					.0250	58	
	14A	0600	12	8	77	27	5.5	15	H	80	17	20	27			.0333	93	

GROUP II—12-Hour Periods

Fire: Line No.	Fire: Time of Start	Fire: Hours of Spread	Weather: Wind Vel.	Weather: Temp	Weather: RH	Weather: Stick	Weather: BI	FUEL	Topography: Slope Up %	Topography: Slope Up Aver. Deg.	Topography: Slope Down %	Topography: Slope Down Aver. Deg.	Topography: Percent Flat	Topography: Sketch	Spread: Rate	Spread: Angle to Wind	Spread: Type
2A	0600	12	14	88	11	3.0	38	B	65	8	35	11			.2000	34	H
2B	0600	12	14	89	10	3	38	B	25	5	40	13	35		.2917	10	H
2C	0600	12	14	88	11	3	38	B	100	10					.0833	9	H
3A	1800	12	5	64	25	4	11	B	100	3					.0917	54	H
3B	1800	12	5	64	25	4	11	B			35	15	65		.0500	130	O
4A	0600	12	16	87	11	3	48	B			100	7			.1417	96	H
4B	0600	12	16	85	12	3	48	B	45	12			55		.1071	3	H
4C	0600	12	16	88	10	3	48	B					100		.0500	165	H
5A	1800	12	2	67	37	5	6	B			100	14			.0333	93	O
6A	0600	12	22	93	16	4	16	B	85	6	15	13			.0750	102	H
7A	1800	12	6	72	30	5	10	B					100		.0333	31	H
2A	0600	12	10	91	19	5	26	G	40	14	10	27	50		.1400	125	F
2A	1800	12	2	63	53	6	4	B			100	10			.0333	20	H
2B	1800	12	2	63	53	6	4	B	45	10	55	14			.0083	94	F
3A	0600	12	7	82	44	4	9	B	30	11	35	16	35		.0667	117	H
3B	0600	12	7	80	44	4	9	B	40	12	20	18	40		.1000	169	H
3C	0600	12	7	85	43	4	9	B	100	18					.0167	34	F
4A	1800	12	2	62	57	6	4	B			25	18	75		.0167	31	O
5A	0600	12	9	85	48	4.5	10	B					100		.0167	173	O
6A	0600	12	12	61	75	7	3	B	100	27					.0083	147	O
7A	0600	12	12	61	75	7	3	B	45	10	55	10			.0083	65	O
5A	0600	12	11	82	30	4.5	18	B			100	22			.0083	136	R
6A	1800	12	4	64	49	5.5	5	B	30	22	70	31			.0333	10	H
8A	0600	12	9	65	36	5	10	B	75	10	25	14			.0083	144	F
9A	1800	12	8	78	34	5.5	9	B			100	29			.0125	122	F
10A	1800	12	3	61	60	6.5	3	B			100	10			.0167	38	F
11A	0600	12	11	77	35	5.5	12	B			100	10			.0083	145	R
2A	0400	12	2	60	26	4.5	8	T	15	28	85	13			.0250	141	R
3A	1600	12	3	46	38	5.5	7	T	85	11	15	10			.0500	5	H
4A	0400	12	3	58	29	4.5	9	T			100	10			.0250	33	O
4B	0400	12	3	59	29	4.5	9	T					100		.0167	109	O
5A	1600	12	0	45	50	6	4	T			100	18			.0083		O
6A	0400	12	8	59	30	5	11	T			100	12			.0333	28	H
7A	1600	12	4	45	49	6	6	T	75	10	25	18			.0333	48	H
7B	1600	12	4	45	49	6	6	T			100	15			.0167	45	F

GROUP II—12-Hour Periods

FIRE: Fire No.	FIRE: Line No.	FIRE: Time of Start	FIRE: Hours of Spread	WEATHER: Wind Vel.	WEATHER: Temp.	WEATHER: RH	WEATHER: Stick	WEATHER: BI	FUEL	TOPOGRAPHY: SLOPE UP %	TOPOGRAPHY: SLOPE UP Aver. Deg.	TOPOGRAPHY: SLOPE DOWN %	TOPOGRAPHY: SLOPE DOWN Aver. Deg.	TOPOGRAPHY: Percent Flat	TOPOGRAPHY: Sketch	SPREAD: Rate	SPREAD: Angle to Wind	SPREAD: Type
19	8A	0400	12	12	59	23	5	19	T			85	12	15		.1000	10	H
	9A	1600	12	6	45	37	5.5	9	T					100		0750	0	H
	9B	1600	12	6	45	37	5.5	9	T					100		.0333	59	F
	10A	0400	12	17	55	24	5	30	T					100		.0167	62	H
	11A	1600	12	8	43	36	5.5	10	T	100	10					.0167	91	H
	12A	0400	12	15	56	25	5	25	T	100	27					.0167	127	H
20	1A	1800	12	21	54	11	3	78	B			100	20			.0502	57	F
	1B	1800	12	21	54	11	3	78	B	75	19			25		.0502	127	F
	1C	1800	12	21	54	11	3	78	B	60	15	40	18			.0943	65	H
	1D	1800	12	21	54	11	3	78	B	40	16	50	24	10		.1162	45	H
	1E	1800	12	21	54	11	3	78	B	10	13	90	10			.1260	20	H
	2A	0600	12	16	73	9	3	64	B	60	25	25	22	15		.0693	117	H
	2B	0600	12	16	76	10	3	58	B	70	16	30	19			.0345	92	H
	3A	1800	12	15	56	16	3	42	B	65	22	35	24			.0474	178	H
	3B	1800	12	15	56	16	3	42	B	30	11	70	10			.0785	117	H
	4A	1800	12	15	67	9	3	52	B	85	24			15		.0504	141	H
	4B	0600	12	15	67	9	3	52	B	35	17	65	11			.2900	12	H
	5A	1800	12	4	58	17	3	13	B	70	17			30		.0286	157	O
	5B	1800	12	4	58	17	3	13	B			30	27	70		.0220	76	H
	5C	1800	12	4	58	17	3	13	B			100	22			0315	40	O
	6A	0600	12	10	75	7	2.5	34	B	60	20	40	25			.0378	177	F
	6B	0600	12	10	76	8	2.5	34	B	45	19	55	16			0503	125	H
	6C	0600	12	10	76	8	2.5	34	B	20	10			80		.0692	92	H
	7A	1800	12	4	62	18	3.5	13	B	45	17	30	26	25		.0252	166	H
21	2A	1800	12	3	64	38	5	6	B	75	26			25		.0833	34	H
	2B	1800	12	3	64	38	5	6	B	40	34			60		.1082	1	[illegible]
23	2A	2100	12	36	42	42	9.5	36	G BT					100		.1659	29	[illegible]
24	2A	1700	12	14–20	65	22	8	39	G	10	10	15	10	75		.6370	47	[illegible]
26	2A	1000	12	20	82	37	7.5	25	BT	80	15	20	10			.0750	24	[illegible]
	2B	1000	12	20	82	37	7.5	25	T	100	10					.0695	25	[illegible]
	3A	2200	12	2	65	45	8.0	4	B	100	16					.0167	162	[illegible]
27	3A	0800	12	4	68	22	5.5	7	BT					100		.0556	62	[illegible]
	3B	0800	12	4	68	22	5.5	7	BT					100		.0389	7	[illegible]
29	2A	0600	12	16	88	12	3.0	57	G					100		.0918	23	[illegible]
	2B	0600	12	16	88	12	3.0	57	G			30	1	70		.1225	76	[illegible]

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
re lo.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
9	2C	0600	12	16	88	12	3.0	57	G			60	18	40		.1710	52	H
	2D	0600	12	16	88	12	3.0	57	G	10	18	50	17	40		.1795	7	H
	3A	1800	12	12	64	27	3.0	32	G	30	11	20	12	50		.2210	94	H
	3B	1800	12	12	64	27	3.0	32	G	25	12	75	13			.1390	37	H
	3C	1800	12	12	64	27	3.0	32	G	20	14	55	15	25		.1665	72	H
	3D	1800	12	12	64	27	3.0	32	G	75	11	25	16			.1125	100	H
	4A	0600	12	3-5	84	17	3.0	17	BT					100		.0945	40	O
	4B	0600	12	3-5	84	17	3.0	17	BT			25	13	75		.0945	71	O
	4C	0600	12	3-5	84	17	3.0	17	BT	15	10	25	10	60		.1975	75	O
	4D	0600	12	3-5	84	17	3.0	17	BT			15	10	85		.0347	110	O
	5A	1800	12	3	60	38	4.0	11	BT	100	10					.0333	28	H
	5B	1800	12	3	60	38	4.0	11	BT	50	10			50		.0806	115	H
	5C	1800	12	3	60	38	4.0	11	BT					100		.0306	140	O
	5D	1800	12	3	60	38	4.0	11	BT			100	12			.1210	134	O
	6A	0600	12	18	88	18	3.5	50	BT	35	12	65	12			.1265	7	H
	6B	0600	12	18	88	18	3.5	50	BT	50	13	50	12			.1505	14	H
	7A	1800	12	16	64	39	4.0	36	BT	35	10	15	18	50		.0563	70	H
	8A	0600	12	20	84	21	2.5	60	BT	85	10	15	18			.0640	16	H
	8B	0600	12	20	84	21	2.5	60	BT					100		.1015	11	H
	9A	1800	12	16	62	41	4.0	35	BT	35	11	65	11			.0668	50	H
	9B	1800	12	16	62	41	4.0	35	BT	50	10	60	10			.1155	57	H
	9C	1800	12	16	62	41	4.0	35	BT			100	10			.0319	130	F
	9D	1800	12	16	62	41	4.0	35	BT			100	10			.0236	132	F
/	2A	2000	12	3	76	35	5.0	8	BT	100	9					.0334	152	H
	2B	2000	12	3	76	35	5.0	8	BT	100	10					.0444	178	H
	2C	2000	12	3	76	35	5.0	8	BT	100	13					.0389	174	H
	2D	2000	12	3	76	35	5.0	8	BT	100	10					.0341	176	H
	3A	0800	12	4	92	22	4.5	12	BT					100		.0542	8	H
	3B	0800	12	4	92	22	4.5	12	BT	60	17	40	10			.1155	8	H
	3C	0800	12	4	92	22	4.5	12	BT	100	17					.1180	158	H
	3D	0800	12	4	92	22	4.5	12	BT	100	24					.0722	79	F
2	4A	2130	12	4	74	22	5.0	9	B	40	34	45	35	15		.0431	147	H
	4B	2130	12	4	74	22	5.0	9	B	75	21			25		.0264	152	F
	5A	0930	12	6	85	21	4.0	15	B	100	26					.0612	95	H
3	2A	1550	12	0	72	33	6.0	5	BGT			100	16			.0181		O

GROUP II — 12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
33	2B	1550	12	0	72	33	6.0	5	BGT			100	17			.0208		O
	2C	1550	12	0	72	33	6.0	5	BGT	40	16	35	18	25		.0292		O
	3A	0350	12	7	85	19	5.5	11	BGT			100	10			.0097	164	R
	3B	0350	12	7	85	19	5.5	11	BGT			100	19			.0222	138	R
34	2A	2200	12	3	52	46	4.5	8	B					100		.0333	48	H
	3A	1000	12	7	61	52	5.5	8	B	40	12	60	10			.0319	85	F
	3B	1000	12	7	64	52	5.5	8	B			100	13			.0680	40	H
	3C	1000	12	7	65	51	5.5	8	BH	30	10	70	20			.0556	42	H
	3D	1000	12	7	65	51	5.5	8	BH	65	17	35	22			.0902	9	H
	4A	2200	12	3	59	55	6.0	4	H			100	10			.0139	40	H
	4B	2200	12	3	59	55	6.0	4	H			100	19			.0195	41	H
	4C	2200	12	3	59	55	6.0	4	H			100	32			.0208	14	H
35	2A	2000	12	2	49	41	4.5	6	BT	75	23			25		.0305	71	[illegible]
	2B	2000	12	2	49	41	4.5	6	BT	100	7					.0417	15	H
	3A	0800	12	10	63	25	2.5	23	BT	65	10	35	11			.1805	22	H
	3B	0800	12	10	64	26	2.5	23	BT					100		.0305	15	F
36	2A	0700	12	5	81	19	5	10	B	80	13	20	16			.1405	3	H
	2B	0700	12	5	81	19	5	10	B	35	10	65	17			.0806	29	H
	3A	1900	12	3	64	35	5.5	7	BT	60	21	40	30			.0139	54	H
	3B	1900	12	3	64	35	5.5	7	BT					100		.0264	82	H
	4A	0700	12	3	75	18	5	10	BT			100	18			.0319	129	[illegible]
37	2A	1830	12	2	64	32	5	6	B	100	5					.0716	55	H
	2B	1830	12	2	64	32	5	6	B	30	14			70		.0100	40	H
	2C	1830	12	2	64	32	5	6	B	45	8	55	14			.0233	27	[illegible]
	2D	1830	12	2	64	32	5	6	B	50	6	50	6			.0100	143	[illegible]
	2E	1830	12	2	64	32	5	6	B					100		.0092	70	[illegible]
	3B	0630	12	13	74	31	4	24	T	25	14			75		.1283	111	
	3C	0630	12	13	72	32	4	24	T	65	7	20	21	15		.2450	59	
	3D	0630	12	13	77	30	4	24	B			45	9	55		.3840	28	
	3E	0630	12	13	67	33	4	24	T			60	13	40		.2600	13	
	3F	0630	12	13	74	31	4	24	T			60	18	40		.2730	22	
	3G	0630	12	13	67	33	4	24	T			25	6	75		.1330	117	
42	2A	1800	12	3	69	75	6.5	3	G			100	21			.0052	81	
	2B	1800	12	3	69	75	6.5	3	G			100	8			.0026	34	
	2C	1800	12	3	69	75	6.5	3	G			100	26			.0095	22	

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
42	3A	0600	12	14	88	40	5	26	G			75	15	25		.0291	71	H
	3B	0600	12	14	88	40	5	26	G			100	26			.0104	114	O
	3C	0600	12	14	86	40	5	26	G			100	10			.0094	63	O
43	2A	1000	12	3	90	25	4.5	13	BG	85	34	15	25			.0483	22	H
	2B	1000	12	3	95	27	4.5	13	BG	65	20	35	22			.0667	124	H
	3A	2200	12	2	65	56	6	5	BG	100	22					.0457	134	H
	3B	2200	12	2	65	56	6	5	BG	25	26	75	16			.0150	81	O
	3C	2200	12	2	65	56	6	5	BG	100	24					.0216	130	O
	4A	1000	12	6	87	20	4.5	16	BG	100	24					.0112	123	H
	4B	1000	12	6	83	21	4.5	16	BG	45	25	45	26	10		.1450	102	H
	4C	1000	12	6	83	21	4.5	16	BG	20	22	50	22	30		.2038	84	H
	5A	2200	12	3	67	41	5.5	9	BG	85	22			15		.0083	126	H
	6A	1000	12	3	87	15	4.5	13	BG	60	25	40	17			.0384	103	H
	6B	1000	12	3	82	17	4.5	14	BG	85	26			15		.0384	156	H
46	1A	0600	12	4	87	16	4.5	12	B	75	10	25	26			.0772	149	F
	2A	1800	12	1	59	36	6.0	6	B	100	4					.0010	44	H
	2B	1800	12	1	59	36	6.0	6	B			50	9	50		.0150	105	H
	3A	0600	12	13	71	48	5.5	15	B	100	14					.0433	112	H
	4A	1800	12	8	57	62	7.5	5	B	85	8	15	22			.0651	3	H
	4B	1800	12	8	57	62	7.5	5	B	100	3					.0600	7	H
	4D	1800	12	8	57	62	7.5	5	B			100	19			.0133	47	O
	4E	1800	12	8	57	62	7.5	5	B	100	22					.0314	55	O
	5A	0600	12	6	81	28	7	8	B	20	11	80	8			.0468	30	O
	5B	0600	12	6	81	28	7	8	B			65	15	35		.0650	4	O
	5C	0600	12	6	81	28	7	8	B			70	14	30		.0833	27	O
	5D	0600	12	6	81	28	7	8	B			70	11	30		.0600	39	O
	5E	0600	12	6	81	28	7	8	B			100	6			.0663	70	O
	5F	0600	12	6	81	28	7	8	B			100	13			.0184	101	O
	6A	1800	12	3	64	28	6	7	B			100	16			.0234	0	O
	6B	1800	12	3	64	28	6	7	B	55	7	45	19			.0332	14	O
	7A	0600	12	10	82	11	4	27	BT					100		.0467	72	H
	7B	0600	12	10	83	11	4	27	BT			100	12			.0450	10	H
	7C	0600	12	10	82	11	4	27	BT			50	13	50		.1165	11	H
	8A	1800	12	2	67	20	4	27	BT			100	13			.0151	94	O
	9A	0600	12	23	92	9	3	86	B	60	14	25	15	15		.1816	141	H

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
46	11A	0600	12	15	74	29	3	33	B	100	16					.0417	13	H
47	2A	0600	12	8	92	23	5	15	B	55	12	15	7	30		.3333	58	H
	2B	0600	12	8	95	21	5	15	B	35	21	20	22	45		.2701	72	H
	2C	0600	12	8	96	20	5	17	B	15	9	70	11	15		.2990	79	H
	2D	0600	12	8	97	20	5	17	B	55	15	45	15			.1231	82	H
	2E	0600	12	8	97	20	5	17	B	55	10	45	13			.0749	96	H
	2F	0600	12	8	96	21	5	15	B	65	14	35	20			.0500	62	R
	2G	0600	12	8	96	21	5	15	B	60	17	40	14			.0683	111	R
	2H	0600	12	8	95	21	5	15	B	60	15	30	22	10		.0851	111	R
	2I	0600	12	8	93	22	5	15	B	35	24	25	16	40		.0802	99	R
	4A	0600	12	4	91	23	5	9	B			100	11			.0275	128	R
	4B	0600	12	4	91	23	5	9	B			100	10			.0158	131	R
	4C	0600	12	4	90	24	5	9	B			100	17			.0375	169	R
48	2A	0600	12	6	97	20	5	13	B	100	23					.0058	47	O
	2B	0600	12	6	97	20	5	13	B			100	31			.0075	46	O
	2C	0600	12	6	97	20	5	13	B	65	10	35	18			.0142	62	O
	2D	0600	12	6	96	21	5	11	B	45	23	55	18			.0150	87	O
	2E	0600	12	6	96	21	5	11	B	60	14			40		.0183	139	O
50	5A	0600	12	5	80	28	6.0	7	BT	100	35					.0225	64	H
	5B	0600	12	5	83	27	6.0	8	B	75	29	25	25			.0675	32	H
	5C	0600	12	5	83	27	6.0	8	B			65	30	35		.0167	44	H
	5D	0600	12	5	81	28	6.0	7	B			55	29	45		.0358	67	H
	5E	0600	12	5	78	29	6.0	7	B	55	29	10	16	35		.0350	119	H
	6A	1800	12	0	52	47	7.0	4	BT	60	34			40		.0125		O
	6B	1800	12	0	52	47	7.0	4	BT	45	30			55		.0116		O
	6C	1800	12	0	52	47	7.0	4	B	45	32	55	32			.0092		O
51	2A	1800	12	0	62	34	6.5	5	T	100	11					.0117		F
	2B	1800	12	0	62	34	6.5	5	T					100		.0082		F
	3A	0600	12	6	83	14	4.0	18	T			45	31	55		.0184	95	F
	3B	0600	12	6	81	15	4.0	18	T	70	27			30		.0283	37	H
	4A	1800	12	5	59	37	6.0	7	T	65	24			35		.0266	86	O
	4B	1800	12	5	59	37	6.0	7	T	80	25			20		.0285	54	O
52	2A	1800	12	0	62	34	6.5	5	T	70	15	30	15			.0067		C
	2B	1800	12	0	62	34	6.5	5	T			40	11	60		.0167		O
	2C	1800	12	0	62	34	6.5	5	T			100	15			.0083		C

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
ire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
52	2D	1800	12	0	62	34	6.5	5	T			100	39			.0133		O
	2E	1800	12	0	62	34	6.5	5	T			55	27	45		.0083		O
	2F	1800	12	0	62	34	6.5	5	T					100		.0050		O
	3A	0600	12	6	86	13	4.0	18	T	65	22	35	15			.0127	126	O
	3B	0600	12	6	82	14	4.0	18	T			100	27			.0133	121	O
	3C	0600	12	6	81	15	4.0	18	T			55	37	45		.0200	93	O
	3D	0600	12	6	78	16	4.0	16	T			55	15	45		.0266	22	O
	3E	0600	12	6	79	15	4.0	18	T					100		.0100	75	O
	3F	0600	12	6	86	13	4.0	18	T			100	27			.0500	62	O
	4A	1800	12	5	59	37	6.0	7	T			100	22			.0083	8	O
	4B	1800	12	5	59	37	6.0	7	T	100	37					.0050	50	O
	4C	1800	12	5	59	37	6.0	7	T			60	37	25		.0165	92	O
	4D	1800	12	5	59	37	6.0	7	T			15	16	80		.0133	151	O
	4E	1800	12	5	59	37	6.0	7	B			100	30			.0033	142	R
	4F	1800	12	5	59	37	6.0	7	B	100	11					.0033	48	H
	5A	0600	12	11	73	22	4.0	23	T			100	30			.0133	163	R
	5B	0600	12	11	79	19	4.0	26	T			100	19			.0167	148	R
	5C	0600	12	11	82	18	4.0	26	B	60	18	40	25			.0133	89	O
	5D	0600	12	11	81	19	4.0	26	T			100	17			.0133	52	O
	5E	0600	12	11	76	21	4.0	23	T					100		.0050	58	O
	6A	1800	12	2	60	48	5.0	6	T			100	23			.0241	25	O
	7A	0600	12	3	97	14	3.0	14	B			45	18	55		.0584	28	O
53	2A	0600	12	5	80	20	5.0	11	B			100	19			.0274	46	O
	2B	0600	12	5	81	20	5.0	11	B			100	14			.0186	54	O
	2C	0600	12	5	81	20	5.0	11	B	20	19	50	20	30		.0396	84	O
	2D	0600	12	5	79	20	5.0	11	H					100		.0211	117	O
	4A	1800	12	8	65	38	6.5	10	GBH	75	23	25	11			.0412	78	F
	4B	1800	12	8	65	38	6.5	10	H			46	14	55		.0610	17	H
	4C	1800	12	8	65	38	6.5	10	H	30	12	70	28			.0542	1	H
	4D	1800	12	8	65	38	6.5	10	H			60	15	40		.0389	29	H
	5A	0600	12	4	70	32	5.0	8	HB	50	25	35	17	15		.0300	25	H
	5B	0600	12	4	72	31	5.0	8	B	35	29	65	19			.0315	25	H
	5C	0600	12	4	73	31	5.0	8	H	25	25	75	24			.0274	17	H
	5D	0600	12	4	71	32	5.0	8	H			100	16			.0090	23	H
	5E	0600	12	4	75	30	5.0	8	B			70	25	30		.0137	8	H

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
53	6A	1800	12	2	63	45	7.0	4	BH	25	27	75	22			.0147	21	H
	6B	1800	12	2	63	45	7.0	4	H			70	20	30		.0200	18	H
	6C	1800	12	2	63	45	7.0	4	B			100	28			.0143	1	H
	6D	1800	12	2	63	45	7.0	4	BH	30	22	70	24			.0174	29	H
	6E	1800	12	2	63	45	7.0	4	BH			100	22			.0047	76	F
	6F	1800	12	2	63	45	7.0	4	H			100	12			.0089	105	F
	7A	0600	12	2	78	28	5.5	17	B	100	26					.0306	65	H
	7B	0600	12	12	80	26	5.5	19	B	100	13					.0137	93	H
	7C	0600	12	12	81	26	5.5	19	H	75	21	25	31			.0116	109	H
	7D	0600	12	12	80	27	5.5	19	B			100	12			.0179	123	H
	7E	0600	12	12	82	26	5.5	19	BH			100	13			.0353	145	R
	8A	1800	12	25	68	41	6.5	38	B	75	26			25		.0179	156	H
	8B	1800	12	25	68	41	6.5	38	BH			55	31	45		.0189	155	H
	8C	1800	12	25	68	41	6.5	38	B			100	36			.0131	166	R
	8D	1800	12	25	68	41	6.5	38	H			50	24	50		.0406	88	O
	8E	1800	12	25	68	41	6.5	38	H			100	17			.0605	89	O
	8F	1800	12	25	68	41	6.5	38	BH	20	15	80	15			.0964	25	O
	8G	1800	12	25	68	41	6.5	38	H			100	19			.0726	12	O
	8H	1800	12	25	68	41	6.5	38	H			100	16			.0358	14	O
	8I	1800	12	25	68	41	6.5	38	H	55	10	45	10			.0226	57	O
	8J	1800	12	25	68	41	6.5	38	H	75	12	25	15			.0289	106	O
54	4A	0600	12	3	93	20	4.0	12	B					100		.0110	31	O
	4B	0600	12	3	94	19	4.0	12	H			100	15			.0047	7	O
	4C	0600	12	3	88	21	4.0	12	B			100	13			.0142	86	O
	4D	0600	12	3	92	20	4.0	12	H	100	17					.0095	6	H
	4E	0600	12	3	90	21	4.0	12	H	35	15	35	22	30		.0158	17	O
	4F	0600	12	3	91	20	4.0	12	B			100	20			.0237	31	O
	4G	0600	12	3	90	21	4.0	12	B			55	40	45		.0205	87	O
	4H	0600	12	3	88	22	4.0	12	B			100	25			.0095	95	O
	5A	1800	12	0	71	39	4.5	7	B			100	7			.0120		O
	5B	1800	12	0	71	39	4.5	7	H			100	22			.0110		O
	5C	1800	12	0	71	39	4.5	7	B					100		.0047		O
	5D	1800	12	0	71	39	4.5	7	B			100	22			.0095		O
	6A	0600	12	0	86	24	3.0	11	H	40	24	60	2			.0458		H
	6B	0600	12	0	85	25	3.0	11	H	100	14					.0269		H

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
54	6C	0600	12	0	87	24	3.0	11	H	100	19					.0411		H
	6D	0600	12	0	86	24	3.0	11	H	100	21					.0316		H
59	2A	1800	12	2	69	38	5.5	7	T					100		.0050	94	O
	2B	1800	12	2	69	38	5.5	7	T	100	16					.0050	45	H
	2C	1800	12	2	69	38	5.5	7	T	100	8					.0100	39	H
	2D	1800	12	2	69	38	5.5	7	T	100	13					.0167	10	H
	5A	1800	12	20	65	25	4.5	53	T	15	26	20	20	55		.0567	2	O
	5B	1800	12	20	65	25	4.5	53	T			65	14	35		.0400	2	O
	5C	1800	12	20	65	25	4.5	53	T	30	8			70		.0383	7	O
	5D	1800	12	20	65	25	4.5	53	T			75	13	25		.0317	43	O
	5E	1800	12	20	65	25	4.5	53	T			70	13	30		.0650	47	O
	5F	1800	12	20	65	25	4.5	53	T			75	20	25		.0916	28	O
	5G	1800	12	20	65	25	4.5	53	T			70	14	30		.0783	46	O
	5H	1800	12	20	65	25	4.5	53	T	75	8	25	13			.0183	145	O
	5I	1800	12	20	65	25	4.5	53	T			45	11	55		.0200	130	O
	5J	1800	12	20	65	25	4.5	53	T	35	14			65		.0183	180	O
	6A	0600	12	17	81	24	4.5	38	T					100		.0650	150	O
	6B	0600	12	17	83	23	4.5	38	T					100		.0668	129	O
	6C	0600	12	17	84	22	4.5	38	T	15	34	85	18			.0384	58	O
	6D	0600	12	17	85	22	4.5	38	T	15	20	30	18	55		.0500	45	O
	6E	0600	12	17	86	21	4.5	38	T	15	22	60	21	25		.0533	29	O
	6F	0600	12	17	85	22	4.5	38	T			100	10			.0383	42	O
	6G	0600	12	17	83	23	4.5	38	T			85	17	15		.0700	9	O
	6H	0600	12	17	82	23	4.5	38	T	15	10	85	17			.0683	9	O
	6I	0600	12	17	84	22	4.5	38	T			50	22	50		.0650	38	O
	6J	0600	12	17	85	23	4.5	38	T			70	11	30		.0450	50	O
	6K	0600	12	17	86	22	4.5	38	T			20	18	80		.0268	46	O
	6L	0600	12	17	85	22	4.5	38	T			100	18			.0300	28	O
	6M	0600	12	17	84	23	4.5	38	T			100	17			.0250	50	O
	7A	1800	12	3	62	50	6.5	6	T			100	15			.0050	95	O
	7B	1800	12	3	62	50	6.5	6	T			100	18			.0100	92	O
	7C	1800	12	3	62	50	6.5	6	T	100	10					.0670	116	O
	7D	1800	12	3	62	50	6.5	6	T					100		.0050	113	O
	7E	1800	12	3	62	50	6.5	6	T					100		.0033	113	O
	7F	1800	12	3	62	50	6.5	6	T			100	17			.0150	13	O

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
59	7G	1800	12	3	62	50	6.5	6	T			100	12			.0133	22	O
	7H	1800	12	3	62	50	6.5	6	T			100	18			.0150	34	O
	7I	1800	12	3	62	50	6.5	6	T					100		.0083	61	O
	7J	1800	12	3	62	50	6.5	6	T					100		.0068	44	O
	7K	1800	12	3	62	50	6.5	6	T			100	11			.0159	26	O
	7L	1800	12	3	62	50	6.5	6	T	25	27			75		.0133	5	O
	7M	1800	12	3	62	50	6.5	6	T					100		.0281	24	O
	7N	1800	12	3	62	50	6.5	6	T			100	18			.0100	36	O
	7O	1800	12	3	62	50	6.5	6	T			100	10			.0100	7	O
	7P	1800	12	3	62	50	6.5	6	T			100	14			.0083	11	O
	7Q	1800	12	3	62	50	6.5	6	T			100	16			.0010	4	O
	7R	1800	12	3	62	50	6.5	6	T			100	14			.0100	13	O
	7S	1800	12	3	62	50	6.5	6	T			100	14			.0167	24	O
60	2A	1800	12	2	62	46	7.0	4	BT	40	22			60		.0158	20	O
	2B	1800	12	2	62	46	7	4	BT	100	15					.0190	5	H
	2C	1800	12	2	62	46	7	4	BT	100	19					.0222	64	O
	6A	1800	12	16	59	33	5.5	24	T	35	10	25	10	40		.0554	39	H
	6B	1800	12	16	59	33	5.5	24	T	25	25			75		.0555	30	H
	6C	1800	12	16	59	33	5.5	24	T	55	13			45		.0675	18	H
	6D	1800	12	16	59	33	5.5	24	T	35	13	65	22			.0916	14	H
	6E	1800	12	16	59	33	5.5	24	T	45	13	45	18	10		.1679	0	H
	6F	1800	12	16	59	33	5.5	24	T	40	15	60	21			.2462	10	H
	6G	1800	12	16	59	33	5.5	24	T	25	19	45	23	30		.1990	23	H
	6H	1800	12	16	59	33	5.5	24	T	20	17	45	21	35		.1911	30	H
	6I	1800	12	16	59	33	5.5	24	T	25	21	35	17	40		.2210	30	H
	6J	1800	12	16	59	33	5.5	24	T	35	18	25	22	40		.1780	42	H
	6K	1800	12	16	59	33	5.5	24	T			45	20	55		.1290	55	H
	7A	0600	12	5	74	33	6	8	T	45	14	30	30	25		.0815	3	H
	7B	0600	12	5	77	32	6	8	T	25	23	75	19			.0865	0	H
	7C	0600	12	5	77	32	6	8	T	70	17			30		.0832	18	H
	7D	0600	12	5	80	30	6	8	T	35	17	10	25	55		.0815	27	H
	7E	0600	12	5	82	29	6	8	T	30	13	40	18	30		.0620	50	H
	7F	0600	12	5	83	29	6	8	T	10	18	30	22	60		.0525	75	H
	7G	0600	12	5	84	29	6	8	T	35	19	65	16			.0750	73	H
	8A	1800	12	3	55	62	7	4	T	100	24					.0244	45	H

GROUP II — 12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
0	8B	1800	12	3	55	62	7	4	T	100	19					.0278	28	H
	8C	1800	12	3	55	62	7	4	T			65	22	35		.0167	65	O
	8D	1800	12	3	55	62	7	4	T	100	9					.0100	78	O
	8E	1800	12	3	55	62	7	4	T			100	8			.0131	42	O
	8F	1800	12	3	55	62	7	4	T			20	13	80		.0229	42	O
1	2A	1900	12	3	59	59	8.5	4	T					100		.0067	145	O
	2B	1900	12	3	59	59	8.5	4	T	100	18					.0050	58	O
	2C	1900	12	3	59	59	8.5	4	T					100		.0083	32	O
	2D	1900	12	3	59	59	8.5	4	T	25	14	75	11			.0133	3	H
	2E	1900	12	3	59	59	8.5	4	T					100		.0050	78	O
	2F	1900	12	3	59	59	8.5	4	T	100	14					.0033	145	O
	2G	1900	12	3	59	59	8.5	4	T	100	14					.0067	130	O
	3A	0700	12	6	82	27	7	10	T	100	19					.0180	39	H
	3B	0700	12	6	82	27	7	10	T	65	14	35	14			.0200	20	H
	3C	0700	12	6	84	26	7	10	T	100	12					.0217	12	H
	3D	0700	12	6	84	26	7	10	T					100		.0100	175	H
	3E	0700	12	6	84	26	7	10	T	50	9	50	9			.0167	162	H
	3F	0700	12	6	83	26	7	10	T	100	9					.0150	135	H
	3G	0700	12	6	83	26	7	10	T	100	13					.0150	72	H
	4A	1900	12	2	62	48	8	5	T	100	6					.0083	132	H
	4B	1900	12	2	62	48	8	5	T					100		.0067	160	H
	4C	1900	12	2	62	48	8	5	T					100		.0100	178	H
	4D	1900	12	2	62	48	8	5	T	100	5					.0100	144	H
	4E	1900	12	2	62	48	8	5	T	100	26					.0067	100	H
	4F	1900	12	2	62	48	8	5	T	100	10					.0100	97	H
	5A	0700	12	12	86	21	6	19	T			65	11	35		.0216	57	H
	5B	0700	12	12	85	21	6	19	T			100	17			.0150	78	H
	5C	0700	12	12	84	22	6	19	T	100	10					.0083	164	R
	5D	0700	12	12	84	22	6	19	T	70	17			30		.0136	170	F
2	2A	1800	12	3	54	54	5.0	4	BT			100	10			.0183	8	O
	2B	1800	12	3	54	54	5.0	4	BT	30	10			70		.0200	12	O
	2C	1800	12	3	54	54	5.0	4	BT			100	10			.0167	43	O
	2D	1800	12	3	54	54	5.0	4	BT			100	11			.0083	154	R
	2E	1800	12	3	54	54	5.0	4	BT					100		.0083	151	O
	2F	1800	12	3	54	54	5.0	4	BT					100		.0083	179	O

GROUP II—12-Hour Periods

FIRE				WEATHER					FUEL	TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
68	4A	1800	12	10	56	37	4.5	18	T	35	17			65		.0667	5	H
	4B	1800	12	10	56	37	4.5	18	TG	50	22	50	5			.0700	7	H
69	2A	1500	12	4	56	41	4.5	10	B					100		.0450	55	H
	2B	1500	12	4	56	41	4.5	10	B					100		.0416	53	H
	2C	1500	12	4	56	41	4.5	10	B					100		.0367	48	H
	3A	0300	12	10	84	14	3.5	25	B					100		.0766	51	H
	3B	0300	12	10	84	14	3.5	25	B					100		.1070	40	H
	4A	1500	12	10	62	30	4	18	B					100		.1010	20	H
	4B	1500	12	10	62	30	4	18	B					100		.1667	18	H
	4C	1500	12	10	62	30	4	18	B					100		.1766	10	H
	4D	1500	12	10	62	30	4	18	B					100		.1800	3	H
	4E	1500	12	10	62	30	4	18	B					100		.1820	12	H
	4F	1500	12	10	62	30	4	18	B					100		.1768	16	H
	4G	1500	12	10	62	30	4	18	B					100		.1300	26	H
70	1A	0800	12	14	66	50	10	12	T	35	18			65		.0863	28	H
	1B	0800	12	14	67	49	10	12	T	60	20			40		.0487	24	H
	1C	0800	12	14	69	48	10	12	T	50	15			50		.0250	15	H
	1D	0800	12	14	70	48	10	12	T					100		.0063	40	F
	1E	0800	12	14	70	48	10	12	T					100		.0037	85	F
	1F	0800	12	14	70	48	10	12	T			100	24			.0050	144	R
	1G	0800	12	14	70	48	10	12	T					100		.0043	131	F
	1H	0800	12	14	69	48	10	12	T	40	11			60		.0175	49	H
	1I	0800	12	14	66	50	10	12	T	60	17			40		.0400	42	H
	1J	0800	12	14	67	49	10	12	T	50	17			50		.0600	33	H
71	2A	0600	12	17	83	67	8	12	BT					100		.8600	7	H
	2B	0600	12	17	83	67	8	12	BT					100		.8380	0	H
	3A	0600	12	10	81	54	9	6	BT					100		.3320	9	H
	3B	0600	12	10	81	54	9	6	BT					100		.2610	2	H
79	1A	1800	12	4	78	36	8	6	GB	100	10					.0167	125	
	1B	1800	12	4	78	36	8	6	GB					100		.0167	175	
	1C	1800	12	4	78	36	8	6	GB					100		.0200	133	
	1D	1800	12	4	78	36	3	6	GB	100	10					.0133	93	
	1E	1800	12	4	78	36	8	6	GB	70	10			30		.0200	55	
	1F	1800	12	4	78	36	8	6	GB	100	19					.0434	22	
	1G	1800	12	4	78	36	8	6	GB	75	16			25		.0366	17	

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
30	2A	0600	12	14	92	13	6	34	G	80	13	20	11			.0400	68	F
	2B	0600	12	14	92	13	6	34	G	100	80					.0317	63	F
	2C	0600	12	14	91	13	6	34	G	80	16			20		.0250	56	F
	2D	0600	12	14	91	12	6	34	G			100	27			.0167	66	F
	2E	0600	12	14	91	13	6	34	G			60	18	40		.0150	46	F
	2F	0600	12	14	93	13	6	34	G	40	14			60		.0067	8	F
	2G	0600	12	14	92	13	6	34	G					100		.0083	21	F
	2H	0600	12	14	91	13	6	34	G	40	23	60	11			.0366	24	F
	2I	0600	12	14	91	13	6	34	G	60	16					.0800	6	H
	2J	0600	12	14	88	13	6	34	G	80	19			20		.1469	7	H
	2K	0600	12	14	90	14	6	34	G	65	19	15	13	20		.1150	7	H
	2L	0600	12	14	90	14	6	34	G	80	17	10	22	10		.1050	8	H
	2M	0600	12	14	90	14	6	34	G	85	20	15	24			.0916	13	H
	2N	0600	12	14	92	13	6	34	G	50	17	30	20	20		.0634	18	H
	2O	0600	12	14	91	13	6	34	G	60	18			40		.0416	22	H
	2P	0600	12	14	90	14	6	34	G	50	16	50	16			.0250	60	F
	2Q	0600	12	14	91	13	6	34	G			100	20			.0067	91	F
	5A	1800	12	4	66	19	6	13	G	100	14					.0167	135	H
	5B	1800	12	4	66	19	6	13	G	100	15					.0217	150	H
	5C	1800	12	4	66	19	6	13	G	100	26					.0233	56	H
	5D	1800	12	4	66	19	6	13	G	70	24			30		.0284	63	H
31	3A	1900	12	3	49	40	8	6	TG					100		.0200	73	F
	3B	1900	12	3	49	40	8	6	TG					100		.0133	75	F
	3C	1900	12	3	49	40	8	6	TG					100		.0150	61	F
	3D	1900	12	3	49	40	8	6	TG					100		.0150	50	F
	3E	1900	12	3	49	40	8	6	TG					100		.0167	19	H
	3F	1900	12	3	49	40	8	6	TG					100		.0162	7	H
	3G	1900	12	3	49	40	8	6	TG					100		.0150	0	H
	5A	1900	12	3	49	40	8	6	TG					100		.0700	73	H
	5B	1900	12	3	49	40	8	6	G					100		.0550	74	H
	5C	1900	12	3	49	40	8	6	G					100		.0600	79	H
	5D	1900	12	3	49	40	8	6	TG					100		.0616	68	H
	5E	1900	12	3	49	40	8	6	G					100		.0400	95	H
	5F	1900	12	3	49	40	8	6	G					100		.0683	58	H
	5G	1900	12	3	49	40	8	6	G					100		.0950	48	H

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPFEAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
81	5H	1900	12	3	49	40	8	6	G					100	—	.1350	32	H
	5I	1900	12	3	49	40	8	6	G					100	—	.0600	77	H
	5J	1900	12	3	49	40	8	6	TG					100	—	.1360	82	H
	5K	1900	12	3	49	40	8	6	TG					100	—	.1016	84	H
	5L	1900	12	3	49	40	8	6	TG					100	—	.0717	90	H
	5M	1900	12	3	49	40	8	6	TG					100	—	.0317	128	F
	5N	1900	12	3	49	40	8	6	TG					100	—	.0333	157	F
	6A	0700	12	12	54	42	8	12	TG					100	—	.0434	21	H
	6B	0700	12	12	54	42	8	12	G					100	—	.0384	21	H
	6C	0700	12	12	54	42	8	12	G					100	—	.0500	18	H
	6D	0700	12	12	54	42	8	12	G					100	—	.0318	20	H
	6E	0700	12	12	54	42	8	12	G					100	—	.0433	17	H
	6F	0700	12	12	54	42	8	12	G					100	—	.0332	21	H
	6G	0700	12	12	54	42	8	12	G					100	—	.0384	28	H
	6H	0700	12	12	54	42	8	12	TG					100	—	.0183	0	H
	6I	0700	12	12	54	42	8	12	TG					100	—	.0266	0	H
	6J	0700	12	12	54	42	8	12	TG					100	—	.0200	0	H
	6K	0700	12	12	54	42	8	12	TG					100	—	.0167	0	H
	6L	0700	12	12	54	42	8	12	TG					100	—	.0167	0	H
	6M	0700	12	12	54	42	8	12	TG					100	—	.0084	67	F
	6N	0700	12	10	54	42	8	12	G					100	—	.0217	10	H
	6O	0700	12	10	54	42	8	12	TG					100	—	.0300	152	H
	7A	1900	12	8	52	43	9	7	GB					100	—	.0150	30	H
	7B	1900	12	8	52	43	9	7	GB					100	—	.0167	35	H
	7C	1900	12	8	52	43	9	7	GB					100	—	.0250	22	H
	7D	1900	12	8	52	43	9	7	GB					100	—	.0150	58	H
	7E	1900	12	8	52	43	9	7	GB					100	—	.0250	20	H
	7F	1900	12	8	52	43	9	7	GB					100	—	.0200	30	[illegible]
	7G	1900	12	8	52	43	9	7	TG					100	—	.0165	31	[illegible]
	7H	1900	12	8	52	43	9	7	TG	20	10			80	—	.0167	31	[illegible]
	7I	1900	12	8	52	43	9	7	TG					100	—	.0184	31	[illegible]
	7J	1900	12	8	52	43	9	7	TG					100	—	.0184	45	[illegible]
	7K	1900	12	8	52	43	9	7	TG					100	—	.0200	45	[illegible]
	7L	1900	12	8	52	43	9	7	TG					100	—	.0150	45	[illegible]
	7M	1900	12	8	52	43	9	7	TG					100	—	.0167	45	[illegible]

GROUP II—12 Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
ire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
31	7N	1900	12	8	52	43	9	7	G					100		.0100	54	H
	7O	1900	12	8	52	43	9	7	G					100		.0184	4	H
	7P	1900	12	8	52	43	9	7	TG					100		.0416	37	H
	7Q	1900	12	8	52	43	9	7	GB					100		.0200	29	H
	7R	1900	12	8	52	43	9	7	GB					100		.0200	9	H
32	1A	1900	12	19	59	37	7	39	TB					100		.1250	82	H
	1B	1900	12	19	59	37	7	39	TB					100		.1417	67	H
	1C	1900	12	19	59	37	7	39	TB					100		.2333	50	H
	1D	1900	12	19	59	37	7	39	TB					100		.5833	73	H
	1E	1900	12	19	59	37	7	39	TB					100		.5250	65	H
	1F	1900	12	19	59	37	7	39	TB					100		.5916	65	H
	1G	1900	12	19	59	37	7	39	TB					100		.7000	60	H
	1H	1900	12	19	59	37	7	39	TB					100		.6250	57	H
	1I	1900	12	19	59	37	7	39	TB					100		.9250	57	H
	1J	1900	12	19	59	37	7	39	TB					100		.8533	56	H
	1K	1900	12	19	59	37	7	39	TB					100		.7250	55	H
	1L	1900	12	19	59	37	7	39	TB					100		.7917	53	H
	1M	1900	12	19	59	37	7	39	TB					100		1.017	53	H
	1N	1900	12	19	59	37	7	39	TB					100		1.083	53	H
	1O	1900	12	19	59	37	7	39	TB					100		1.117	48	H
	1P	1900	12	19	59	37	7	39	TB					100		1.042	48	H
	1Q	1900	12	19	59	37	7	39	TB					100		1.000	45	H
	1R	1900	12	19	59	37	7	39	TB					100		.9750	43	H
	1S	1900	12	19	59	37	7	39	TB					100		1.025	41	H
	1T	1900	12	19	59	37	7	39	TB					100		1.033	35	H
	1U	1900	12	19	59	37	7	39	TB					100		1.067	34	H
	1V	1900	12	19	59	37	7	39	TB					100		1.050	32	H
	1W	1900	12	19	59	37	7	39	TB					100		1.050	29	H
	1X	1900	12	19	59	37	7	39	TB					100		1.092	25	H
	1Y	1900	12	19	59	37	7	39	TB					100		1.108	23	H
	1Z	1900	12	19	59	37	7	39	TB					100		1.100	22	H
3	2A	0600	12	11	94	13	4.5	25	B	30	34	45	24	25		.0602	41	H
	2B	0600	12	11	92	14	4.5	25	B	50	18	50	17			.0750	34	H
	2C	0600	12	11	92	14	4.5	25	B	70	17	30	13			.0902	30	H
	2D	0600	12	11	90	14	4.5	25	B	65	22	15	17	20		.1050	26	H

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY: SLOPE UP		SLOPE DOWN				SPREAD		
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
93	2E	0600	12	11	88	15	4.5	25	B	65	25			35		.0918	0	H
	2F	0600	12	11	91	14	4.5	25	B	35	17			65		.0367	10	H
	3A	1800	12	5	64	38	5.5	7	B			35	18	65		.0500	90	F
	3B	1800	12	5	64	38	5.5	7	B	45	19	40	22	15		.0746	88	F
	3C	1800	12	5	64	38	5.5	7	B	40	35	20	24	40		.0750	100	F
	4A	0600	12	8	87	18	5	15	B			100	16			.0950	46	F
	4B	0600	12	8	87	18	5	15	B			70	15	30		.0800	40	F
	4C	0600	12	8	90	17	5	15	B			75	26	25		.0565	34	F
	4D	0600	12	8	90	17	5	15	B	25	24	75	22			.0400	31	F
	4E	0600	12	8	91	16	5	15	B	75	12	25	11			.0250	37	F
96	2A	1200	12	20	90	10	3.5	58	TB					100		.0336	1	H
	2B	1200	12	20	88	10	3.5	58	TB			35	25	65		.0333	20	H
	2C	1200	12	20	87	11	3.5	58	TB			100	25			.0359	34	
	2D	1200	12	20	86	11	3.5	58	TB			70	35	30		.0433	49	
100	2A	1800	12	12	76	18	4.5	25	B					100		.0150	101	
	2B	1800	12	12	76	19	4.5	25	B	30	11	70	11			.0417	117	
	2C	1800	12	12	77	17	4.5	25	B	25	18	20	19	55		.1250	114	
	2D	1800	12	12	77	17	4.5	25	B	25	11	15	17	60		.1380	108	
	2E	1800	12	12	77	17	4.5	25	B	25	10			75		.1550	105	
	2F	1800	12	12	74	18	4.5	25	B	70	15			30		.1820	68	
	2G	1800	12	12	75	16	4.5	25	B	55	14			45		.1365	59	
	2H	1800	12	12	77	16	4.5	25	B	50	14			50		.0868	64	
	2I	1800	12	12	78	16	4.5	25	B			100	10			.0450	19	
	2J	1800	12	12	78	16	4.5	25	B			100	10			.0434	84	
	2K	1800	12	12	79	15	4.5	25	B					100		.0417	106	
	2L	1800	12	12	80	15	4.5	25	B					100		.0266	107	
	2M	1800	12	12	80	15	4.5	25	B					100		.0367	117	
	2N	1800	12	12	80	15	4.5	25	B					100		.0550	134	
	2O	1800	12	12	79	15	4.5	25	B			100	7			.0733	139	
	2P	1800	12	12	80	15	4.5	25	B	15	11	85	10			.1530	163	
	2Q	1800	12	12	78	16	4.6	25	B			45	13	55		.2020	172	
	3A	0600	12	13	92	17	4.0	27	B			70	18	30		.0618	116	
	3B	0600	12	13	93	16	4.0	27	B	30	9	30	10	40		.5200	126	
	3C	0600	12	13	93	16	4.0	27	B			25	18	75		.1230	127	
	3D	0600	12	13	93	16	4.0	27	B			35	18	65		.1500	132	

GROUP II—12-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
0	3E	0600	12	13	95	16	4.0	27	B	30	7	20	18	50		.2480	134	F
	3F	0600	12	13	96	15	4.0	27	B	15	10	40	16	45		.2720	135	H
	3G	0600	12	13	97	15	4.0	27	B	25	9	30	10	45		.5090	134	F
	3H	0600	12	13	96	15	4.0	27	B			20	12	80		.5200	138	H
	3I	0600	12	13	97	15	4.0	27	B			30	14	70		.5600	140	H
	3J	0600	12	13	97	15	4.0	27	B			25	13	75		.5790	141	H
	3K	0600	12	13	97	15	4.0	27	B			30	13	70		.7990	144	H
	3L	0600	12	13	95	16	4.0	27	B			10	7	90		.9190	145	H
	3M	0600	12	13	96	15	4.0	27	B			10	8	90		.8790	148	H
	3N	0600	12	13	95	16	4.0	27	B			10	6	90		.6640	150	H
	3O	0600	12	13	95	16	4.0	27	B	10	14	10	9	80		.6390	154	H
	3P	0600	12	13	95	16	4.0	27	B	10	23	10	8	80		.6420	157	H
	3Q	0600	12	13	95	15	4.0	27	B	20	90	10	9	70		.6210	162	H
	3R	0600	12	13	98	14	4.0	27	B	10	8	10	8	80		.5590	163	H
	3S	0600	12	13	96	15	4.0	27	B	20	9	10	9	70		.5170	165	H
	3T	0600	12	13	99	14	4.0	27	B			10	10	90		.4080	166	H
	3U	0600	12	13	98	15	4.0	27	B	10	25			90		.3980	178	H
	3V	0600	12	13	98	15	4.0	27	B	10	14			90		.3850	180	H
	3W	0600	12	13	98	15	4.0	27	B	20	9			80		.3850	177	H
	3X	0600	12	13	100	14	4.0	27	B	20	10	25	9	55		.3900	177	H
	3Y	0600	12	13	101	13	4.0	27	B	10	14	35	8	55		.2935	175	H
	3Z	0600	12	13	101	13	4.0	27	B	10	14	10	13	80		.1800	169	H
	3AA	0600	12	13	102	13	4.0	27	B					100		.1380	179	H
	3BB	0600	12	13	104	12	4.0	27	B					100		.1080	171	H

GROUP III—13-23-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
1	1A	1630	13½	3	69	33	6.0	8	GHB	65	20	25	3	10		.1332	179	H
	1B	1630	13½	3	69	33	6.0	8	GH	65	18			35		.1300	156	H
	1C	1630	13½	3	69	33	6.0	8	GH	55	21	45	15			.1042	120	H
	1D	1630	13½	3	69	33	6.0	8	GH	65	30	35	22			.0625	80	F
4	5A	1700	13	5	78.3	11.7	1.4	19	B	25	16	45	17	30		.0516	22	H
	5B	1700	13	5	76.1	11.6	1.4	19	B	55	19	45	24			.0302	3	O
	5C	1700	13	5	73.5	12.6	1.4	19	B	60	11	40	14			.0198	38	O
	5D	1700	13	5	69.2	14.3	1.4	19	B			100	25			.0127	19	O
	5E	1700	13	5	66.1	15.8	1.4	19	B	100	10					.0079	116	O
	5F	1700	13	5	69.9	14.0	1.4	19	B	30	29	70	33			.0302	160	R
	5G	1700	13	5	70.5	13.8	1.4	19	B	20	38	80	32			.0421	140	R
	6A	0600	13	5	83.4	15.3	1.2	19	TB	100	23					.0381	37	H
	6B	0600	13	5	83.5	15.2	1.2	19	B	75	24			25		.0476	60	F
	6C	0600	13	5	87.2	13.7	1.2	19	TB			100	20			.0159	160	R
	6D	0600	13	5	86.7	13.9	1.2	19	TB	60	15			40		.0635	126	O
	6E	0600	13	5	88.5	13.2	1.2	19	TB					100		.0635	119	O
	7A	1900	13	2	63.2	20.7	1.1	13	B			90	29			.0254	0	O
	7B	1900	13	2	67.7	18.9	1.1	13	B	80	29	20	37			.0207	64	O
	7C	1900	13	2	69.6	18.2	1.1	13	TB	75	23			25		.0277	73	O
	7D	1900	13	2	71.7	17.3	1.1	13	B	80	31					.0119	159	O
	7E	1900	13	2	72.3	17.1	1.1	13	TB	50	30	25	11	25		.0223	133	O
	7F	1900	13	2	69.1	18.4	1.1	13	TB			100	33			.0103	122	O
	7G	1900	13	2	75.5	15.8	1.1	13	TB			100	15			.0103	100	O
	7H	1900	13	2	66.2	19.5	1.1	13	TB	100	27					.0119	80	O
	9A	1800	22	2	65.1	22.4	1.1	13	TB	70	21	30	11			1333	168	[illegible]
18	1A	1600	14	12	78	56	5	10	B	100	10					.0218	99	[illegible]
45	1A	0925	19	8	88	26	5	14	BT	100	27					.0688	13	[illegible]
47	1A	1345	16¼	8	100	16	4.5	18	B	35	13	20	10	45		.0945	11	[illegible]
	1B	1345	16¼	8	100	16	4.5	18	B	45	10			55		.1322	10	[illegible]
	1C	1345	16¼	8	100	16	4.5	18	B	45	8	45	10	10		.1286	26	[illegible]
	1D	1345	16¼	8	100	16	4.5	18	B	45	11	45	7	10		.0909	47	[illegible]
	1E	1345	16¼	8	99	17	4.5	18	B	20	31	25	12	55		.0903	72	[illegible]
48	1A	1345	16¼	8	100	16	4.5	18	B			75	21	25		.0130	9	[illegible]
	1B	1345	16¼	8	101	16	4.5	18	B			100	14			.0213	78	[illegible]
	1C	1345	16¼	8	99	17	4.5	18	B			80	10	20		.0198	136	[illegible]

GROUP III—13-23-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
re o.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
8	1D	1345	16¼	8	99	17	4.5	18	B	50	18	50	12			.0192	177	O
	1E	1345	16¼	8	99	17	4.5	18	B	35	22			65		.0105	112	O
9	3A	1800	14	4	62	37	6.0	7	B	20	14			80		.0361	62	O
	3B	1800	14	4	62	37	6.0	7	B	50	21	40	13	10		.1108	109	H
	3C	1800	14	4	62	37	6.0	7	B	100	16					.0250	175	O
	5A	1800	14	5	59	43	6	5	BT			30	17	70		.0606	120	H
	5B	1800	14	5	59	43	6	5	BT			80	13	20		.0572	71	H
	5C	1800	14	5	59	43	6	5	BT	100	5					.0588	12	H
	5E	1800	14	5	59	43	6	5	BT	70	27			30		.0446	71	R
	5F	1800	14	5	59	43	6	5	BT	60	25			40		.0446	68	R
	5G	1800	14	5	59	43	6	5	BT	100	8					.0411	102	R
	7A	1800	14	2	63	47	6.5	4	BT	50	15			50		.0500	121	H
	7B	1800	14	2	63	47	6.5	4	BT	100	16					.0470	50	R
1	1A	0200	16	7	85	14	6.0	12	B	60	25			40		.0650	41	H
	1B	0200	16	7	86	14	6.0	12	B	75	21	10	19	15		.0625	23	H
	1C	0200	16	7	88	13	6.0	12	B	70	21			30		.0350	1	H
2	1A	0200	16	7	83	15	6.0	12	B	75	23	25	26			.0418	3	H
	1B	0200	16	7	83	15	6.0	12	B	65	25	35	10			.0400	31	H
	1C	0200	16	7	83	15	6.0	12	B	100	23					.0234	80	F
	1D	0200	16	7	84	14	6.0	12	B	45	11	55	11			.0112	126	F
	1E	0200	16	7	85	14	6.0	12	B			100	15			.0050	174	R
	1F	0200	16	7	85	14	6.0	12	B			100	26			.0663	81	F
7	2A	1400	20	6	72	32	6	9	B			100	24			.0111	18	O
	2B	1400	20	6	72	32	6	9	B			50	14	50		.0083	81	O
1	1A	1100	15	10	80	50	6.5	5	BT					100		.7240	10	H
	1B	1100	15	10	80	50	6.5	5	BT					100		.6660	14	H
	1C	1100	15	10	80	50	6.5	5	BT					100		.4250	22	H
	1D	1100	15	10	80	50	6.5	5	BT					100		.3950	25	H
	1E	1100	15	10	80	50	6.5	5	BT					100		.3730	30	H
	2C	0600	18	17	83	67	8	12	BT					100		.3550	3	H
	2D	0600	18	17	83	67	8	12	BT					100		.4080	8	H
	2E	0600	18	17	83	67	8	12	BT					100		.3330	16	H
3	1A	0000	18	10	68	46	10	8	BT					100		.0146	68	O
	1B	0000	18	10	68	46	10	8	BT					100		.0407	15	O
	1C	0000	18	10	68	46	10	8	BT					100		.0098	45	O

GROUP III—13-23-Hour Periods

FIRE				WEATHER					FUEL	TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
73	2A	2100	23	12	75	56	12	5	T					100		.0589	90	O
	2B	2100	23	12	75	56	12	5	T					100		.0511	90	O
74	2A	0600	13	11	88	32	6	14	BT					100		.0192	39	F
	2B	0600	13	11	88	32	6	14	BT					100		.0320	33	F
	2C	0600	13	11	88	32	6	14	BT					100		.0384	31	F
	2D	0600	13	11	88	32	6	14	BT					100		.0961	32	H
	2E	0600	13	11	88	32	6	14	BT					100		.1476	8	H
	2F	0600	13	11	88	32	6	14	BT					100		.0320	80	F
	2G	0600	13	11	88	32	6	14	BT					100		.0384	75	F
	2H	0600	13	11	88	32	6	14	BT					100		.1152	61	H
83	2A	2100	19	8	63	15	4	23	B			25	20	75		.0561	14	F
	2B	2100	19	8	64	14	4	23	B	30	10	40	20	30		.0740	17	F
	2C	2100	19	8	64	14	4	23	B	25	13	55	13	20		.0879	10	F
	2D	2100	19	8	63	14	4	23	B			20	15	80		.0941	18	F
	2E	2100	19	8	62	15	4	23	B	20	15	35	12	45		.1019	22	F
	2F	2100	19	8	62	15	4	23	B	10	10	20	10	70		.1075	30	F
	2G	2100	19	8	62	15	4	23	B			10	10	90		.1075	27	F
85	4A	1600	14	9	59	32	5.5	9	T	25	12			75		.0773	20	H
	4B	1600	14	9	59	32	5.5	9	T					100		.0428	15	H
	4C	1600	14	9	59	32	5.5	9	T					100		.0228	34	H
	4D	1600	14	9	59	32	5.5	9	T	100	14					.0186	33	H
	4E	1600	14	9	59	32	5.5	9	T					100		.0300	30	H
	5A	0600	15	18	69	29	5.5	26	T					100		.0413	15	H
	5B	0600	15	18	69	29	5.5	26	T			100	12			.0293	52	[illegible]
	5C	0600	15	18	69	29	5.5	26	T					100		.0668	37	[illegible]
	5D	0600	15	18	69	29	5.5	26	T					100		.1025	22	[illegible]
	5E	0600	15	18	69	29	5.5	26	T					100		.1012	18	[illegible]
89	2A	1500	17	4	74	51	6.5	5	B	75	22	25	23			.0258	165	[illegible]
	2B	1500	17	4	74	51	6.5	5	B					100		.0247	161	[illegible]
	2C	1500	17	4	74	51	6.5	5	B	100	7					.0223	169	[illegible]
	2D	1500	17	4	74	51	6.5	5	B	80	20			20		.0282	163	[illegible]
	2E	1500	17	4	74	51	6.5	5	B	25	30			70		.0224	120	[illegible]
	2F	1500	17	4	74	51	6.5	5	B	100	17					.0176	111	[illegible]
	2G	1500	17	4	74	51	6.5	5	B	25	13			75		.0423	105	[illegible]
	2H	1500	17	4	74	51	6.5	5	B	60	24			40		.0353	10	[illegible]

GROUP III—13-23-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
9	2I	1500	17	4	74	51	6.5	5	B	100	18					.0587	5	H
	2J	1500	17	4	74	51	6.5	5	B	65	22			35		.0458	1	H
	2K	1500	17	4	74	51	6.5	5	B	60	22			40		.0400	9	H
	2L	1500	17	4	74	51	6.5	5	B	100	18					.0259	16	H
	2M	1500	17	4	74	51	6.5	5	B					100		.0247	44	H
2	1A	1730	14.5	28	80	6	3.5	84	B	25	17	60	12	15		.0962	35	H
	1B	1730	14.5	28	78	7	3.5	84	B	50	19	50	17			.0989	46	H
	1C	1730	14.5	28	78	7	3.5	84	B	40	17	60	16			.0910	58	H
	1D	1730	14.5	28	79	6	3.5	84	B	20	17	80	22			.0372	66	F
	1E	1730	14.5	28	79	7	3.5	84	B			100	18			.0248	166	R
	1F	1730	14.5	28	80	6	3.5	84	B			100	19			.0345	153	R
4	1A	1100	19	3	96	20	4.5	12	T	50	12	15	14	35		.1662	35	H
	1B	1100	19	3	95	21	4.5	12	T	60	13			40		.1484	26	H
	1C	1100	19	3	96	20	4.5	12	T	55	13	15	9	30		.1148	18	H
	1D	1100	19	3	96	20	4.5	12	T	60	10	40	8			.0875	13	H
	1E	1100	19	3	95	21	4.5	12	T	45	21			55		.0589	6	H
7	1F	1230	20½	23	89	23	8	39	TB					100		.4229	35	H
	1G	1230	20½	23	89	23	8	39	TB					100		.4229	36	H
	1H	1230	20½	23	89	23	8	39	TB					100		.4000	37	H
	1I	1230	20½	23	89	23	8	39	TB					100		.8868	37	H
	1J	1230	20½	23	89	23	8	39	TB					100		.3544	35	H
	1K	1230	20½	23	89	23	8	39	TB					100		.3610	37	H
	1L	1230	20½	23	89	23	8	39	TB					100		.3678	38	H
	1M	1230	20½	23	89	23	8	39	TB					100		.3618	39	H
	1N	1230	20½	23	89	23	8	39	TB					100		.3667	39	H
	1O	1230	20½	23	89	23	8	39	TB					100		.3610	40	H
	1P	1230	20½	23	89	23	8	39	TB					100		.3496	40	H
	1Q	1230	20½	23	89	23	8	39	TB					100		.3553	41	H
	1R	1230	20½	23	89	23	8	39	TB					100		.3463	41	H
	1S	1230	20½	23	89	23	8	39	TB					100		.3284	42	H
	1T	1230	20½	23	89	23	8	39	TB					100		.3203	43	H
	1U	1230	20½	23	89	23	8	39	TB					100		.3122	44	H
8	1A	1100	21	18	85	40	8	18	B					100		.3238	12	H
	1B	1100	21	18	85	40	8	18	B					100		.2953	5	H
	1C	1100	21	18	85	40	8	18	B					100		.3571	1	H

GROUP III—13-23-Hour Periods

FIRE				WEATHER					FUEL	TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI		%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
98	1D	1100	21	18	85	40	8	18	B					100		.2476	16	H
102	1A	1300	21	12	75	65	10.5	6	B					100		.0428	58	F
	1B	1300	21	12	75	65	10.5	6	B					100		.0667	76	F
	1C	1300	21	12	75	65	10.5	6	B					100		.0714	86	F
	1D	1300	21	12	75	65	10.5	6	B					100		.0192	98	F
	1E	1300	21	12	75	65	10.5	6	B					100		.0190	129	F
	1F	1300	21	12	75	65	10.5	6	B					100		.0476	144	F
	1G	1300	21	12	75	65	10.5	6	B					100		.0572	58	F
	1H	1300	21	12	75	65	10.5	6	B					100		.0666	65	F
	1I	1300	21	12	75	65	10.5	6	B					100		.0476	106	F
	1J	1300	21	12	75	65	10.5	6	B					100		.0712	114	F
	1K	1300	21	12	75	65	10.5	6	B					100		.0761	123	F
	1L	1300	21	12	75	65	10.5	6	B					100		.0660	136	F
	1M	1300	21	12	75	65	10.5	6	B					100		.0618	118	F
	1N	1300	21	12	75	65	10.5	6	B					100		.0523	136	F
	1O	1300	21	12	75	65	10.5	6	B					100		.0523	149	F
	1P	1300	21	12	75	65	10.5	6	B					100		.0427	127	F
	1Q	1300	21	12	75	65	10.5	6	B					100		.0381	142	F
	1R	1300	21	12	75	65	10.5	6	B					100		.0381	172	F
	1S	1300	21	12	75	65	10.5	6	B					100		.0286	124	F
	1T	1300	21	12	75	65	10.5	6	B					100		.0286	150	F
	1U	1300	21	12	75	65	10.5	6	B					100		.0142	121	F
105	1A	1630	17.5	12	97	8	2.5	43	B	100	22					.0160	139	[illegible]
	1B	1630	17.5	12	96	9	2.5	43	B	100	18					.0229	121	[illegible]
	1C	1630	17.5	12	96	9	2.5	43	B	35	14	35	8	30		.1985	5	[illegible]
	1D	1630	17.5	12	97	8	2.5	43	B	40	18	35	10	25		.1600	15	[illegible]
	1E	1630	17.5	12	96	9	2.5	43	B	50	16	30	16	20		.1465	20	[illegible]
	1F	1630	17.5	12	97	8	2.5	43	B	45	22	55	20			.1060	138	[illegible]
	1G	1630	17.5	12	98	8	2.5	43	B	45	17	55	20			.0858	56	[illegible]

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
e .	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
	3A	0600	24	30	86	34	5.0	44	B	20	12			80		.1181	16	H
	3B	0600	24	30	86	34	5.0	44	B	10	10	10	11	80		.0907	4	H
	3C	0600	24	30	86	34	5.0	44	B			55	12	45		.0271	67	F
5	3A	0400	24	8	97	12	2.0	26	B	100	10					.0292	26	H
	3B	0400	24	7	83	36	4.0	10	B	30	22	25	14	45		.0146	164	F
3	2A	0600	24	11	71	46	6	12	B	15	14	40	11	45		.0583	179	H
	3A	0600	24	10	84	37	5	13	B			100	27			.0042	52	O
	4A	0600	24	11	85	27	4.5	21	B			100	14			.0167	52	H
	4B	0600	24	11	83	26	4.5	21	B			100	22			.0125	74	H
	7A	0600	24	12	80	32	4.5	18	B			100	40			.0042	170	R
	12A	1800	24	9	78	36	6	9	B			75	17	25		.0167	124	H
3	3A	1800	24	8	76	28	5.5	15	H			35	21	65		.0395	11	O
	3B	1800	24	8	76	28	5.5	15	H	65	18	35	10			.0185	17	H
	3C	1800	24	8	75	29	5.5	11	HB			85	17	15		.0227	49	O
	3D	1800	24	8	79	27	5.5	15	B			100	22			.0226	65	O
5	2A	1000	24	19	85	8	3.0	55	B	50	13	20	17	30		.2108	0	H
	2B	1000	24	19	82	9	3.0	55	B	40	10	20	10	40		.1810	7	H
	2C	1000	24	19	83	9	3.0	55	B			35	10	65		.0635	56	H
	3A	1000	24	15	84	13	3.0	40	B	10	12			90		.2146	15	H
6	2A	0800	24	14	74	30	4.5	24	T	25	10	25	10	50		.0866	5	H
	2B	0800	24	14	74	30	4.5	24	T	50	12	25	12	25		.0841	2	H
	2C	0800	24	14	73	30	4.5	24	T	50	12	10	13	40		.0767	12	H
	2D	0800	24	14	72	30	4.5	24	T	65	13	10	26	25		.0750	21	H
	2E	0800	24	14	73	30	4.5	24	T	75	10	15	10	10		.0533	30	H
	2F	0800	24	14	74	30	4.5	24	T	45	10	25	10	30		.0416	33	H
	2G	0800	24	14	74	30	4.5	24	T			40	10	60		.0291	45	H
	2H	0800	24	14	74	30	4.5	24	T			60	12	40		.0233	50	H
	2I	0800	24	14	73	30	4.5	24	T					100		.0200	61	H
	2J	0800	24	14	73	30	4.5	24	T	40	15			60		.0133	69	H
[illegible]	3A	1000	24	2	75	32	6	6	B	70	.11	30	14			.0104	47	H
[illegible]	2A	2400	24	5	69	42	8.5	5	T					100		.0025	23	H
	2B	2400	24	5	68	43	8.5	5	T					100		.0029	1	H
	2C	2400	24	5	67	43	8.5	5	T					100		.0025	6	H
	2D	2400	24	5	65	44	8.5	5	T			100	12			.0058	101	R
	2E	2400	24	5	65	44	8.5	5	T			100	14			.0021	153	R

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
70	2F	2400	24	5	65	44	8.5	5	T					100		.0025	117	R
	2G	2400	24	5	64	44	8.5	5	T					100		.0021	160	R
	3A	2400	24	10	77	32	5.5	13	B	100	10					.0067	36	H
	3B	2400	24	10	75	33	5.5	13	B	60	12			40		.0083	38	H
	3C	2400	24	10	74	33	5.5	13	B					100		.0010	27	H
	4A	2400	24	8	77	20	5.5	13	T					100		.0025	121	F
	4B	2400	24	8	75	21	5.5	13	T	100	10					.0043	76	H
	4C	2400	24	8	74	21	5.5	13	T	100	10					.0050	79	H
	4D	2400	24	8	73	22	5.5	13	T	20	12			80		.0083	64	H
	4E	2400	24	8	72	22	5.5	13	B	100	17					.0150	43	H
	4F	2400	24	8	70	23	5.5	13	B					100		.0050	100	H
	4G	2400	24	8	70	23	5.5	13	B	100	10					.0058	67	H
	5A	2400	24	7	73	21	4.5	11	T			30	18	70		.0150	17	H
	5B	2400	24	7	72	22	4.5	11	T	55	11			45		.0117	23	H
	5C	2400	24	7	69	22	4.5	11	B					100		.0074	14	H
	5D	2400	24	7	69	22	4.5	11	T	100	11					.0125	15	H
	5E	2400	24	7	69	22	4.5	11	T	100	15					.0083	3	H
	5F	2400	24	7	69	22	4.5	11	T	100	15					.0050	12	H
71	2F	0600	24	17	83	67	8	12	BT					100		.1980	22	H
	2G	0600	24	17	83	67	8	12	BT					100		.1670	34	[illegible]
	2H	0600	24	17	83	67	8	12	BT					100		.1580	45	[illegible]
	2I	0600	24	17	83	67	8	12	BT					100		.1440	60	[illegible]
	3C	0600	24	10	81	54	9	6	BT					100		.1110	10	[illegible]
	3D	0600	24	10	81	54	9	6	BT					100		.0970	18	[illegible]
	3E	0600	24	10	81	54	9	6	BT					100		.0860	34	[illegible]
77	4A	2000	24	15	98	18	5	31	BG	100	18					.0050	66	[illegible]
	4B	2000	24	15	98	18	5	31	BG	100	22					.0050	167	[illegible]
	4C	2000	24	15	95	17	5	31	BG	100	31					.0050	165	[illegible]
	4D	2000	24	15	95	17	5	31	BG					100		.0050	161	[illegible]
	4E	2000	24	15	95	17	5	31	BG	100	11					.0040	158	[illegible]
	4F	2000	24	15	95	17	5	31	BG	25	27			75		.0067	140	[illegible]
	4G	2000	24	15	95	17	5	31	BG					100		.0033	133	[illegible]
	4H	2000	24	15	95	17	5	31	BG					100		.0017	133	[illegible]
	4I	2000	24	15	93	18	5	31	BG					100		.0134	99	[illegible]
	4J	2000	24	15	93	18	5	31	BG			25	10	75		.0250	92	[illegible]

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
e .	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
7	4K	2000	24	15	95	17	5	31	BG	80	10			20		.0534	101	F
	4L	2000	24	15	98	16	5	31	BG	30	18	30	20	40		.0616	90	F
	4M	2000	24	15	98	16	5	31	BG	10	25	20	25	70		.0584	90	F
	4N	2000	24	15	103	14	5	31	BG	20	25	10	25	70		.0584	79	F
	4O	2000	24	15	105	13	5	31	BG	30	25	30	24	40		.0500	96	F
	4P	2000	24	16	105	13	5	31	BG	10	10	10	10	80		.0450	85	F
	4Q	2000	24	15	105	13	5	31	BG					100		.0416	88	F
	4R	2000	24	15	105	13	5	31	BG			50	10	50		.0465	84	F
	4S	2000	24	15	105	13	5	31	BG			50	10	50		.0500	71	F
	4T	2000	24	15	98	16	5	31	BG	60	14			40		.0133	80	F
	4U	2000	24	15	98	16	5	31	BG	100	16					.0165	79	F
	4V	2000	24	15	95	17	5	31	BG	100	14					.0165	87	F
	4W	2000	24	15	95	17	5	31	BG					100		.0084	107	F
	4X	2000	24	15	105	13	5	31	BG	15	10	30	10	55		.1670	21	H
	4Y	2000	24	15	103	14	5	31	BG	20	10	35	10	45		.1718	28	H
	4Z	2000	24	15	103	14	5	31	BG	20	10	20	16	60		.1785	32	H
	4AA	2000	24	15	103	14	5	31	BG	45	27	15	16	40		.1920	36	H
	4BB	2000	24	15	103	14	5	31	BG	10	15	15	20	75		.2025	38	H
	4CC	2000	24	15	100	15	5	31	BG	20	10	30	8	50		.1950	43	H
	4DD	2000	24	15	100	15	5	31	BG			45	13	55		.1881	48	H
	5A	2000	24	15	107	19	4	31	BG			100	10			.0117	25	H
	5B	2000	24	15	107	19	4	31	BG			80	12	20		.0150	21	H
	5C	2000	24	15	107	19	4	31	BG			40	10	60		.0166	21	H
	5D	2000	24	15	107	19	4	31	BG			100	10			.0150	9	H
	5E	2000	24	15	107	19	4	31	BG			60	16	40		.0200	20	H
	5F	2000	24	15	107	19	4	31	BG			100	16			.0184	70	H
	5G	2000	24	15	107	19	4	31	BG			85	12	15		.0200	73	H
	5H	2000	24	15	107	19	4	31	BG			100	15			.0184	83	H
	5I	2000	24	15	107	19	4	31	BG			60	15	40		.0167	98	H
	5J	2000	24	15	107	19	4	31	BG	60	10	40	14			.0200	40	H
3	1A	1400	24	12	85	22	10	13	T	60	12	40	5			.0329	115	H
	1B	1400	24	12	85	22	10	13	T	60	10			40		.0100	99	H
	1C	1400	24	12	85	22	10	13	T	70	10			30		.0083	83	H
[illegible]	3A	1800	24	9	105	14	5	14	GB	50	10	50	10			.0128	90	H
	3B	1800	24	9	105	14	5	14	GB	20	14	60	18	20		.0317	98	H

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
79	3C	1800	24	9	105	14	5	14	GB	30	23	30	13	40		.0500	105	H
	3D	1800	24	9	103	15	5	14	GB	40	21	60	12			.0550	93	H
	3E	1800	24	9	103	15	5	14	GB	30	25	60	12	10		.0816	90	H
	3F	1800	24	9	103	15	5	14	GB	70	20	20	12	10		.0916	88	H
	3G	1800	24	9	103	15	5	14	GB	35	20	45	12	20		.0965	83	H
	3H	1800	24	9	100	16	5	14	GB	10	18	75	13	15		.1150	77	H
	3I	1800	24	9	100	16	5	14	GB	15	18	65	11	20		.1069	76	H
	3J	1800	24	9	103	15	5	14	GB	20	19	60	15	20		.1050	64	H
	3K	1800	24	9	103	15	5	14	GB	20	22	25	16	55		.0975	60	H
83	3A	1600	24	10	72	7	3	23	B			20	10	80		.1100	8	H
	3B	1600	24	10	71	7	3	33	B	10	25	40	14	50		.1340	6	H
	3C	1600	24	10	68	8	3	33	B	20	17	20	11	60		.1699	5	H
	3D	1600	24	10	68	8	3	33	B	20	16	40	10	40		.1775	0	H
	3E	1600	24	10	69	7	3	33	B	10	22	45	16	45		.1680	10	H
	3F	1600	24	10	68	8	3	33	B	10	16	40	21	50		.1250	4	H
	3G	1600	24	10	69	7	3	33	B	20	15	50	17	30		.1105	6	[illegible]
	3H	1600	24	10	67	8	3	33	B	30	18	45	18	25		.0989	10	H
	3I	1600	24	10	68	8	3	33	B	40	15	30	13	30		.0880	10	H
	3J	1600	24	10	69	7	3	33	B	10	13	30	18	60		.0853	10	[illegible]
	4A	1600	24	2	70	5	3	14	B	35	15	30	13	35		.1194	10	H
	4B	1600	24	2	70	5	3	14	B	25	17	45	12	30		.0983	71	[illegible]
	4C	1600	24	2	71	5	3	14	B	20	20	50	15	30		.0890	66	[illegible]
	4D	1600	24	2	70	5	3	14	B	30	17	25	20	50		.0655	54	[illegible]
	4E	1600	24	2	72	5	3	14	B	25	22	35	17	40		.0576	50	[illegible]
	4F	1600	24	2	72	5	3	14	B	15	16	55	20	30		.0490	42	[illegible]
	4G	1600	24	2	72	5	3	14	B	10	16	60	14	30		.0420	37	[illegible]
	4H	1600	24	2	72	5	3	14	B	50	12	50	16			.0366	24	[illegible]
	4I	1600	24	2	72	4	3	14	B	15	24	50	10	35		.0314	21	[illegible]
	4J	1600	24	2	74	3	3	14	B	10	14	75	10	15		.0341	18	[illegible]
	4K	1600	24	2	73	4	3	14	B	25	10	25	14	50		.0498	10	[illegible]
	4L	1600	24	2	73	4	3	14	B	25	22	45	10	30		.0630	12	[illegible]
	4M	1600	24	2	70	5	3	14	B	40	14	25	16	35		.0655	15	[illegible]
	4N	1600	24	2	70	5	3	14	B	45	16	20	25	35		.0610	18	[illegible]
	4O	1600	24	2	68	6	3	14	B	70	17	20	21	10		.0550	23	[illegible]
	4P	1600	24	2	68	6	3	14	B	30	20	35	14	35		.0530	25	[illegible]

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
re No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
3	4Q	1600	24	2	70	5	3	14	B	15	20	75	15	10		.0455	29	H
	4R	1600	24	2	66	6	3	14	B	50	12	35	15	15		.0393	25	H
4	3K	1600	24	10	67	8	3	33	B	80	14			20		.0231	171	H
	3L	1600	24	10	67	8	3	33	B	70	28			30		.0237	162	H
	3M	1600	24	10	66	8	3	33	B	85	15			15		.0237	164	H
	3N	1600	24	10	67	8	3	33	B	75	17			25		.0229	170	H
	3O	1600	24	10	69	7	3	33	B	100	12					.0208	140	H
	3P	1600	24	10	67	8	3	33	B	70	22	10	18	20		.0213	141	H
	3Q	1600	24	10	67	8	3	33	B	100	16					.0213	160	H
	3R	1600	24	10	68	8	3	33	B	75	25	10	22	15		.0213	170	H
	3S	1600	24	10	69	7	3	33	B	60	14			40		.0210	165	H
	3T	1600	24	10	71	7	3	33	B	35	18	16	22	50		.0206	152	H
	4S	1600	24	2	65	7	3	14	B	45	20	30	23	25		.0735	168	H
	4T	1600	24	2	67	6	3	14	B	30	19	40	26	30		.0537	173	H
	4U	1600	24	2	64	7	3	14	B	25	10	10	30	15		.0320	177	H
	4V	1600	24	2	65	7	3	14	B	100	14					.0215	176	H
	4W	1600	24	2	65	7	3	14	B	30	10			70		.0170	168	H
	4X	1600	24	2	65	7	3	14	B	100	10					.0192	162	H
	4Y	1600	24	2	63	8	3	14	B	70	15	30	10			.0249	155	H
	4Z	1600	24	2	65	7	3	14	B	55	12			45		.0367	162	H
	4A'	1600	24	2	65	7	3	14	B	40	13	30	10	40		.0635	165	H
	4B'	1600	24	2	64	7	3	14	B	45	10	25	10	30		.0785	166	H
	4C'	1600	24	2	64	7	3	14	B	40	10	10	10	50		.0970	168	H
7	1A	1800	24	13	93	19	3.5	33	T	100	16					.0117	140	F
	1B	1800	24	13	93	19	3.5	33	T	65	10			35		.0424	79	F
	1C	1800	24	13	93	19	3.5	33	T	20	10			80		.1116	70	H
	1D	1800	24	13	93	19	3.5	33	T	20	11			80		.1225	49	H
	1E	1800	24	13	93	19	3.5	33	T	15	11			85		.1415	25	H
	1F	1800	24	13	93	19	3.5	33	T	30	10			70		.1688	11	H
	1G	1800	24	13	93	19	3.5	33	T	65	6			35		.1366	2	H
	1H	1800	24	13	93	19	3.5	33	T	35	10			65		.0657	28	F
	2A	1800	24	4	89	22	8.5	9	T	65	10	35	10			.0831	38	H
	2B	1800	24	4	89	22	8.5	9	T	30	10	70	10			.0540	44	H
	2C	1800	24	4	89	22	8.5	9	T			100	10			.0083	51	H
	3A	1800	24	5	87	12	5	11	T					100		.0125	30	H

GROUP IV--24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
87	3B	1800	24	5	87	12	5	11	T			35	12	65		.0366	18	H
	3C	1800	24	5	87	12	5	11	T			80	10	20		.0192	24	H
	4A	1800	24	6	87	12	5	12	T	60	13	40	10			.0449	27	F
	4B	1800	24	6	87	12	5	12	T			100	10			.0423	3	F
	4C	1800	24	6	87	12	5	12	T					100		.0350	60	F
	4D	1800	24	6	87	12	5	12	T	30	10			70		.0366	41	F
	5A	1800	24	6	87	16	5	12	T			45	10	55		.0450	19	H
	5B	1800	24	6	87	16	5	12	T			100	10			.0158	45	H
	5C	1800	24	6	87	16	5	12	T					100		.0691	64	H
	5D	1800	24	6	87	16	5	12	T	50	10	30	10	20		.0681	101	F
	6A	1800	24	7	85	24	5.5	12	T					100		.0108	118	H
	6B	1800	24	7	85	24	5.5	12	T			100	10			.0067	132	H
	6C	1800	24	7	85	24	5.5	12	T					100		.0294	165	H
	7A	1800	24	6	90	17	5	14	T					100		.0100	46	H
	7B	1800	24	6	90	17	5	14	T					100		.0075	26	H
	7C	1800	24	6	90	17	5	14	T	100	10					.0083	40	H
	8A	1800	24	9	92	16	4.5	22	T			100	10			.0167	20	H
	8B	1800	24	9	92	16	4.5	22	T			100	10			.0200	1	H
	8C	1800	24	9	92	16	4.5	22	T	35	10	20	10	45		.0291	14	H
	8D	1800	24	9	92	16	4.5	22	T			30	10	70		.0409	20	H
88	2A	0000	24	17	100	28	6	27	T					100		.0220	85	F
	2B	0000	24	17	101	28	6	27	T	55	14	45	10			.0216	75	F
	2C	0000	24	17	98	29	6	27	T	65	6			35		.0279	43	F
	2D	0000	24	17	94	30	6	27	T	100	9					.0430	21	[illegible]
	2E	0000	24	17	93	30	6	27	T	65	20			35		.0542	12	[illegible]
	2F	0000	24	17	93	31	6	27	T	80	14			20		.0736	2	[illegible]
	2G	0000	24	17	97	29	6	27	T	100	12					.0088	14	[illegible]
	3A	0000	24	4	85	21	6	9	T	65	8	35	10			.0083	53	[illegible]
	3B	0000	24	4	84	21	6	9	T	60	14	40	10			.0142	85	[illegible]
	3C	0000	24	4	83	22	6	9	T					100		.0112	155	[illegible]
	3D	0000	24	4	82	22	6	9	T					100		.0067	135	
	3E	0000	24	4	83	22	6	9	T	45	10	55	10			.0142	148	
	3F	0000	24	4	82	22	6	9	T					100		.0112	144	
	3G	0000	24	4	79	23	6	9	T			100	10			.0033	59	
	3H	0000	24	4	80	23	6	9	T			100	10			.0017	39	

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
ire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
38	3I	0000	24	4	80	23	6	9	T			100	17			.0042	36	R
	4A	0000	24	5	84	21	6	9	T	60	13	40	10			.0108	67	H
	4B	0000	24	5	84	21	6	9	T					100		.0158	68	H
	4C	0000	24	5	85	22	6	9	T	55	13	45	10			.0075	62	H
	5A	0000	24	7	80	18	6	13	T					100		.0150	125	F
	5B	0000	24	7	80	18	6	13	T	50	15			50		.0179	147	F
	6A	0000	24	6	75	20	6	9	T	100	20					.0071	147	R
	6B	0000	24	6	75	20	6	9	T	100	10					.0030	143	R
	6C	0000	24	6	75	20	6	9	T	100	10					.0067	129	R
70	2A	0800	24	24	71	12	4	84	B	100	12					.0117	152	R
	2B	0800	24	24	71	12	4	84	B					100		.0075	170	R
	2C	0800	24	24	74	11	4	84	B	70	14	30	16			.0142	152	R
	2D	0800	24	24	77	10	4	84	B	70	21	30	14			.0092	148	R
	2E	0800	24	24	78	9	4	84	B	60	10	40	7			.0184	139	R
91	2A	0800	24	24	76	10	4	84	B	35	13	35	17	30		.1300	44	H
	2B	0800	24	24	75	10	4	84	B	40	18	40	14	20		.1429	46	H
	2C	0800	24	24	73	11	4	84	B	40	24	45	16	15		.0530	54	F
	2D	0800	24	24	73	12	4	84	B	20	14	80	15			.0457	51	F
	2E	0800	24	24	72	12	4	84	B	25	9	75	10			.0544	61	F
	2F	0800	24	24	71	12	4	84	B	30	11	45	8	25		.0417	61	F
	2G	0800	24	24	72	12	4	84	B	25	8	35	9	40		.0300	69	F
	3A	0800	24	28	78	7	4	84	B	50	13	25	15	25		.0364	87	F
	3B	0800	24	28	78	7	4	84	B	25	13	30	13	45		.0655	101	F
	3C	0800	24	28	79	6	4	84	B	15	22	40	20	45		.0585	92	F
	3D	0800	24	28	80	6	4	84	B	55	22	45	14			.0515	109	F
	3E	0800	24	28	76	10	4	84	B	50	17	40	17			.0896	103	F
6	6A	2400	24	12	79	14	4.5	27	TB	20	19	25	11	55		.0450	13	H
	6B	2400	24	12	78	14	4.5	27	TB	55	10	25	10	20		.0425	12	H
	6C	2400	24	12	78	14	4.5	27	TB	35	14			65		.0358	5	H
	6D	2400	24	12	76	15	4.5	27	TB	10	19			90		.0225	18	H
	6E	2400	24	12	75	15	4.5	27	TB	70	19	30	25			.0208	22	H
	6F	2400	24	12	75	15	4.5	27	TB	30	22	40	14	30		.0200	48	H
	6G	2400	24	12	75	15	4.5	27	TB	45	11			55		.0384	29	H
	6H	2400	24	12	74	15	4.5	27	TB	40	10			60		.0391	37	H
	7A	2400	24	15	84	15	4.5	29	TB	40	10			60		.0125	24	F

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
96	7B	2400	24	15	83	15	4.5	29	TB	55	17	25	18	20		.0125	17	F
	7C	2400	24	15	83	15	4.5	29	TB	25	22			75		.0100	2	F
	7D	2400	24	15	82	15	4.5	29	TB	100	16					.0083	13	H
	7E	2400	24	15	83	15	4.5	29	TB	100	19					.0058	35	H
	7F	2400	24	15	82	15	4.5	29	TB	45	18	25	10	30		.0308	31	H
	7G	2400	24	15	81	16	4.5	29	TB	50	12	10	13	40		.0425	17	H
	7H	2400	24	15	81	16	4.5	29	TB	45	12	25	10	30		.0517	11	H
98	3A	1800	24	15	91	40	8	13	B					100		.0917	28	F
	3B	1800	24	15	91	40	8	13	B					100		.0416	33	H
	3C	1800	24	15	91	40	8	13	B					100		.1417	10	H
	3D	1800	24	15	91	40	8	13	B					100		.0833	38	H
	3E	1800	24	15	91	40	8	13	B					100		.0500	25	F
	3F	1800	24	15	91	40	8	13	B					100		.2250	15	H
	3G	1800	24	15	91	40	8	13	B					100		.0750	45	F
	3H	1800	24	15	91	40	8	13	B					100		.0750	45	F
	3I	1800	24	15	91	40	8	13	B					100		.0667	59	F
	4A	1800	24	15	91	41	8	13	B					100		.3833	7	H
99	1A	0600	24	9	72	40	7	8	B					100		.0416	24	F
	1B	0600	24	9	72	40	7	8	B					100		.0350	27	F
	1C	0600	24	9	72	40	7	8	B					100		.0333	31	F
	1D	0600	24	9	72	40	7	8	B					100		.0208	33	F
	1E	0600	24	9	72	40	7	8	B					100		.0158	41	F
	2A	0600	24	10	76	57	7.5	6	B					100		.0317	85	[illegible]
	2B	0600	24	10	76	57	7.5	6	B					100		.0250	82	[illegible]
	2C	0600	24	10	76	57	7.5	6	B					100		.0200	72	[illegible]
	2D	0600	24	10	76	57	7.5	6	B					100		.0150	62	[illegible]
	2E	0600	24	10	76	57	7.5	6	B					100		.0100	77	[illegible]
	2F	0600	24	10	76	57	7.5	6	B					100		.0075	69	[illegible]
	2G	0600	24	10	76	57	7.5	6	B					100		.0042	69	[illegible]
101	2A	1800	24	11	67	34	8.0	12	H			20	10	80		.0151	164	[illegible]
	2B	1800	24	11	67	34	8.0	12	H	50	10	20	10	30		.0110	169	[illegible]
	2C	1800	24	11	67	34	8.0	12	H					100		.0127	179	[illegible]
	2D	1800	24	11	67	34	8.0	12	H					100		.0140	167	[illegible]
	2E	1800	24	11	67	34	8.0	12	H	20	11	30	10	50		.0151	159	[illegible]
	2F	1800	24	11	67	34	8.0	12	H	15	10	15	10	70		.0201	153	[illegible]

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
01	2G	1800	24	11	67	34	8.0	12	H	25	10	15	10	60		.0218	152	H
	2H	1800	24	11	67	34	8.0	12	H	35	15	10	10	55		.0219	151	H
	2I	1800	24	11	67	34	8.0	12	H	25	10			75		.0220	151	H
	2J	1800	24	11	67	34	8.0	12	H	30	10	20	10	50		.0222	147	H
	2K	1800	24	11	67	34	8.0	12	H	45	10	40	10	15		.0194	165	H
	2L	1800	24	11	67	34	8.0	12	H	30	10	30	10	40		.0196	169	H
	2M	1800	24	11	67	34	8.0	12	H	30	10	70	10			.0221	161	H
	2N	1800	24	11	67	34	8.0	12	H	25	10	75	10			.0199	155	H
	2O	1800	24	11	67	34	8.0	12	H	15	10	40	10	45		.0164	155	H
	2P	1800	24	11	67	34	8.0	12	H					100		.0106	138	H
	2Q	1800	24	11	67	34	8.0	12	H					100		.0103	125	F
	2R	1800	24	11	67	34	8.0	12	H					100		.0108	107	F
	2S	1800	24	11	67	34	8.0	12	H					100		.0133	74	F
	2T	1800	24	11	67	34	8.0	12	H	10	11			90		.0156	60	F
	2U	1800	24	11	67	34	8.0	12	H	25	10	75	10			.0164	53	F
	2V	1800	24	11	67	34	8.0	12	H					100		.0179	39	R
	2W	1800	24	11	67	34	8.0	12	H					100		.0191	30	R
	2X	1800	24	11	67	34	8.0	12	H	45	10	10	10	45		.0191	25	R
	2Y	1800	24	11	67	34	8.0	12	H	35	10			65		.0209	27	R
	3A	1800	24	3	64	44	8.5	5	H					100		.0037	94	F
	3B	1800	24	3	64	44	8.5	5	H	60	15			40		.0040	91	F
	3C	1800	24	3	64	44	8.5	5	H	80	14			20		.0053	111	F
	3D	1800	24	3	64	44	8.5	5	H	20	11	40	15	40		.0056	121	F
	3E	1800	24	3	64	44	8.5	5	H			60	10	40		.0060	129	F
	3F	1800	24	3	64	44	8.5	5	H			40	15	60		.0060	136	H
	3G	1800	24	3	64	44	8.5	5	H			100	15			.0074	150	H
	3H	1800	24	3	64	44	8.5	5	H			75	17	25		.0074	143	H
	3I	1800	24	3	64	44	8.5	5	H			100	10			.0077	135	H
	3J	1800	24	3	64	44	8.5	5	H			100	10			.0085	121	F
	3K	1800	24	3	64	44	8.5	5	H			80	12	20		.0087	82	O
	3L	1800	24	3	64	44	8.5	5	H			70	15	30		.0090	101	O
	3M	1800	24	3	64	44	8.5	5	H			100	15			.0089	112	O
	3N	1800	24	3	64	44	8.5	5	H			100	10			.0076	117	O
	3O	1800	24	3	64	44	8.5	5	H			100	14			.0068	126	O
	3P	1800	24	3	64	44	8.5	5	H			100	10			.0058	135	O

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp.	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
101	3Q	1800	24	3	64	44	8.5	5	H			100	10			.0052	101	O
	3R	1800	24	3	64	44	8.5	5	H					100		.0052	139	O
	3S	1800	24	3	64	44	8.5	5	H			40	10	60		.0050	129	O
	3T	1800	24	3	64	44	8.5	5	H			100	10			.0060	105	O
	3U	1800	24	3	64	44	8.5	5	H			70	10	30		.0071	117	O
	3V	1800	24	3	64	44	8.5	5	H			30	11	70		.0082	150	O
	3W	1800	24	3	64	44	8.5	5	H	20	11	60	11	20		.0082	133	O
	3X	1800	24	3	64	44	8.5	5	H	35	10	25	10	40		.0089	160	O
	3Y	1800	24	3	64	44	8.5	5	H	50	10	10	10	40		.0108	155	O
	3Z	1800	24	3	64	44	8.5	5	H	20	10			80		.0142	160	C
	3A′	1800	24	3	64	44	8.5	5	H	20	10			80		.0171	160	O
	3B′	1800	24	3	64	44	8.5	5	H	35	10	40	10	25		.0260	167	C
	3C′	1800	24	3	64	44	8.5	5	H	20	10			80		.0329	173	C
	3D′	1800	24	3	64	44	8.5	5	H	15	10			85		.0350	178	O
	3E′	1800	24	3	64	44	8.5	5	H	15	10			85		.0376	179	C
	3F′	1800	24	3	64	44	8.5	5	H					100		.0358	175	C
	3G′	1800	24	3	64	44	8.5	5	H	15	10	20	10	65		.0382	175	C
	3H′	1800	24	3	64	44	8.5	5	H	30	10	25	10	45		.0360	172	[illegible]
	3I′	1800	24	3	64	44	8.5	5	H	40	10	50	10	10		.0318	163	[illegible]
	3J′	1800	24	3	64	44	8.5	5	H	45	10			55		.0329	155	[illegible]
	3K′	1800	24	3	64	44	8.5	5	H	15	10	30	10	55		.0348	148	[illegible]
	3L′	1800	24	3	64	44	8.5	5	H					100		.0352	153	[illegible]
	3M′	1800	24	3	64	44	8.5	5	H					100		.0380	141	[illegible]
	3N′	1800	24	3	64	44	8.5	5	H			35	10	65		.0394	135	[illegible]
	3O′	1800	24	3	64	44	8.5	5	H			25	10	75		.0390	126	[illegible]
	3P′	1800	24	3	64	44	8.5	5	H	25	10	60	10	15		.0380	124	[illegible]
	3Q′	1800	24	3	64	44	8.5	5	H	15	10	50	10	35		.0376	114	[illegible]
	3R′	1800	24	3	64	44	8.5	5	H	15	10	15	10	70		.0369	117	[illegible]
	3S′	1800	24	3	64	44	8.5	5	H	30	10	30	10	40		.0360	116	[illegible]
	3T′	1800	24	3	64	44	8.5	5	H					100		.0340	124	[illegible]
	3U′	1800	24	3	64	44	8.5	5	H					100		.0310	132	[illegible]
	3V′	1800	24	3	64	44	8.5	5	H			15	10	85		.0216	130	[illegible]
	3W′	1800	24	3	64	44	8.5	5	H			15	10	85		.0192	133	[illegible]
	3X′	1800	24	3	64	44	8.5	5	H					100		.0174	131	[illegible]
	3Y′	1800	24	3	64	44	8.5	5	H					100		.0168	122	[illegible]

GROUP IV--24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
01	4A	1800	24	3	85	38	7.5	6	H			50	10	50		.0087	97	O
	4B	1800	24	3	85	38	7.5	6	H					100		.0060	93	O
	4C	1800	24	3	85	38	7.5	6	H					100		.0074	88	O
	4D	1800	24	3	85	38	7.5	6	H					100		.0079	90	O
	4E	1800	24	3	85	38	7.5	6	H					100		.0100	99	O
	4F	1800	24	3	85	38	7.5	6	H			20	10	80		.0126	105	O
	4G	1800	24	3	85	38	7.5	6	H			10	7	80		.0142	109	O
	4H	1800	24	3	85	38	7.5	6	H					100		.0150	15	O
	4I	1800	24	3	85	38	7.5	6	H					100		.0092	157	O
	4J	1800	24	3	85	38	7.5	6	H					100		.0108	162	O
	4K	1800	24	3	85	38	7.5	6	H					100		.0095	153	O
	4L	1800	24	3	85	38	7.5	6	H	25	12			75		.0090	147	O
	4M	1800	24	3	85	38	7.5	6	H	15	10			75		.0087	141	O
	4N	1800	24	3	85	38	7.5	6	H					100		.0092	133	O
	4O	1800	24	3	85	38	7.5	6	H			15	10	85		.0103	175	O
	4P	1800	24	3	85	38	7.5	6	H					100		.0108	122	O
	4Q	1800	24	3	85	38	7.5	6	H			30	10	70		.0110	118	O
	4R	1800	24	3	85	38	7.5	6	H			15	10	85		.0105	105	O
	4S	1800	24	3	85	38	7.5	6	H			15	12	85		.0092	98	O
	4T	1800	24	3	85	38	7.5	6	H			40	12	60		.0074	98	O
	4U	1800	24	3	85	38	7.5	6	H			15	10	85		.0063	92	O
	4V	1800	24	3	85	38	7.5	6	H					100		.0037	107	O
	4W	1800	24	3	85	38	7.5	6	H					100		.0074	107	O
	4X	1800	24	3	85	38	7.5	6	H					100		.0026	111	O
	4Y	1800	24	3	85	38	7.5	6	H					100		.0029	121	O
	4Z	1800	24	3	85	38	7.5	6	H			100	9			.0022	134	O
	4A'	1800	24	3	85	38	7.5	6	H			45	12	55		.0037	150	O
	4B'	1800	24	3	85	38	7.5	6	H					100		.0053	145	O
	4C'	1800	24	3	85	38	7.5	6	H					100		.0066	132	O
	4D'	1800	24	3	85	38	7.5	6	H					100		.0058	131	O
	4E'	1800	24	3	85	38	7.5	6	H					100		.0053	136	O
	4F'	1800	24	3	85	38	7.5	6	H					100		.0050	128	O
	4G'	1800	24	3	85	38	7.5	6	H					100		.0037	142	O
	5A	1800	24	8	80	44	8	7	H					100		.0050	87	O
	5B	1800	24	8	80	44	8	7	H	10	11	10	10	80		.0071	93	O

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
101	5C	1800	24	8	80	44	8	7	H	10	10	10	10	80		.0075	96	O
	5D	1800	24	8	80	44	8	7	H					100		.0074	70	O
	5E	1800	24	8	80	44	8	7	H					100		.0079	63	O
	5F	1800	24	8	80	44	8	7	H					100		.0079	17	O
	5G	1800	24	8	80	44	8	7	H					100		.0053	40	O
	5H	1800	24	8	80	44	8	7	H					100		.0032	56	O
	5I	1800	24	8	80	44	8	7	H					100		.0037	74	O
	5J	1800	24	8	80	44	8	7	H					100		.0058	87	O
103	1A	0000	24	9	67	65	10.5	3	H					100		.0972	4	H
	1B	0000	24	9	67	65	10.5	3	H					100		.0892	0	H
	1C	0000	24	9	67	65	10.5	3	H					100		.0850	3	H
	1D	0000	24	9	67	65	10.5	3	H					100		.0792	89	H
	2A	0000	24	7	66	68	11.0	2	H					100		.0726	141	H
	2B	0000	24	7	66	68	11.0	2	H					100		.0930	138	H
	4A	0000	24	5	78	31	6.5	7	H					100		.0176	103	H
	4B	0000	24	5	78	31	6.5	7	H					100		.0125	114	H
	5A	0000	24	6	66	43	7.5	5	H					100		.0021	72	H
	5B	0000	24	6	66	43	7.5	5	H					100		.0058	46	H
	5C	0000	24	6	66	43	7.5	5	H					100		.0108	44	H
106	2A	0000	24	8	98	12	3.5	22	T	60	13	40	15			.0725	159	H
	2B	0000	24	8	97	13	3.5	22	T	65	13	35	15			.0687	154	H
	2C	0000	24	8	96	13	3.5	22	T	40	17	60	14			.0725	138	H
	2D	000	24	8	96	13	3.5	22	T	30	20	20	11	50		.0646	133	H
	2E	0000	24	8	96	13	3.5	22	T	70	11	30	4			.0646	125	H
	2F	0000	24	8	96	13	3.5	22	T	100	10					.0770	121	[illegible]
107	2A	0000	24	6	95	14	4	20	T					100		.0167	105	[illegible]
	2B	0000	24	6	95	14	4	20	T					100		.0375	97	[illegible]
	2C	0000	24	6	95	14	4	20	T					100		.0583	87	[illegible]
	2D	0000	24	6	96	14	4	20	T	30	11			70		.0625	81	[illegible]
	2E	0000	24	6	96	13	4	20	T					100		.0625	73	[illegible]
	2F	0000	24	6	97	13	4	20	T					100		.0771	71	[illegible]
	2G	0000	24	6	93	15	4	20	T					100		.0771	76	[illegible]
	2H	0000	24	6	95	14	4	20	T	100	10					.0625	70	[illegible]
	2I	0000	24	6	95	14	4	20	T	70	11	30	15			.0646	62	[illegible]
	2J	000	24	6	103	11	4	20	T			75	16	25		.0416	10	[illegible]

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI	FUEL	%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
7	2K	0000	24	6	106	10	4	20	T			80	12	20		.0562	4	H
	2L	0000	24	6	105	10	4	20	T			50	11	50		.0645	6	H
	2M	0000	24	6	105	10	4	20	T			45	10	55		.0687	8	H
	2N	0000	24	6	105	10	4	20	T			40	15	60		.0625	15	H
	2O	0000	24	6	100	12	4	20	T			25	18	75		.0521	22	H
	2P	0000	24	6	103	11	4	20	T			100	10			.0146	50	F
	2Q	0000	24	6	101	12	4	20	T					100		.0208	73	F
	2R	0000	24	6	102	12	4	20	T					100		.0208	89	F
	2S	0000	24	6	101	12	4	20	T	100	7					.0208	99	F
08	2A	1800	24	10	85	27	5.5	17	T			100	22			.0104	3	O
	2B	1800	24	10	85	27	5.5	17	T			100	10			.0192	32	O
	2C	1800	24	10	85	27	5.5	17	T					100		.0167	63	O
	3A	1800	24	6	84	30	6.5	9	T	45	15	55	14			.0317	144	F
	3B	1800	24	6	84	30	6.5	9	T	40	14	60	15			.0313	103	F
	3C	1800	24	6	84	30	6.5	9	T					100		.0675	25	H
	3D	1800	24	6	84	30	6.5	9	T			100	10			.0631	16	H
	3E	1800	24	6	84	30	6.5	9	T			100	10			.0279	8	H
	4A	1800	24	4	76	17	4	12	T			100	10			.0184	108	F
	4B	1800	24	4	76	17	4	12	T			100	10			.0279	124	F
9	2A	0000	24	7	87	29	7	7	T			100	31			.0036	115	R
	2B	0000	24	7	87	29	7	7	T			100	30			.0066	103	R
	2C	0000	24	7	87	29	7	7	T			100	21			.0120	102	R
	2D	0000	24	7	87	29	7	7	T			100	25			.0162	96	R
	2E	0000	24	7	86	30	7	7	T			100	28			.0114	86	R
	2F	0000	24	7	82	31	7	7	T			100	25			.0042	82	R
	2G	0000	24	7	82	31	7	7	T			100	17			.0025	30	R
	2H	0000	24	7	82	31	7	7	T			100	15			.0021	24	R
	2I	0000	24	7	82	31	7	7	T					100		.0062	23	R
	2J	0000	24	7	79	33	7	7	T	25	27	20	24	55		.0055	23	F
	2K	0000	24	7	80	32	7	7	T	30	20	20	20	50		.0218	27	F
	2L	0000	24	7	84	32	7	7	T	70	20	20	16	10		.0141	22	H
	2M	0000	24	7	82	31	7	7	T	15	20	30	22	55		.0094	13	F
	2N	0000	24	7	83	29	7	7	T	100	30					.0052	9	H
	2O	0000	24	7	83	29	7	7	T	100	35					.0031	15	H
	3A	0000	24	3	90	20	7	9	T			100	18			.0156	35	O

GROUP IV—24-Hour Periods

FIRE				WEATHER						TOPOGRAPHY						SPREAD		
										SLOPE								
										UP		DOWN						
Fire No.	Line No.	Time of Start	Hours of Spread	Wind Vel.	Temp	RH	Stick	BI		%	Aver. Deg.	%	Aver. Deg.	Percent Flat	Sketch	Rate	Angle to Wind	Type
109	3B	0000	24	3	89	21	7	9	T			100	20			.0156	8	O
	3D	0000	24	3	89	21	7	9	T			100	10			.0135	2	O
	3E	0000	24	3	91	20	7	9	T	15	16	15	16	70		.0140	15	O
	3F	0000	24	3	91	20	7	9	T	100	10					.0186	40	O
	4A	0000	24	4	98	16	5	10	T			100	10			.0047	7	F
	4B	0000	24	4	98	16	5	10	T			100	10			.0161	29	H
	4C	0000	24	4	98	16	5	10	G			100	10			.0161	52	H
	4D	0000	24	4	98	16	5	10	G					100		.0177	74	H
	4E	0000	24	4	97	16	5	10	G			100	12			.0167	78	H
	4F	0000	24	4	98	16	5	10	T			100	26			.0094	95	F
	5A	0000	24	4	98	24	7	7	T			100	18			.0104	20	F
	5B	0000	24	4	98	24		7	T			100	20			.0093	25	F
	5C	0000	24	4	98	24	7	7	T			100	25			.0119	0	H
	5D	0000	24	4	99	24		7	T					100		.0156	21	H
	5E	0000	24	4	99	24	7	7	T			100	15			.0198	29	H
	5F	0000	24	4	99	24	7	7	T			40	18	60		.0218	41	H
	5G	0000	24	4	98	24		7	T			100	10			.0171	44	H
	5H	0000	24	4	98	24	7	7	T			100	20			.0093	57	H

Appendix E

Urban Fire Spread Data

The following tables contain rate-of-spread and as-
ɔciated data for large city fires. There is no standard ngth of time over which the rate of spread was calcu-
.ted. For each fire studied, a rate of spread was calcu-
.ted whenever two consecutive locations and times could ɛ identified. Locations and times were noted more or ɛss at random in the fire reports. Often this was when a articularly large or historic building caught fire. Actually ıis probably pegged the fire location accurately. Such efinite landmarks are rare in most wildland areas.

Explanation of Table Headings

FIRE

Name: City and State where fire occurred.

Date: Month, day, and year during which each par- cular fire spread occurred.

Period of Spread: Time of day fire arrived at a cer- in location and time fire had spread to a location far- er on. Spread might be by spotting (firebrands) or ound spread as noted in Remarks.

Rate of Spread: Rate of fire spread, in miles per ɔur.

WEATHER

Temp.: Dry bulb temperature, in degrees Fahrenheit, ually for the beginning of the Period of Spread.

Wind speed: Measured wind velocity in miles per ɔur.

Wind dir.: Direction wind coming from to eight ɔints of the compass.

Rel. humid.: Relative humidity in a standard U.S. eather Bureau thermoscreen, in percent.

Dryness: An adjective description of the weather ɛtors before the fire which may have influenced the ɔisture content of fuels at the time of the fire.

BUILDINGS

T.: Type of building. Numerical code, 1 to 4, to rate type of building construction and massiveness.

B.: Builtupness. Percent of total ground area occupied by buildings.

S.: Number of stories in buildings.

V.: Structure value. Numerical expression of relative rate of fire spread that integrates the factors of building type, builtupness, and number of stories. Structure value is a tentative rating of urban fuels as to relative rate of fire spread. To rate any city area (fuel), identify the proper index number—1 to 4, as listed below—for each of the three fuel factors. Record the numbers, then add them. The sum is the Structure Value in a scale ranging from 3 to 12. The smaller the sum, the greater the relative rate of fire spread to be expected.

Type of Building

1. Light wooden
2. Heavy wooden
3. Light stone or concrete
4. Heavy stone or concrete

Builtupness

1. Very heavy (40 percent or more)
2. Heavy (30 to 39 percent)
3. Medium (20 to 29 percent)
4. Sparse (less than 20 percent)

Number of Stories

1. One
2. Two or three
3. Four to six
4. Seven or more

TOPOGRAPHY

Slope: General slope of the ground and direction. Fire spreading up slope is +. Fire spreading down slope is −. Fire spreading on level ground is 0.

REMARKS

Remarks: Short statements aimed to help interpret the data. Usually indicates whether spread was by spotting (firebrands) or ordinary ground spread.

Fire		Spread		Weather					Buildings				Slope	Remarks
Name	Date	Period	Rate	Temp.	Wind Speed	Wind Dir.	Rel. Humid.	Dryness	T	B	S	V		
Chicago, Illinois	3/15/22	0050-0230	0.063	40	13	N	65	Last rain 3-11 (Dry Fbr season)	4	40+	2-15	9	0	
Ottawa-Hull, Canada	4/26/00	1030-1300	0.212	60	30	N	70	Last rain 4-19 (.10in)	2	30-39	1	5	0	Spotting (Spread by)
	4/26/00	1300-1930	0.298	60	30	N	60		1	20-29	2-10	5	0	Spotting (Spread by)
Chicago, Illinois (Great)	10/8/71	2100-2200	0.227	67	4	SW	42	Extreme Drought	2	30-39	2	6	0	Spotting (Spread by)
	10/9/71	2200-2330	0.201	67	5	SW	44		3	20-29	4	8	0	
	10/8/71	2330-2400	0.499	67	5	SW	44		2	20-29	1	6	0	
	10/9/71	2400-0130	0.227	67	5	SW	45		3	30-39	4+	7	0	Spotting (Spread by)
	10/9/71	0130-0230	0.454	67	5	SW	46		3	20-29	3	8	0	
	10/9/71	0230-0300	0.832	67	5	SW	46		1	20-	2-3	6	0	
	10/9/71	0300-0320	0.624	67	4	SW	46		2	20-	2+	7	0	Spotting (Spread by)
	10/9/71	0700-0900	0.217	67	4	SW	49		2	20-29	1-10	7	0	Spotting (Spread by)
	10/9/71	0900-1200	0.327	67	6	SW	45		1	20-	1	6	0	Spotting (Spread by)
	10/9/71	1200-1700	0.265	82	7	SW	41		1	20-	1	6	0	

Fire		Spread		Weather					Buildings				Slope	Remarks
Name	Date	Period	Rate	Temp.	Wind Speed	Wind Dir.	Rel. Humid.	Dryness	T	B	S	V		
San Francisco, California	4/18/06	1330-1530	0.047	60	20	W	45		2	30-39	2	6	0	Ground Spread
	4/18/06	1300-1600	0.331	60	20	W	45		2	30-39	2	6	0	Spotting (spread by) some incendiarism
	4/18/06	0600-1200	0.022	57	6-	W	65		2	30-39	2	6	0	U.S. Weather Bur. office burned 11:00 A.M. (Ground Spread)
	4/18/06	0900-1300	0.090	55	14	W	60		2	20-29	2-6	7	0	Ground Spread
	4/18-19/06	2100-0030	0.076	55	5	W	75		3	30-39	25	8	0	Ground Spread
	4/18/06	1000-1230	0.040	55	14	W	60		2	30-39	1	5	0	Ground Spread
	4/18/06	0530-1730	0.047	55	2-19	SW	55		2	30-39	3+	6	0	Ground Spread
	4/18/06	0530-1730	0.033	55	2-10	W	55		3	30-39	2	8	0	
	4/19/06	1900-2200	0.025	55	20	W			1	30-39	2	5	0	Ground Spread
	4/19/06	1130-1330	0.142	65	10	E			1	30-39	2	5	0	
	4/18/06	0600-1600	0.123	60	2-12	W	55		1	30-39	2-3	5	0	
	4/18/06	0900-2400	0.025	55	5-19	W	60		1	30-39	2-3	5	0	Ground Spread
	4/20/06	0600-1800	0.063	60	26	W			2	30-39	2-3	6	0	

Fire		Spread		Weather					Buildings				Slope	Remarks
Name	Date	Period	Rate	Temp.	Wind Speed	Wind Dir.	Rel. Humid.	Dryness	T	B	S	V		
Baltimore, Ohio	2/07/04	1050-2100	0.022	58-64	16	WSW	75	recent snow (still melting 2/7/04)	3	40+	6-10	8	0	Ground Spread, explosion spread blaze
	2/07/04	2100-2200	0.054	58-60	22	W	86	↓	4	40+	8-16	9	0	Ground Spread
	2/07/04	2200-2345	0.031	53	22	NW	88	↓	3	40+	8-10	8	0	Ground Spread
	2/07/04	2345-2350	3.175	50	20+	NW	88	↓	3	40+	3	6	0	Spread by Spotting
Boston, Mass.	11/9/72	1900-2400	0.030	42	5-9	NNW	60	1.89" rain 11-7-72	3	40+	4	7	0	Ground Spread (Angle to wind = 135° - most nearly with wind)
	11/9/72	1900-2400	0.042	42	5-9	NNW	60	↓	3	40+	4	7	0	Ground Spread (Angle to wind = 080°)
	11/9/72	1900-2400	0.025	42	5-9	NNW	60	↓	3	40+	4	7	0	Ground Spread (Angle to wind = 360° - most nearly into wind)
	11/9/72	1900-2400	0.030	42	5-9	NNW	60	↓	3	40+	4	7	0	Ground Spread (Angle to wind = 290°)
Berkeley, Calif.	9/17/23	1420-1500	0.397	87	25	NE	27	very Dry	1	20-29	2½	6	-6°	Spread by Spots
	9/17/23	1500-1600	0.454	89	28	NE	25	very Dry	1	20-29	2½	6	-6°	Spread by Spots
Atlanta, Ga.	5/21/17	1246-1430	0.451	83-86	14-16	S	43-	2 weeks since rain	1	20-29	1	5	0	Spread by Spots (Angle to wind = 000°)
	5/21/17	1430-1630	0.567	84-86	16	S	35+	↓	1	20-29	1	5	0	Spread by Spots (Angle to wind = 000°)

Fire		Spread		Weather					Buildings				Slope	Remarks
Name	Date	Period	Rate	Temp	Wind Speed	Wind Dir.	Rel. Humid.	Dryness	T	B	S	V		
Atlanta, Ga.	5/21/17	0400-0700	0.063	46-50	20	W	93	2 weeks since rain	3	40+	4	7	0	Ground Spread (Angle to wind = 090°)
Dorris, Calif.	7/28/34	1500-1600	0.499	86	24-27	SE	20	Dry	1	20-29	1	5	0	Spread by Spots (Angle to wind = 000°)
Augusta, Ga.	3/22/16	1820-2020	0.095	78-80	18-22	W	58	2 weeks without rain	3	30-39	1-5	8	0	Ground Spread (Angle to wind = 090°)
	3/22/16	2020-2030	4.536	78	18	NW	58	↓	1	20-29	1	5	0	Spread by Spots (Angle to wind = 135°)
	3/22/16	2020-2030	2.835	78	18	NW	58	↓	1	20-29	1	5	0	Spread by Spots (Angle to wind = 135°)
Nagasaki, Japan	8/9/45	1102-1502	0.156	75	3	NW	humid		3	20-29	2-3	8	0	Ground Spread
Fall River, Mass.	2/2/28	1730-1900	0.038	14	15	NW	55	wet	3	40+	6	7	0	Ground Spread (Angle to wind = 135°)
	2/2/28	1730-1945	0.017	14	17	SW	55	↓	3	40+	4	7	0	Ground Spread (Angle to wind = 045°)
	2/2/28	1945-2015	0.076	14	18	S	55	↓	3	40+	5	7	0	Ground Spread (Angle to wind = 340°)
	2/2/28	1945-2030	0.050	14	19	S	55	↓	3	40+	4	7	0	Ground Spread (Angle to wind = 040°)
	2/2/28	2030-2300	0.015	14	22	S	55+	↓	2	40+	1	4	0	Ground Spread (Angle to wind = 035°)

Fire		Spread		Weather					Buildings				Slope	Remarks
Name	Date	Period	Rate	Temp	Wind Speed	Wind Dir.	Rel. Humid.	Dryness	T	B	S	V		
Boston, Mass. Railroad Freight Shed	5/10/62	1555-1630	0.261	64	22-35	NW	6	Dry	1	20-	2	7	0	Ground Spread (Angle To wind = 135°)
	5/10/62	1600-1630	0.227	64	22-35	NW	6	↓	1	20-	1	6	0	Ground Spread (Angle to wind = 135°)
Chicago, Illinois Stockyard	5/19/34	1620-1645	0.369	92	15	SW	25	VERY DRY	1	20-	1	6	0	Ground Spread (Angle to wind = 010°)
	5/19/34	1620-1645	0.507	92	15	SW	25	VERY DRY	1	20-	1	6	0	Ground Spread (Angle to wind = 070°)
	5/19/34	1645-1700	0.499	92	15	SW	25	VERY DRY	3	30-39	1-3	7	0	Spread by Spots (Angle to wind = 070°)
	5/19/34	1645-1715	0.095	92	15	SW	25	VERY DRY	3	20-29	1-4	8	0	Ground Spread (Angle to wind = 070°)
	5/19/34	1620-1730	0.074	91	14	SW	25	VERY DRY	1	20-	1	6	0	Ground Spread (Angle to wind = 070°)
	5/19/34	1730-1735	0.307	91	14	SW	25	VERY DRY	3	20-29	1-3	8	0	Ground Spread (Angle to wind = 030°)
Camden, N.J.	7/30/40	1315-1730	0.014	76	15-21	SW	57	No rain in July	2	40+	5	6	0	Ground Spread (Angle to wind = 180°)
Chicago, Ill.	10/7/71	2230-2250	0.142	70	14	S	55	Very Dry	1	20-29	2	6	0	Ground Spread (Angle to wind = 000°)
Arverne, N.Y.	6/15/22	1715-1800	0.227	70	9	S	63	Last rain 6-11 Trace 9th & 15th	1	20-	2-3	7	0	Spread by Spots (Angle to wind = 000°)

Fire		Spread		Weather					Buildings				Slope	Remarks
Name	Date	Period	Rate	Temp	Wind Speed	Wind Dir.	Rel. Humid.	Dryness	T	B	S	V		
Bandon, Oregon	9/26/36	2215-2235	1.474	70+	38	E	8	very Dry	1	20-	1-2	6	0	Spread by Spots (angle to wind = 270°)
	9/26/36	2235-2315	1.928	70+	38	E	8		1	20-	1-2	6	0	Spread by Spots (angle to wind = 270°)
	9/26/36	2245-2400	0.423	70+	38	E	8		2	20-29	1-2	6	0	Spread by Spots (angle to wind = 270°)
Paris, Texas	3/21/16	1730-1900	0.315	91-95	27-29	S	26⁻	very Dry	1	20-29	1-2	5	0	Spread by Spots (angle to wind = 010°)
	3/21/16	1900-2100	0.047	87-91	27-29	S	26⁻		3	40+	4-6	7	0	Ground Spread (angle to wind = 000°)
	3/21/16	2100-2215	0.076	85-87	26-29	S	26⁻		3	40+	4-6	7	0	Ground Spread (angle to wind = 000°)
	3/21/16	2215-2245	0.095	83-85	26	S	26⁻		3	40+	4-6	7	0	Ground Spread (angle to wind = 000°)
	3/21/16	2245-2400	0.378	80-83	24-26	S	26⁻		1	20-29	1-2	5	0	Spread by Spots (angle to wind = 010°)
W. New York, N.J.	8/18/61	1649-1659	2.999	80	8	N	49	Dry	2	20-	2-4	7	0	Spread by Spots
	8/18/61	1649-1714	0.095	77	8	N	56	Dry	2	20-29	2-4	7	0	Ground Spread
Astoria, Oregon	12/8/22	0212-0245	0.034	35	16	S	100	Raining and snowing	2	30-39	1-3	6	0	Ground Spread (brands but no fires set)
	12/8/22	0212-0300	0.047	35	29	S	100	Raining and snowing	2	30-39	1-3	6	0	Ground Spread (brands but no fires set)

Fire		Spread		Weather					Buildings				Slope	Remarks
Name	Date	Period	Rate	Temp.	Wind Speed	Wind Dir.	Rel. Humid.	Dryness	T	B	S	V		
Cleelom, Washington	6/25/18	1220-1600	0.219	75	15	W	X	Dry - .37" rain in June	1	30-39	1-2	4	0	Spread by Spots

GPO 967-435

Managing California's Snow Zone Lands for Water

Henry W. Anderson

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PSW

Pacific Southwest Forest and Range
Experiment Station - Berkeley, California
Forest Service - U. S. Department of Agriculture
in cooperation with
California Department of Water Resources
Sacramento 2, California

Foreword

Since 1956, the Pacific Southwest Forest and Range Experiment Station and the California Department of Water Resources have conducted the California cooperative snow management research program. Other organizations cooperating in the project include the University of California, U. S. Geological Survey, U. S. Weather Bureau, Fiberboard Corporation, and Pacific Gas and Electric Company.

This report summarizes the results of basic studies of snow zone hydrology completed during the first seven years of this joint program. It describes the results of the first application of management tests for improved water yield in the California snow zone.

We hope soon to have more elaborate techniques to meet the specific problems of increasing the amount of water yield, improving the timing of water yield, and preventing floods and sedimentation.

We do not yet know all there is to know about managing high elevation forest lands for improved water yield. But the information now available may help those who must decide about water resources management and plan for the future.

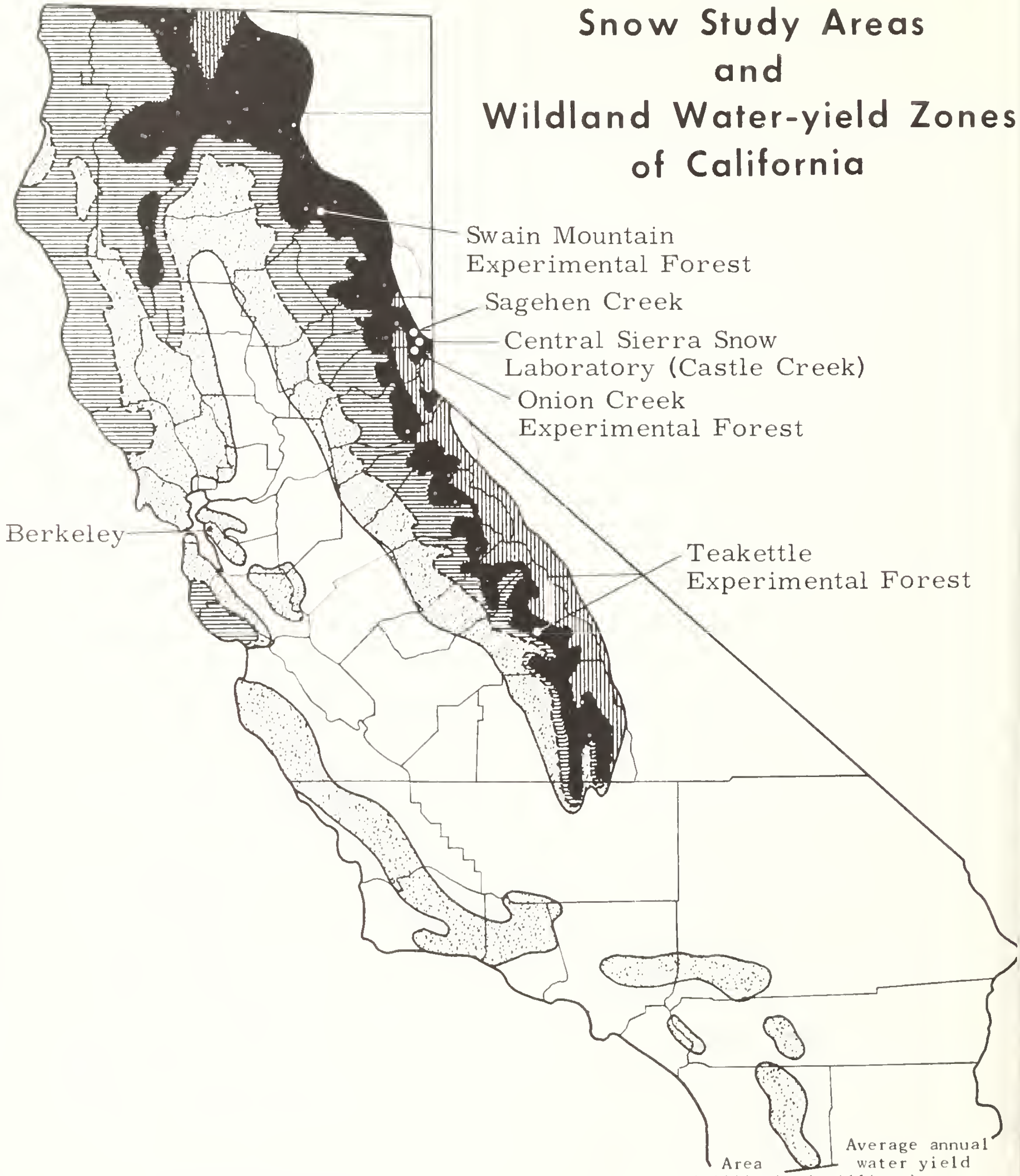
The Author

Henry W. Anderson has been with the Forest Service Experiment Station in Berkeley since 1946, except for two years at the San Dimas Experimental Forest, Glendora, Calif. He was first a hydrologist in the Station's division of flood control surveys, then did research on soil stabilization, became head of watershed studies in the Sierra snow zone in 1955, and is now in charge of watei source hydrology research in the wildlands of California and Hawaii. He is the author or co-author of more than 45 technical publications on hydrology, sedimentation, and watershed management. Born in Des Moines, Iowa, he earned both his bachelor's (in 1943) and master's degrees (in 1947) in forestry at the University of California, Berkeley.

Contents

Figure 1

Snow Study Areas and Wildland Water-yield Zones of California



WILDLAND ZONES	Area (million acres)	Average annual water yield (million acre feet)	Average annual water yield (percent)
Woodland-brush-grass zone	18	9	12
Lower conifer zone	12	23	32
Snow zone: Commercial forest	9	27	38
Alpine	3	9	13
WILDLAND TOTAL	42	68	95
ENTIRE STATE	101	71	100

No single method of managing forested watersheds will provide improvement in all aspects of water yield. Consequently, some objectives of water resources managers are contradictory. If we want more water, it is likely to come sometimes when we do not want it, and we may have to make special provisions to keep that extra water from doing damage. If we want delayed water yield for summer irrigation, we may sometimes adversely delay the yield for winter power production. The purest water of the forest comes from the least use of the forest. Objectives of flood control are not likely to be compatible with those of greatest water yield. In some places the conflict over objectives will be critical; in other places, trivial.

Those who must produce timber for the mill and water for use want answers to such questions as: What difference does it make when logging is done in this way or that? At this place or that? On the north side of Granite Peak and in Holcomb Valley? In thin stands and dense stands? How does a particular logging practice affect water yield?

This report includes information which, when combined with what the water resources manager knows about his particular watershed and its behavior, may allow him to make critical management decisions. But only he can decide whether the differences are likely to be worthwhile to him and the water users.

Water Yield and Water Sources

Before we consider water management, perhaps we should look at "inventory sheets" of our water supply: What do we have, when do we get it, where is it coming from, how variable is it, and why does it vary? Answers to such questions will indicate the areas where management for water is likely to be the most effective.

Water Yield by California Streams

Water yield by California streams comes largely from four zones: (a) the high elevation alpine snowpack zone; (b) the commercial timber snowpack zone; (c) the lower conifer zone; (d) the woodland, brush, and grass zone at lower elevations (fig. 1). Together these four zones yield 95 percent of California's streamflow (Colman 1955). The two snowpack zones combined yield 51 percent, the lower conifer "rain zone" 32 percent, and the foothill woodland zone about 12 percent. The average annual yield of water from the four zones is 71 million acre-feet (California Department of Water Resources 1957). This amount would be enough to meet California's foreseeable needs if water was delivered where needed, and in an orderly manner each year. But much of today's water is produced far from the point of need, flood flows are far from orderly, and water yield varies widely from year to year.

In an average year, we have enough water to fill most of our reservoirs and to refill them after the first early summer irrigation use. If we always had the average water yield, we would have no problems, but we do not. Some years are dry and we thirst for water; other years are wet and we lose our water in flood runoff.

Variability of Annual Streamflow

How does annual streamflow vary in the elevation and geographic zones of California? It is least variable from the high elevation snow zone, highly variable from the foothill watersheds of the south part of the Sierra Nevada, and most variable from areas adjacent to the southern San Joaquin Valley and coastal areas south of San Luis Obispo (Corps of Engineers 1958).

How often do we get dry years in the different zones? "Dry years" can be defined as those in which a zone yields less than half the normal streamflow. The snow zone along the Sierra Nevada crest and whole north end of California are high water-producing sources and the most consistent producers. Less than 1 year in 10 is a "dry year" in these zones. In the southern Sierra Nevada's lower conifer zone, 2 to 3 years in 10 are dry. And, as we go lower in the Sierra Nevada to the foothill woodlands zone, not only do we get less water annually, but it is more variable: 3 to 5 years in 10 are dry years.

Why this variability in annual streamflow? We might possibly look further into the causes, because they have implications in forest management for water yield. Certainly in comparing the variability of streamflow in northern California and the southern Sierra Nevada, the number of winter storms which cross the northern part is not only greater, but less variable from year to year. But if we consider the variability in the southern Sierra Nevada as a unit, the remarkably low variability at high elevations deserves explanation.

Let us consider differences in precipitation and winter losses of water. Most water stored in the Sierra Nevada snowpack is nearly immune from evaporation losses, flash flood runoff, and rapid melt. Water loss by evaporation from the snowpack is small: 4.5 inches on exposed ridges, 2 inches in large open area, and less than 1 inch under forest stands (Anderson 1958; Kittredge 1953; West 1959; West and Knoerr 1959). Snow held until late spring gains water by condensation rather than losing it by evaporation. The surface of the snow reflects most of the heat from the sun: 90 percent reflected from new snow, and 60 percent as the surface ages (Miller 1955). Small snowstorms are hydrologically important in the Sierra Nevada snowpack zone, restoring the high reflectivity of the snow surface. The snow and snowmelt water cools the soil, tending to minimize transpiration losses by the trees over long periods. As a result of the short, fairly cool summer and occasional summer and fall rainstorms, water in some years may remain unused in the soil at the end of the summer and thus contribute to next year's streamflow (Anderson and Gleason 1959).

In contrast, let us examine the hydrology of the lower elevation forests and woodland brush and grass zones. Precipitation is mostly in the form of rain or light snowfall that melts after a few hours or days. Part of the rain of every storm is caught by the forest trees, evaporates rapidly during breaks in the storm and between storms, and is thus lost. Whenever water is stored in the soil, transpiration by the trees is likely to be active. Between every storm, the vegetation, litter, and soil surface dry by evaporation (Rowe 1955; Rowe and Colman 1951). Small storms contribute little except to replenish and keep active these evaporative losses. Only in large storms does significant water penetrate the soil mantle and add to streamflow. Large storms in these lower zones are almost always rainstorms which in some places may produce floods and erosion problems rather than usable water. Clearly, the variability in annual streamflow from the rain zone and the woodland brush, and grass zone is associated with the size and number of storms and the opportunity for evaporative losses. The number, size, and distribution of these storms vary widely from year to year and bring about the wide difference in streamflow for the foothill woodland zones and to a lesser degree for the forest zones immediately above.

Seasonal Distribution of Streamflow

The interplay of winter rains and summer droughts, high elevation snowpack storage and fall rains, and runoff in dry and wet years all contribute to wide variability in the seasonal distribution of streamflow. Natural seasonal variability in streamflow may influence the objectives of our management for water. Let us consider briefly this variability as expressed by monthly streamflow in a snow zone watershed.

Monthly streamflow distribution even in snow zone watersheds differs widely between average dry and wet years (table 1). If we look at the critical period from June to September, we find in the average year that we get 24 percent of our water during that period. But in the driest of 10 years not only is the flow low for the year, but we get only 7 percent of our water during this important June to September period. Analyses of other snow zone watersheds in this area show similar results—flows come earlier in the dry years (Court 1961). Management that would pro-

Table 1. Streamflow distribution, in inches, in a watershed whose yield is chiefly from snowmelt (North Fork of Kings River at Cliff Camp, elevation 6,144 to 12,595 feet)

Month	Streamflow					
	Medium		10-year minimum[1]		10-year maximum[1]	
Oct.	0.05		0.04		0.33	
Nov.	.12		.05		1.00	
Dec.	.30		.06		.98	
Jan.	.39		.08		.82	
Feb.	.53		.14		1.06	
Mar.	1.33		.36		1.97	
Apr.	4.72		2.24		7.29	
May	10.52		3.20		17.20	
June	6.00	24%	.73	7%	17.37	4
July	.81		.12		4.55	
Aug.	.11		.04		.46	
Sept.	.04		.02		.14	
Year	29		12		53	

[1] 10-year minimums and maximums are fl expected to be not exceeded and exceeded, respectively, in 10 percent of all years.

Figure 2.—Towers support meterological instruments which help evaluate moisture losses in summer and winter, snowmelt in winter, and the effects of wind, humidity, and temperature on water losses and snowmelt.

›ng water yield in these dry years would be most eneficial.

But we do not really manage whole watersheds; e manage individual forest sites on watersheds, ach of which may require its own prescription. Knowledge of how snow accumulates and melts at different elevations and on different aspects and slopes, and of how forest cover plays its role will prescribe management of high elevation forests for water yield.

Accumulation and Melt of the Snowpack

Let us concern ourselves first with two important characteristics of the Sierra Nevada snowpack: (a) maximum accumulation of snow, which is usually taken as the April 1 snowpack expressed as depth of water (inches) in the pack, and (b) ablation of the pack, or the rate of melt of snow water from the pack after April 1.[1] This first characteristic of the snowpack—the maximum accumulation—is a good indicator of total water yield[2] after April 1 each year; the second characteristic—melt rate—determines when that water is delivered.

Effects of Topography

Studies have shown wide differences in maximum snow accumulation and snowmelt under natural conditions differing in topography, including elevation, slope, aspect, exposure (narrow canyons v. broad valleys), curvature (ridge v. slope v. valley bottom), and forest characteristics that affect interception, shading, shelter from the wind, and cold air drainage (fig. 2).

Elevation Effects

The effect of elevation on snow accumulation and melt is shown by averages for the Yuba River Basin of the north central Sierra Nevada. Maximum snow accumulation there increases by 1.2 to 2.2 inches per 100 feet (Anderson and Pagenhart 1957; Anderson and Richards 1960, 1961; Mixsell et al. 1951); the long term average increase in the south fork of the Yuba River Basin is about 2 inches per 100 feet (Hannaford, Wolfe, and Miller 1958).

The spring melt rate of the snowpack tends to decrease with greater elevation. Re-analysis of the data of Mixsell et al. (1951) showed that between elevations of 6,800 and 8,600 feet, melt in April and May 1950, was greater by 0.4 inches of water per month for each drop of 100 feet in elevation (Anderson and Pagenhart 1957). By combining these results with the long term average progression of melt with season (Anderson 1956), we get the general picture of change in snow and snowmelt with elevation (fig. 3). These relations of snowmelt to elevation apply to average slope exposure, curvature, and forest.

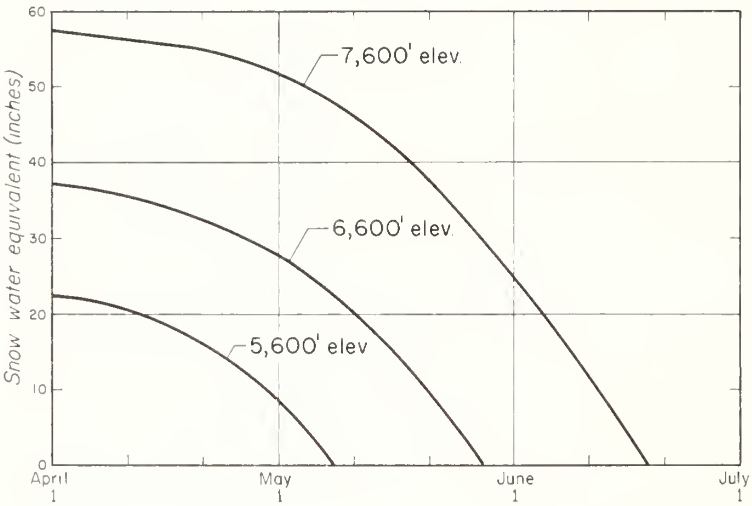


Figure 3.—Snow water in pack at average site and year, for three elevations, Yuba River Basin, California.

Slope and Aspect Effects

Slope and aspect effects on snow accumulation and melt rank next in importance to elevation (Anderson and Pagenhart 1957). Slope effect on maximum snow accumulation were best mea ured when slope was expressed in terms of t energy received on its surface. In winter the sou slopes of 25 percent gradient received three tim as much solar radiation as a north slope of 25 p

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[1]Ablation consists mostly of snowmelt, but small amounts of gains by condensation or less by evaporation usually occur. It probably can be safely said that 95 percent of the ablation produces melt water in the Sierra Nevada.

[2]The maximum snowpack serves as a good indicator of the subsequent water yield because by April 1 the soil is nearly everywhere fully wet by winter snowmelt and fall and winter rains (Anderson 1960).

cent gradient. This fact principally explains why the north slope had 21 inches more water in the pack than did the south slope at the time of maximum snow accumulation. (South slopes also are exposed to the prevailing south and southwest winds. But these separate effects need more study, because trees can modify energy and wind effects in different ways.)

In the spring snowmelt, energy received on various slopes was also the most important single factor (Anderson and Pagenhart 1957). Mid-April melt of snow was 70 percent greater on the south slopes of 25 percent gradient than on the north slopes of 25 percent gradient. Thus, south slopes had less snow water stored at the time of maximum pack and then more rapid melt.

Curvature and Exposure Effects

The effects of curvature and exposure on snow accumulation and melt are only about one-fourth as great as those of elevation and solar energy differences. Snow accumulation and melt are different on ridges than on valley bottoms. These differences have been evaluated by classification of position on slope or shape of the terrain in terms of curvature: (1) Highly concave at the bottom of the slope, (2) moderately concave, (3) neutral in midslope or level, (4) moderately convex, and (5) highly convex at the ridge (Anderson and Pagenhart 1957; Mixsell et al. 1951).

At the time of maximum snow accumulation, ridge tops had 5.6 inches less water than did valley bottoms, according to an analysis of data from the Central Sierra Snow Laboratory (Anderson and Pagenhart 1957). Why? On exposed ridges loss of snow water by evaporation is twice that in a flat valley bottom (West 1959). Wind tends to blow drifting snow from exposed ridges. At a snow course on Boreal Ridge on April 22, 1958, we found only 1 to 6 inches of snow water on an exposed ridge, 180 to 200 inches in the drifted cornice, and 76 inches average in sheltered forest opening. Spring snowmelt also was about 20 percent faster on the ridges than in valley bottoms (Anderson and Pagenhart 1957; Mixsell et al. 1951).

Exposure also affects snow accumulation and melt. Snow accumulation tended to be less and melt faster in open exposed sites than in narrow canyons, even after considering the amount of direct solar radiation received. Open sites had 4 inches less water at the time of maximum accumulation, and the early spring melt rate was some 50 percent greater in the exposed sites than in the narrow canyons. The bottom of narrow draws, which have the least curvature and exposure, have maximum snow accumulation. Minimum melt rates also are found there, making them a good place to store snow. These results suggest the possibility of creating snow "ponds" to act as snow catchment and retention areas.

Heat Equivalent of Terrain

The relative effects of slope, elevation, and other topographic variables on maximum snow accumulation and on snowmelt can be compared by converting their effects into heat equivalents (Miller 1955). By using the results of multiple regression analyses of Mixsell et al. (1951) and Anderson and Pagenhart (1957), we get:

	Average difference in heat equivalent	
	Dec.-March	April-May
Range of topographic variable:	*(Calories per day)*	
Slope and aspect (25 percent N to 35 percent S)	+35	+41
Elevation (100 feet decrease)	+20	+37
Curvature (concave to convex)	+23	+23
Exposure (open to closed)	+ 5	+ 9
Forest (none to dense)	+20	−72

To convert melting snow to 1 inch of water requires 200 calories per square centimeter of area. We get, for example, 41/200 or about 0.2 inch per day more snowmelt in spring on a 25 percent south slope than on a 25 percent north slope. The maximum contrasts are between elevation zones and between forest and open areas; the forest prevented rapid snowmelt in the spring, but supplied heat in winter to evaporate or melt intercepted snow and snow near tree trunks.

In the above reported terrain effects on snow accumulation and melt, each effect was a partial one. That is, each was the independent effect of that terrain condition for average conditions of forest cover. Now let us consider some of that complexity known as "the forest effects on snow accumulation and melt."

Effects of Forests

Nearly 50 years ago, Church (1914) started making observations of snow in forests and openings. He advocated the use of timber screens instead of solid forests to create snow drifting and to delay snowmelt. From observation and measurement of snow in many sites, Church (1933, p. 538) concluded: "The ideal forest is one honeycombed with glades whose extent is so related to the height of the trees that the sun cannot reach the surface of the snow. Such a forest will permit far more snow to reach the ground than will a forest of great and uniform density and yet will amply protect the snow from the effect of sun and wind."

Kittredge (1953) made studies in the central Sierra Nevada mixed conifer belt at elevations between 5,200 and 6,200 feet, where snow accumulation ranged from 3 to 30 inches. He sought to find out what kinds of forests and what densities and sizes of openings in forests were most effective in promoting snow accumulation and melt. He concluded that openings with a width about 1 to 2 times the tree height had the most snow. The effects of species and densities were so tied in with topographic variation as to make impossible direct comparisons of their effects on snow accumulation. Kittredge further concluded that "clear cutting in small groups should both yield the most water and prolong the summer flow. Strip cutting might also give results if the clear cut strips are narrow, if they follow, as far as possible, the contours, and are oriented east and west rather than north and south."

Studies of the California cooperative snow management research program in recent years have elaborated on the suggestions of Church and Kittredge and tested the effects of different methods of management. These studies add to our knowledge of how forests influence snow accumulation and melt and how cutting a forest may be done so as to maximize water yield, delay snowmelt runoff, or minimize local flood runoff and sedimentation.

How a forest affects snow accumulation and melt depends on its density, the height of its trees, and the position of the trees with regard to their neighbors and to the topography associated with the forest site. The specific role of a forest is determined by its effects on wind, shade, radiation, and pondage of cold air.

Wind

The wind affects the location of snow, its method of drifting, and its melting rate. Holes in the forest canopy, whether natural or made when forests are cut in blocks or strips, act as traps for snow during snowfall. Falling snow is trapped in the opening and then deposited by back eddy into the forest on the windward side of the open-ing. This excess of snow results in some deficit o snow in the forest to the leeward (Anderson and Gleason 1959, 1960; Anderson, Rice, and Wes 1958). Almost all wind during storms in the Sierr Nevada blows from the southwest or south (Cour 1957). The most snow in openings is deposited where it can be best protected from the sun, tha is, in the shade of the trees. Wind also affects evaporation of the snowpack (West 1959).

Shade

Shade effects on snowmelt are such that the maximum shade results in the least melt. But abou 85 percent shade is nearly as effective as 100 percent shade (Anderson 1956). The effects of shade for canopy densities greater than 85 percent, are partly negated by winter melt and interception. Trees to the south of a snowpack have a marked influence on snowmelt, but trees to the north are only about 12 percent as effective in preventing melt. The trees to the north do intercept sky radiation, but they also heat up from the direct sun rays and radiate back longwave radiation to the snowpack.

Longwave Radiation

Longwave radiation effects on snowmelt are influenced by the forest in several ways. The fores reflects longwave radiation better than does the snowpack, but it prevents longwave radiation a night upon the snowpack. In open areas, hea loss by longwave radiation at night causes snow to form a crust; whereas in a forest, longwave radiation is intercepted by the trees and back radiated to the snow, and less crust forms.

The familiar melt cone around tree trunks and depressions of snow under tree canopies is in pai the radiation phenomenon and, of course, part interception. The cone may be of little quantitativ importance. A study of snow accumulation aroun 111 trees (Anderson, Rice, and West 1958) showe that in forest stands averaging 50 percent canop cover, only one-half inch less water in the snowpack within forest stands was attributable to th cone around the trees.

Cold Air

Cold air drainage effects of trees at the downhill border of openings are quite striking. Maximum snow accumulation in a study was always found in the downhill side of forest openings, no matter whether the opening was on a north, south east, or west slope (Anderson, Rice, and West 1958). We inferred that cold air draining downhill during the long winter accumulation period was repeatedly trapped against the trees on the downhill side. This cold air cooled the snow and effectively prevented winter melt of the pack. In selected individual forest openings, West (1961) found that the lower side of the opening on a north slope had 3 inches more snow and on a south slope 13 inches more than the uphill side of the opening.

The processes are operating in forests and when forests are cut, we change in some degree each process. The result is an increase or decrease in snow accumulation and melt. Let us combine what we know of these processes and estimate how cutting the forest in different ways and patterns will affect water yield.

Forest Cutting in the Snow Zone

Does it make any difference to water yield how forests in the snow zone are cut? To water yield? To the time of delivery of water yield? To water quality? To flood discharge and sedimentation discharges? How much difference if forests are clear cut? If cut in strips of various widths and orientation? If block cut in various sizes? If selectively cut? Or if cut in designs calculated to give maximum snow accumulation?

Clear Cutting

Clear cutting may be defined as cutting blocks of more than 20 acres or strips wider than four imes the tree heights. Such a cutting has its own pecial influence on snow accumulation and melt. Maximum accumulation of snow is greater in the ut than in the uncut forest. For example, it was 4 inches greater at the Central Sierra Snow Laboratory in 1950 (Mixsell et al. 1951) and 12 nches greater as a long term average (Anderson 956).

Snowmelt is rapid in open areas. Data from Mixsell et al. (1951) showed 22 inches greater nelt from April 1 to June 1, 1950 for the open reas than for a dense forest. Anderson (1956) stimated a long term average of 16 inches of now water left in the forest at 7,600 feet elevaon on June 9 when all snow had melted in the rge open areas. Clear cuts that create large open reas do store more snow than does a forest, but ley have much more rapid melt (fig. 4).

Block Cutting

If block cutting of the forest is silviculturally esirable and economic, consider the shape and ze of block on snow accumulation and melt. esearch results so far suggest that if a square block were cut in the forest with each side about one tree height across, the water equivalent in late spring (June 9) would be about 3 inches more than that of a cut strip one tree height across (Anderson 1956). This arrangement would produce the "honeycomb" forest proposed by Church (1933). In a rectangular block five tree heights long by one tree height wide, with the long dimensions oriented east and west, snow water in early summer would be only about one-half inch greater than in the strip.

Studies by Anderson, Rice, and West (1958) have suggested that an L-shaped block cut on east and west slopes may be the most effective in achieving maximum snow accumulation and delaying melt. On west slopes, the arms of the "L" extend along the slope to the north and uphill to the east; on east slopes the "L" is reversed, one arm extending uphill to the west.[3] This shape of opening permits cold air drainage down the downslope arm of the "L" and pondage of that cold air in the arm along the slope. Differences of 2 inches in maximum snow accumulation and as much as 6 inches more snow left in early summer as compared to strip cuts are indicated for these "L" shaped blocks.

Selective Cutting

Selective cutting of forests may increase the maximum snow accumulation by 5 inches of water if the average crown cover is reduced from 90 percent to 50 percent. If the cover was further reduced to 35 percent, the snowpack would be an-

[3]An inverted "T" would probably be a satisfactory alternative to the "L", with the bottom of the inverted "T" extending along the contour, or along the bottom of the slope.

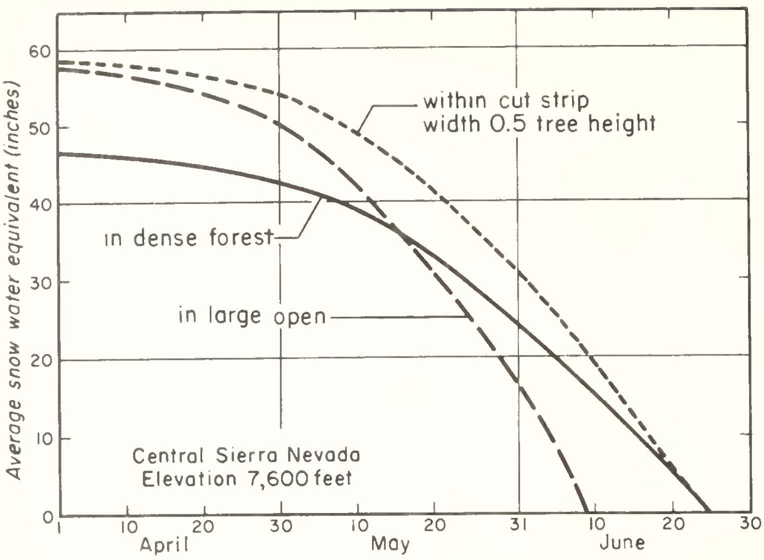

Figure 4. — Snowpack water equivalent at various dates in an average year for two forest conditions and in the open.

other 4 inches greater (Anderson, Rice, and West 1958). In another study in 1958, we found 7 inches more water in a commercial selection cut than in the uncut forest, and 6 inches more a year later (Anderson and Gleason 1959, 1960).

For late spring yield, we found that the advantage of the 35 percent density over the 50 percent density had disappeared, but stands with both of these lower densities had about 4 inches more water in late spring (June 1, 1958) than did the stand of 90 percent density (Anderson, Rice, and West 1958).

Strip Cutting

Strip cutting has some advantages over clear cutting. Maximum snowpack in cut strips occurs when strip widths are approximately one times the height of the surrounding trees (Anderson 1956; Anderson, Rice, and West 1958; Church 1914; Kittredge 1953). Melt of the pack is more rapid in wide strips than in narrow; as the spring season progresses, the maximum unmelted snow is found in narrower and narrower strips. For example, by June 9 in the average year, the maximum snow water equivalent was found in strips only one-half as wide as the trees were tall (Anderson 1956).

How much difference in maximum snow water equivalent would strip cuttings make? We found 12 inches more water in the snowpack at time of maximum accumulation (April 1) in the cut strip than in the uncut forest (fig. 4) (Anderson 1956).

Strips cut in the forest had about 1 inch more water than did large unshaded areas. In late spring (June 9), when all snow was gone from large unshaded areas, 16 inches of water remained in the dense forest and 20 inches in the cut strips. The last snow disappeared from the dense forest and the cut strip at about the same time—16 days later.

What portion of the increased snow found in openings is a true increase rather than mere redistribution of the total snow supply? Data from 58 to 66 snow courses (Anderson, Rice, and West 1958; Anderson and Richards 1960) provide some answers. We can compare the average of snow courses within forests with snow courses having openings as part of the site:

	Snow at maximum pack 1958	1959
Snow courses:	*(inches of water)*	
In forest near opening (area 1½ times area of opening)	56.0	22.6
In opening (average all sizes)	63.2	26.3
Within forests, 35 percent density	57.0	23.2
Within forests, 50 percent density	53.4	21.5
Within forests, 90 percent density	48.1	15.8
Opening associated snow (opening plus extra snow surrounding)	67.1	29.0

Only about half the difference between forest and cut opening (that is, 67.1 − 53.4 = 13.7) was found when comparing openings and adjacent forest (63.2 − 56.0 = 7.2). This is contrary to some interpretations that openings exaggerate the difference between cut and uncut areas. The effect of openngs on snow is not fully indicated by differences n snow within and adjacent to openings.

The effects of management in drought years may be interpreted from the above data. Cutting openings increased snow storage by 35 percent in the drought year of 1959 as contrasted with 26 percent in the near maximum year of 1958 (both compared to a 50 percent forest). In contrast, if by selection cutting we reduced a 90 percent dense forest to one of 35 percent density, we would get nearly as great an effect in the drought year—34 percent increase—but only a 17 percent increase n the year 1958. The effectiveness of selection cut n drought years applies only to the spring snowmelt runoff; soil moisture deficits would deplete total yield. In years of heavy runoff, the snowmelt flood runoff is considerably reduced, so that where forest control of flood runoff is required, selective cutting promises less snowmelt floods than does strip cutting.

For how many years does the excess of snow in cut strips persist? We have measured snow accumulation in a strip made by a powerline clearing made 10 years ago and also in an area of that clearing widened 5 years ago (fig. 5). The excess of snow in the 5-year-old cut area was the same as that expected the first year after the cut—13 inches; the excess in the 10-year-old cut area—where the red fir reproduction is 7 feet tall—was still 10 inches. In the Fraser study in Colorado, remeasurement of the cuttings 13 years after the logging showed no apparent decrease in the excess of snow in the cuttings (Rocky Mountain Forest and Range Experiment Station 1956).

Wall-and-Step Cutting

A special sequence of strip cutting called a wall-and-step cutting has been designed as an "ideal forest" (fig. 4) for maximizing snow accumulation

Figure 5.—How long will cutting of successive strips in the forest affect snow accumulation and melt and water losses? Advance information is being obtained in places where powerline transects simulate such strip cutting.

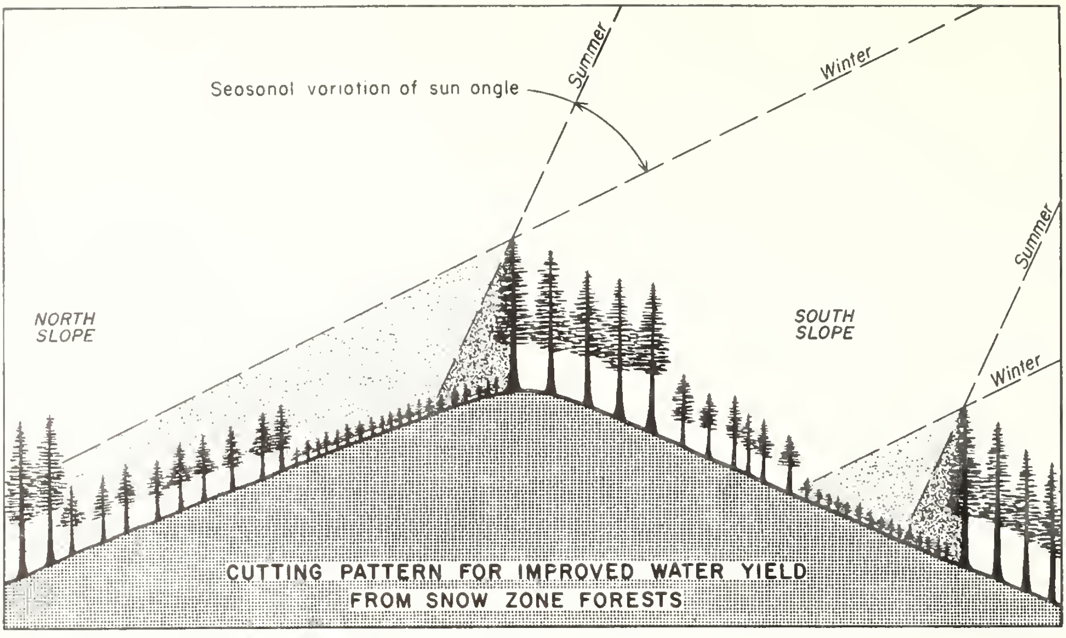

Figure 7.—Wall-and-step forest for maximum snow accumulation and delaying melt.

and delaying melt (Anderson 1956). If maximum accumulation of the snow pack is the management objective and strip cutting is silviculturally desirable and economic, cut the forest in strips oriented across slopes perpendicular to the direction of maximum solar radiation. Generally the strips would be east-west on north and south slopes, northeast-southwest on east slopes, and northwest-southeast on west slopes. Successive strip cutting (fig. 6) would proceed generally to the southward, that is, toward the maximum solar radiation. Once through a cutting rotation, we would have established a wall-and-step forest, with the wall to the south providing shade, and the steps to the north giving the least back radiation (fig. 7).

The width of the cut strip would depend on the slope of the terrain, on the height of the trees expected at the next rotation, and on our objectives. For maximum delayed snowmelt, we suggest strips one-half times the tree height on steep south and west slopes, one to two times the tree height on level areas, and one to four times the tree height on steep north slopes.

When the wall-and-step forest (fig. 7) has been established, calculations indicate an additional 3 inches of snow water at the time of maximum accumulation as compared with results from simple strip cutting (Anderson 1960). First results of a recent test confirm an increase, but suggest more increase than predicted.

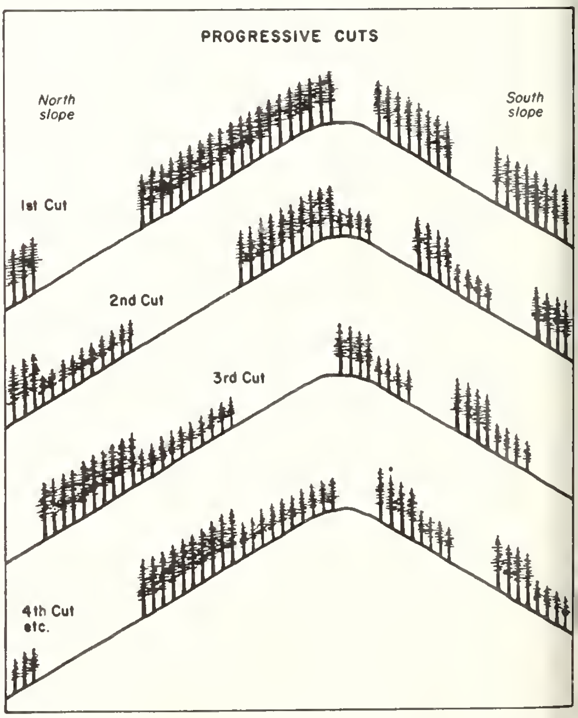

Figure 6.—Progressive cuts establish wall-and-step forest in area rotation.

The recent test included a simulation of a wall-nd-step cutting and strip cuts. The tests also in-luded variation in residual stand treatment and lash disposal (Anderson 1961; West and Adams 963). Five east-west strips (0.6 miles long, 135 eet wide, 400 feet apart) were cut in the fall of 962. The cutting was in an old-growth red fir tand on a 15 percent north slope at elevation of ,700 feet in the Tahoe National Forest near Yuba 'ass, California.

First results were from measurements of the nowpack at some 400 points on April 24, 1963—bout the time of the maximum pack—and again n May 21—when about 60 percent of the pack ad melted. Snow in the center of uncut forests veraged 19 inches on April 24 and 7.7 inches on lay 21 (table 2).

Slightly more than half the increase in snow ac-umulation in the wall-and-step cutting was found vithin the cut strip. The distribution of the in-rease for the wall-and-step and the simple strip ut (both with slash bulldozed downhill) is shown n figure 8. The wall-and-step treatment with slash opped and scattered gave 0.2 inches less snow nd with slash piled gave 0.4 inches less snow nan where the slash was pushed downhill.

The increase in total snow accumulation of 25 ercent for the forest as a whole by the simulated all-and-step cutting is important to management or water yield. The persistence of 70 percent of the increase (3.3 inches) as delayed melt is also encouraging. The concomitant reported benefits of "little or no blowdown in the severe October storm" and "an economical logging show" suggest that the treatment method is feasible.

Differences in snow accumulation and melt result not only from the pattern of cutting but from the slash and residual stand treatment after logging (fig. 9).

Slash left on the ground affects shallow snowpacks—speeding melt when the slash is in the sun, slowing melt when it is shaded. In the 2-chain wide strips at Yuba Pass, burning and piling the slash versus lopping and scattering the slash made little difference. In contrast, the wide 5-chain strips at Swain Mountain showed that the piled and burned area had 4 inches more snow than did the area with slash (Anderson and Gleason 1960). There, when snow accumulated slowly in the fall or when shallow packs occurred late in spring, sunshine penetrated the pack, heated the slash, and speeded snowmelt.

If a residual stand of small trees is left in cut strips, the effectiveness of the cut is reduced, with the reduction depending on width of cut area and shading of the small trees. In the Yuba Pass test, first results show intermediate amount of early snow but more rapid melt of the snow where a residual stand was left than where all trees were removed.

Table 2. Excesses of snow water equivalent, in inches, associated with cutting compared with uncut forests

Date and area considered	Excess of snow associated with treatment-- Slash piled	Slash lopped	Small trees left	Slash dozed downhill	Wall-and-step[1]
April 24, 1963:					
Cut strip only	4.4	6.4	8.0	14.4	18.9
Whole forest	1.1	1.6	2.0	3.6	4.7
May 21, 1963:					
Cut strip only	7.2	7.2	- 5.2	- 1.2	13.2
Whole forest	1.8	1.8	- 1.3	- 0.3	3.3

[1] *In wall-and-step cutting, one-fourth of stand was clear-cut with slash bulldozed down to the lower edge; in an equal width to the north, the taller trees were removed. In the other cuttings, only the strip was cut.*

Figure 8.—Snow in cut strip and in simulated wall-and-step test, Yuba Pass, California, elevation 6,900 feet, April 24, 1963.

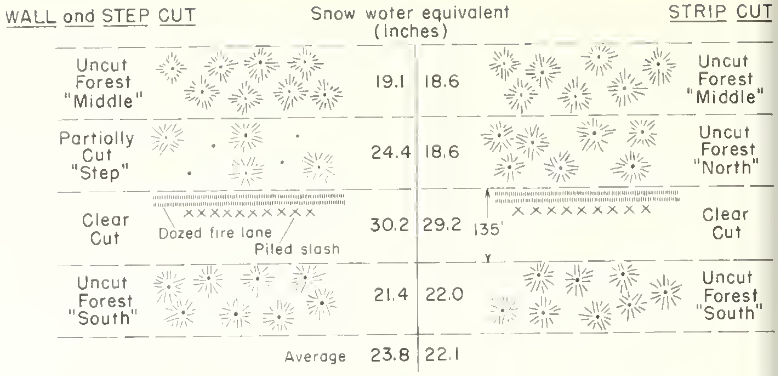

Figure 9.—Slash disposal has an important role in snow accumulation. Slash being windrowed downhill with a bulldozer traps cold air, preventing snow melt in winter.

Effects of Logging on Water Yield

Experiments in Fraser, Colorado, started in 1943, have contributed to our knowledge of the effects of logging on water yield. The studies of Wilm and Neiderhoff (1941) and Wilm and Dunford (1948) on the effects of forest cuttings on snow accumulation and melt, snow evaporation, and soil moisture losses have lead to predictions of increases of "water available for streamflow."

These predictions have been tested on whole watersheds and the data analyzed by Goodell (1958). Cutting of 39 percent of a lodgepole-spruce-fir forest in strips of 1, 2, 3, and 6 chains was begun in 1954 and completed in 1956. Associated with the logging was an average of 4.03 area-inches of streamflow from the watershed in 1956 and 1957. Peak discharges from the logged watershed was 50 and 45 percent greater in two years (1956 and 1958) and 23 percent less in one year (1957) after logging. Similar effects were found in a Sierra Nevada watershed under quite different conditions.

The effect of management on total water yield is largely through change in the water loss by evapotranspiration. We may say, "Snow management will control delivery of water from the snowpack; loss management will control total water yielded as streamflow." Logging effects and duration of these effects on loss differ widely between winter and summer.

Water Losses in Winter and Spring

Winter and spring water losses occur when most of the ground is snow covered. During that period, the losses consist chiefly of interception of snow and winter rain by the trees, evaporation from the snow surfaces, and transpiration by the trees or other vegetation. First, we must admit that we have not found a way of measuring the winter transpiration loss by trees when the ground is snow covered. Estimates of these losses range from 2½ inches to 9 inches (Anderson and Gleason 1959; Miller 1955). We do have, however, good estimates of interception loss and evaporation from snow under various conditions of logged and unlogged forest.

Interception loss is the water lost by evaporation from the wet tree parts or from the snow clinging to the trees. Interception loss from a dense lodgepole pine stand at the Central Sierra Snow Laboratory in April 1958 was 8 percent of the precipitation (West and Knoerr 1958). Interception during snow storms in an 80-year old ponderosa pine stand at Bass Lake, California, was 10 percent of the precipitation (Rowe and Hendrix 1951). Kittredge (1953) gives similar data for other forest types. Interception losses for an average size snow storm of 2 inches of precipitation — assuming stemflow amounting to 3 percent of the precipitation—were: 11 percent of the precipitation for stands of mature ponderosa pine, 15 percent for stands of mixed conifers, and 16 percent for dense stands of mature red or white fir.

The effect of cutting the forests on interception loss is about proportional to the amount of the cut. In a selectively cut mixed forest, Kittredge (1953) found that interception decreased by 50 percent when 50 percent of the tree canopy was removed. Anderson and Gleason (1959) have estimated reductions in interception loss due to logging when winter precipitation was 38 to 41 inches. The saving was 3.4 inches for a strip-cut area, 2.3 inches for a block-cut area, and 1.6 inches for a selection cut area.

Evaporation losses from snow have been found to be small in the Sierra Nevada, except in wide open areas and on exposed ridges. During the winters of 1958 and 1959, at 7,000 feet elevation near the Central Sierra Snow Laboratory, West (1959) found that annual snow evaporation losses under forest stands were 0.4 and 0.9 inches; in small forest openings losses were 1.1 and 1.7 inches. In a 10-day study in April 1959, evaporation from a large open area was 1.7 times that from the small opening, and evaporation from exposed ridges was three times that from the small opening. These results indicate that cutting of areas in strips and blocks can be expected to increase evaporative losses by ½ to 1 inch per year. Clear cutting of large areas might increase losses by 1½ inches year year, on exposed ridges by 3½ inches.

We have concluded that logging reduces the total winter water loss. Combined interception, snow evaporation, and winter transpiration have been estimated to be 5.4 inches less in a cut strip, 3.6 inches less in a cut block, and 2.5 inches less in commercial selection cutting than in an uncut forest (Anderson and Gleason (1959).

Water Losses in Summer and Fall

Water lost from the soil during summer and fall must be replaced by fall precipitation or by winter snowmelt before streams will start to rise. Summer and fall storms may lose much of their effectiveness because of interception by the forest trees and other vegetation. How forests are logged can affect these losses. We have studied the amount of water losses under various types of timber harvest and the duration of the logging effects.

Summer and fall soil moisture losses were taken as a difference in stored moisture in the soil at the end of the snowmelt in the spring and at the beginning of the next winter storms. Soil moisture was measured by a nuclear soil moisture probe. Summer and fall precipitation was added to the soil moisture losses to give total summer water losses. In natural forest sites near the Central Sierra Snow Laboratory, soil moisture deficits ranged from only 3 inches on bare soil sites to as much as 17 inches in heavily forested sites with deep soils.

Logging effects on summer water losses were evaluated by measurements taken under three types of logging and under adjacent unlogged forest stands. Differences in summer water losses between forest cut in strips, in blocks, and by commercial selection cut were compared (Anderson and Gleason 1960). In each case, logging saved water.

Strip cutting saved water by reducing the summer and fall soil moisture losses. Savings for the first 3 years after logging differed with soil depth (table 3), averaging 2.2, 4.0, and 4.6 inches for the 3-, 4- and 5-foot soil depths, respectively.

Duration of summer savings resulting from cutting of strips is important to any evaluation. Savings were greatest the first years after the cutting and in the deepest soils (table 2). For 4-foot soil, the saving was 4.9 inches the first two years, but decreased to 3.4 inches the fourth year after the logging.

Ziemer[4] traced the long-term effects of logging by measuring soil moisture losses in forests logged at times ranging to 12 years before. He found that the logging effect averaged 6.9-inch increase the first year after logging and this diminished to zero by the sixteenth year. Total savings in the cut strip for the 16-year period were estimated as 34 inches.

Other data are consistent with the above. For example, a power line cleared 10 years ago, then widened 5 years ago, showed savings of 1 inch and 3 inches, respectively. It must be pointed out that savings other than summer soil moisture diminish much more slowly with time, interception taking perhaps 35 years to "recover" and evapotranspiration during the spring, fall, and winter somewhat less. These slower diminutions are suggested by the slow decrease in snowpack differences—only 23 percent in 10 years.

Block cutting effects on summer water losses were dependent on the size of the block and the residual trees left in the cutting or the regeneration coming into the stand. A large open block with some residual stand had one-half inch less saving than did the cut strip of table 2. Similarly, the data of Ziemer can be interpreted to show one-half inch less saving in a circular opening (one tree-height across) than in a cut strip. Thus, some of the advantage of small openings in snow accumulation is offset by additional summer water loss by root penetration from the trees at the cut margin.

Selection cutting has a small effect on soil moisture losses. Saving was nearly 2 inches the first two years after the logging and diminished to about 0.8 inch the fourth and fifth years after the logging. Data for a 4-foot soil were:

	Soil Moisture Storage at End of Summer				
	11/2/58	9/2/59	9/15/60	9/8/61	8/16/62
Treatment:			*(inches)*		
Logged (A)	8.25	7.34	6.60	6.86	8.96
Unlogged (B)	6.33	6.12	5.56	6.12	8.11
Saving	1.92	1.22	1.04	0.74	0.85

The trend indicates a zero saving by about the twelfth year, with a total soil moisture saving over the 12-year period of 7.5 inches.

We see that in the area cut the summer soil moisture savings resulting from strip cutting is more than six times that of selection cutting.

Commercial selection cutting.—Basic studies and plot tests can give us first clues to differences which management alternatives may be expected to produce, but measured streamflow is the final check. The effects on streamflow of a commercial selection logging were evaluated at the 4-square-mile Castle Creek watershed near Donner Summit

[4]Ziemer, Robert R. Summer evapotranspiration trends as related to time following logging of high elevation forest stands in Sierra Nevada. 1963. (Unpublished master's thesis on file School of Forestry, University of California, Berkeley.)

in the Sierra Nevada. Most trees exceeding 20 inches in diameter in a 1-square mile area were cut, leaving a good stand of pole-sized trees and reproduction.[5] We found that water yield as streamflow apparently increased by the equivalent of 7 inches deep (in the area logged) for at least 2 years after logging (Anderson and Richards 1960, 1961; Rice and Wallis 1962). These increases were brought about in the two subnormal runoff years of 1959 and 1960. About half the increase came in June. How long the logging effect persisted after 2 years is not known, because a freeway was built on the watershed.

Three cuttings compared.—In another test, we compared water available for streamflow under logged and unlogged conditions for commercial selection cutting, strip cutting, and block cutting for the year starting April 15, 1958 (Anderson and Gleason 1959). The results were obtained from the standard water balance equation: yield equals precipitation minus interception, winter evapotranspiration, summer evapotranspiration, and fall evaporative losses. The method is useful in comparing relative effectiveness of different treatments, but does not give exact values of yield. In making estimates of the water yield, we supplemented our soil moisture loss measurements with snow evaporation data from Kittredge (1953) and West and Knoerr (1959), and with snow interception measurements of Rowe and Hendrix (1951) and West and Knoerr (1959).

Precipitation for the year at the three sites was similar—46 to 47 inches—so that differences in water yield attributable to the logging methods can be compared:

	Water loss	Water saved
Forest condition:	*(inches)*	
Unlogged	21	–
Strip cut	12	9
Block cut	15	6
Selection cut	18	3

Water yield increased under each logging method, ranging from 3 to almost 9 inches. The strip cut was the most effective in saving water, the block cutting next, and the commercial selection cut least.

About half the differences between the commercial cut savings and the strip and block cut savings were in soil moisture losses—water that is held over at the end of fall. That water will be yielded with the first winter melt, or sometimes with late fall floods.

Slash disposal.—The method of slash disposal may affect water losses in summer. Losses of water from the soil during the first three summers after logging at the Swain Mountain Experimental Forest were somewhat different within cut strips under two slash disposal methods:

	Summer soil moisture loss		
	1959	1960	1961
Slash treatment:		*(inches)*	
Piled and burned	3.2	3.7	3.1
Left where it fell	3.8	4.0	3.8

Summer water losses were nearly the same in both treatments. Combined losses from interception and evaporation from the soil were slightly less in the bare soil area in each year. The magnitude of summer losses depended upon the amounts and time of occurrence of the summer precipitation, and upon the evaporation rate.

Brushland Conversion to Forest

High elevation brushlands may be converted to forest, with benefits to water supply. During the conversion period, interception and transpiration losses will be reduced. After the forests are established, snowmelt may be delayed with resultant benefits in delayed water yield in late spring and summer.

[5]The 2.8 million board feet removed was 30 percent of the volume in the logged area and 12 percent of the total volume in the 4-square-mile watershed.

Water Savings in Summer

A test in the fall of 1957 showed that soil moisture was saved in a brushfield cleared by bulldozing manzanita-whitethorn brush and windrowing the brush (Anderson and Gleason 1960). Initial field capacity storage was 18.5 inches of water. Final water storage in the cleared and uncleared areas and water savings for soil 4 feet deep in each of 4 years after clearing were:

Figure 10.—Clearing of brushfields pays double dividend: Water is saved for a number of years after the clearing, and planted trees in the strips may later yield timber products and help slow the snowmelt.

Figure 11.—Sedimentation, a possible conse- quence of any watershed treatment, is being measured here with a depth-integrating sam- pler.

	Final summer soil moisture			
	1958	1959	1960	1961
Treatment:	(inches)			
Brush cleared	15.9	15.0	13.7	11.9
Natural brush	11.6	11.4	11.0	11.6
Saving	4.3	3.6	2.7	0.3

The savings in summer water losses were greater in deeper soils, less in shallower soils; in both soils the saving had diminished to zero by the fifth year.

Water Losses in Winter and Early Spring

Additional savings in winter and early spring snow and rain interception would approximate 6 percent of the precipitation when the brush was not snow-covered (Hamilton and Rowe 1949). This saving was estimated at about 0.5 inches. Early winter and early spring transpiration savings would be about 0.01 inches per day in early winter and 0.02 inches per day in early spring in clear weather days when the brush is not completely snow covered. The resultant saving in the conversion period is 0.8 inches of water. The estimated total savings the first 3 years of the conversion period was about 4 to 5 inches of water per year for soils 4 feet deep.

The saving diminished as brush sprouts occupied the site. By the fifth year after the bulldozing, soil moisture was as low as before the treatment. Even though interception would be expected to be somewhat lower, total saving would be about 1 inch, even for those soils 5 feet deep.

Delayed Yield of Water

Benefits in delayed snowmelt can be expected as trees mature. Delay in snowmelt would exceed that indicated in figure 4 for the cut strip versus the large opening. In 1959, at elevation 6,800 near the Central Sierra Snow Laboratory, melt in brushfields was 3 inches greater than in a comparable large open area bare of brush:

	Snow water		
	4/1	5/10	Melt
Area:	(inches)		
Large grassy open area	23.4	5.9	17.5
Brushfield	23.0	2.4	20.6
Forested (50 percent density)	21.4	8.7	12.7

The above melt rates suggest that when all snow is gone from a brushfield, we would have about 7 inches more snow water in the converted forest in that year of slight snowpack.

Temporary benefits in total water yield and long term benefits in delayed yield, as well as timber values, may be expected from brushland conversion. Such combined water and timber benefits may justify conversion of brushfields which was not justified by either single benefit.

Sedimentation in High Elevation Forests

Sedimentation includes erosion, sediment transport, and sediment deposition. It is thought to be less of a problem in high elevation forests than in any other zone. Precipitation falls mostly as snow or rain, and snowmelt or rain penetrating the deep snowpack causes little soil erosion. Transport of stream sediments is generally low because peak flows, which carry most of the sediment, are dampened by the snowpack. However, this lower meteorological potential, may be offset by greater soil erodibility. Willen[6] found high elevation soils 2.7 times as erodible as low elevation soils of the same geologic parent rock. If the bare areas are large and continuous, rilling may occur, and soil from such rills and surface wash reach minor channels. Once sediment reaches a channel, it can cause damage by restricting channel capacities, affecting water quality, and depositing sediment in culverts, reservoirs, and percolation basins.

The principal sources of sediment subject to management include roads, land slips, logging, skid trails, and land clearings. Often roads are the principal offender (Anderson 1954). Methods of prevention are well known (Haupt 1959; Meadowcroft et al. 1954). Not so well known is the economics of various levels of prevention.

Land slippage may follow logging, land clearing, and road cutting. It may occur soon after

[6]Willen, Donald W. Erodibility indexes and surface soil characteristics of some southern Sierra Nevada forest soils as related to parent rock, topography, and vegetation type. 1963. (Unpublished master's thesis on file at School of Forestry, Univ. Calif., Berkeley.)

treatment owing to excess water storage, or occur years later when the binding roots have decayed. Logging, with its accompanying roads and skid trails, can be expected to increase sediment. The clear cutting of lands subject to slipping into stream channels must be questioned, if sedimentation is any problem. Studies of some method of harvest which will not cause major land slips seem indicated.

Effects of Commercial Selection Cutting

At Castle Creek, near Donner Summit, discharge of suspended sediment for an average year before logging, totaled 900 tons from the 4-square-mile watershed (table 3). The first year after logging one-fourth of the watershed, sediment discharge soared to 4,600 tons a year; the second year after logging, it dropped to 1,800 tons a year. If we consider only the logged area, sediment production was increased by 17 times the first year and by 5 times the second year.

Increases in sediment concentration were associated mostly with the highest discharge classes. For example, the highest 7 percent of the streamflow carried more than 50 percent of the sediment (table 4).

Deposition of coarse sediment in the small debris basin in Castle Creek totaled only 50 tons per year. This amount was 1 to 5 percent of the sediment discharge in the two low-flow years after logging. Part of the coarse eroded material remains upstream of the basin. It may be discharged in later years when the streamflow becomes higher.

Erosion from roads and landings which formed part of the logging operation provided most of the sediment. Minor rivulets were often diverted down logging roads, causing the erosion of all fine material. Landings made by building deep fills across stream channels now have deep V-notched gullies across them (Rice and Wallis 1962). These landings have been an obvious source of increased sedimentation. Rice and Wallis concluded that "even though a total disturbance of the Castle Creek watershed was not great, the location of roads and landings created a large sediment source. More attention to water values could have eliminated much of this source."

Effects of Forest Fire

The effects of forest fire on sediment discharge from snow zone watersheds depend largely on the kinds of runoff events that follow (Anderson 1962). In the area of the Donner Ridge burn (north of Truckee) where only snowmelt runoff

Table 3. Differences in summer soil moisture depletion between logged strips and adjacent forest, Swain Mountain Experimental Forest, 1959-1961

Year, condition, and saving	Soil moisture storage (inches) for soil depths of-- (3 feet)	(4 feet)	(5 feet)
1959:			
Strip	10.7	15.3	19.9
Forest	8.2	10.4	14.8
Saving	2.5	4.9	5.1
1960:			
Strip	10.2	15.0	19.5
Forest	8.1	11.4	15.0
Saving	2.1	3.6	4.5
1961:			
Strip	9.6	14.2	19.3
Forest	7.7	10.8	15.0
Saving	1.9	3.4	4.3

Table 4. Average annual suspended sediment discharge from sediment sampling and streamflow duration before and after logging of 1-square-mile of the 4-square-mile Castle Creek, Yuba River headwaters, California, 1958 and 1959

Discharge class	Mean discharge	Streamflow frequency	Relative volume	Sediment samples	Streamflow in various sediment concentration classes, p.p.m.						Average sediment concentration
					<12.5	13-27	28-72	73-142	143-400	>400	
	C.f.s.	*Percent*		*Number*	- - - -	- - - -	- -	*Percent*	- - - -	- - - -	*P.p.m.*
BEFORE LOGGING, 1958											
<1	0.2	44.0	.006	2	44.0	--	--	--	--	--	7
1- 10	4.1	30.0	.089	15	26.0	4.0	--	--	--	--	9
11- 40	20.2	14.0	.200	14	7.0	6.0	--	--	1.0	--	36
41-100	60.0	8.8	.380	6	--	7.3	1.5	--	--	--	25
101-200	125	2.8	.258	15	0.2	0.4	0.6	1.4	0.2	--	104
201-250	210	0.25	.038	0	--	--	--	--	0.25	--	[1](190)
>250	270	0.15	.029	6	--	--	--	--	--	0.15	(430)
Totals		100.00	1.000	58							
Averages	14.7				7	20	50	108	270	430	[2]64
AFTER LOGGING, 1959											
<1	0.2	44.0	.006	11	36.0	4.0	4.0	--	--	--	12
1- 10	1	30.0	.089	13	23.1	--	--	4.6	2.3	--	43
11- 40	21.0	14.0	.200	18	7.8	4.7	1.5	--	--	--	16
41-100	63	8.8	.380	12	2.2	2.2	0.7	2.2	1.5	--	83
101-200	130	2.8	.258	3	--	--	--	--	1.9	0.9	413
201-250	216	0.25	.038	--	--	--	--	--	--	0.25	(1,700)
>250	280	0.15	.029	--	--	--	--	--	--	0.15	(3,200)
Totals		100.00	1.000	57							
Averages	15.3				7	20	50	108	210	980	[3]303

[1] *Values in parentheses were taken from sediment concentration-discharge curve.*

[2] *Total sediment discharge for 1958: 935 tons.*

[3] *Total sediment discharge for 1959: 4,600 tons.*

Figure 12.—Contour trenches at the Tahoe National Forest are being tested in research on runoff and erosion prevention. Studies are being made on the effects of forest fires and the effectiveness of four alternative treatments on flood peaks, sedimentation, snow storage, and soil moisture loss.

in less than normal amounts occurred in 1961, sediment production was small—a maximum of 78 p.p.m. in runoff water. In the area a few miles to the east where a high intensity summer storm struck the burned area, sediment production was high (Copeland and Croft 1962). Sediment production was 1.5 acre-feet per square mile on untreated areas when rain fell at the rate of 9 inches per hour for a 5-minute period. Where the Forest Service had installed emergency contour trenches, the runoff was contained and little flood flow or sediment discharge occurred. Thus, poor vegetation cover and high intensity rainfall can combine to produce high yields of sedimentation in the snow zone.

Effects of Grazing

No experiments on the effects of grazing on sedimentation in snow zone watersheds have been conducted, but evidence indicates small amounts of sediment production are associated with heavily grazed watersheds under usual snowmelt runoff conditions:

	Area intensively grazed	Annual streamflow	Sediment production
	(percent)	*(inches)*	*(acre feet/ sq. mi./yr.)*
Experimental forest:			
Castle Creek	10	50	[1]0.14
Onion Creek	10	38	0.05
Teakettle	8	21	0.02
Sagehen Creek	10	14	0.004

[1]Before logging in watershed.

The effects of heavy grazing on sedimentation under high intensity rainfall conditions in the Sierra Nevada are still unevaluated. Under major storm conditions, sediment production can be high—15 inches of rain in 3 days in January 1962 produced 0.6 acre feet of sediment per square mile in the Onion Creek watersheds.

Management Effects on Floods

Flood frequencies from snow zone watersheds may change as management changes. We expect changes in each of these basic hydrologic processes: (a) The supply processes—precipitation, rainfall amounts and intensities, snowfall, distribution of snow on the ground, and snowmelt; (b) the storage and detention processes at the surface, in soil, and in channels; and (c) the loss processes—interception, evaporation, transpiration, and, in some places, groundwater "losses" or deep seepage (Anderson 1962). These processes operate differently for snowmelt floods than for rain or rain-on-snow floods. Management effects on floods may be different depending on the kind of flood, the kind of management, and the time of yield of water resulting from management. In one year, a management practice may increase floods, in another decrease the flood.

Snowmelt Floods

Snowmelt floods periodically produce some inundation in the great valleys, usually in June. The amount of the snowpack and its rate of melt are the primary cause variables. Figure 4 illustrates the effect that alternative methods of forest management will have on snowmelt contribution at a specific site to floods. In general, a dense uncut forest has about 11 inches less runoff and much slower melt; selection cutting has some advantages over strip cutting. The synchronization of snowmelt from the many part of watersheds will determine the flood size from large watersheds. Different management practices in various parts of watersheds may augment or destroy such synchronization and so affect floods.

Rain and Rain-on-Snow Floods

Rain and rain-on-snow historically have produced the large floods in California (Hall 1943). In contrast to snowmelt floods, these are complex events—a dozen or more hydrologic processes combine to determine flood size (Anderson 1962). The effect of management on floods depends on the effects on each of these processes.

Let us consider one source of variation in floods—fall soil moisture deficit. This deficit must be replenished before major floods occur. In natural forest site, soil moisture deficits range from 3 to 17 inches.[7] When vegetation was removed by logging or brush removal, soil moisture deficits were 1 to 8½ inches less (Anderson and Gleason 1960; Anderson and Richards 1961).

Soil moisture deficits differ not only between local sites and with vegetative treatment, but for whole watersheds. Conditions and flood results during the December 1937 flood illustrate these differences for whole large watersheds on the west side of the Sierra Nevada. Pre-flood retention in the September to December period reached a maximum in the Feather River Basin—about 20 inches of the 30 inches of precipitation never appeared as runoff (data from McGlashan and Briggs 1939). Runoff in the flood was high—6 to 10 inches. In contrast, the total September through December retention in the Kings River Basin was about 10 inches. But only 1½ inches of this shortage was depleted before the 1937 flood, so that over 8 inches of the precipitation during the flood was stored in the watershed. As a result, the Kings River had a rather low flood runoff of only 1½ inches.

Combinations of shallow or absent snowpacks, frozen ground, and torrential rain occasionally occur, even in the snow zone. Shallow snow or absence of snow occurs about four times for every 50 years.[8] Under such conditions, cold weather, common in the late fall, persists into mid-winter and the ground freezes. Such was the early winter of 1963. The soil had been wetted by a heavy October storm; soil in open areas near the Central Sierra Snow Laboratory was frozen to a depth of 18 inches, and under forests to a depth of 9 inches. Then another heavy rain storm hit—20 inches in 3 days. High unit discharges and large quantities of debris came even from unlogged watersheds. A thousand acres of floating debris were carried into Folsom Reservoir. Peak flows in several central California watersheds approximated the record peak of 1907 (Rantz and Harris 1963).

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[7]Knoerr, Kenneth R. Exponential depletion of soil moisture by evapotranspiration at forest sites in the Sierra Nevada, as related to available soil moisture and vapor pressure deficit, 1960. (Unpublished Ph.D. thesis on file at School of Forestry, Yale Univ., New Haven, Conn.)

[8]U.S. Weather Bureau. Climatological records, Norden, Calif.

Retention differed widely between adjacent watersheds. Of the 21 inches of rainfall in the January 1963 storm, 19 inches ran off in the North Fork of the American River (at French Meadows), only 6.5 inches in the South Fork of the Yuba (near Washington). Thus retention was 2 inches and 14 inches, respectively.

How did cut areas contribute to the peak discharges? The contribution may be appraised in three ways: (a) The frozen soil being deeper has already been mentioned; (b) the soil moisture was greater in the cut areas, as high as 40 percent, as contrasted with 28 in the forest; and (c) bulking of flows with sediment would be expected to be greater from disturbed areas. Thus, the flood consequences of cutting to increase water yield also must be evaluated.

We see that the effects of management practices on floods are not simply related to the single variable of fall soil moisture deficit; other variables may augment or lessen the management effects on floods (Anderson 1962).

Areas Subject to Watershed Management

Opportunities for managing for water yield may be appraised from the amount and kind of vegetation in a watershed.

Vegetation subject to management on the west side of the Sierra Nevada may be extracted from an inventory by Richards (1961). If forest stands exceed 40 percent density and if brushfields are contiguous and greater than 132 feet across, these might be the first area considered for management for improved water yield.

What specific areas of dense timber and large brushfields might be subject to management? For the snow zone of major river basins west of the Sierra Nevada crest, these data are summarized in table 5 and for the Cascades and North Coast watersheds in table 6. We see then that 42 percent of the high elevation Sierra Nevada has vegetative cover which might be subjected to management for improved water yield. In the Sierra Nevada, brushlands subject to management are greatest in the northern river basin, and forests in the southern basins. In the northern watersheds, forest covers about 57 percent of the area and brushland about 20 percent.

Table 5. High elevation areas of major drainage basins, west of the Sierra Nevada crest, subject to management for improved water yield

Drainage basins	Forested[1,2]	Large brushfields[2,3]
	Percent	*Percent*
American River	21	24
Feather River	24	27
Kaweah & Tule Rivers	45	13
Kern River	39	9
Kings River	26	12
Merced River	23	16
Mokelumne River	23	17
San Joaquin River	28	15
Stanislaus River	26	17
Tuolumne River	16	16
Yuba River	22	39
Average	25	17

[1] *Forests of greater than 40 percent canopy cover.*

[2] *West of Sierra Nevada crest, above 5,000 feet latitudes 35° 57½' north to 39° 57½' north.*

[3] *Brushfields more than 132 feet across their narrowest part.*

The benefits of management for water yield de-
end on when and how the forests are cut and the rushlands, if present, are removed.

Benefits in terms of increased water yield may esult from harvesting forest timber crops; bene- ts in brushland conversions may help pay for such onversion. Land managers may wish to defer utting or brush removal until some critical period of drought or need occurs. Today's prescription of how to manage for water is summarized in the appendix.

Further study is needed in this broad field of resources management. Can other logging methods, ones designed specifically to give greater yield or delay yield longer, improve on these results? Other studies are now under way to develop, test, and evaluate "better" methods.

Summary

Research results have suggested how high ele- ation snowpack forests can be managed for water roduction—that is, for such objectives as increas- ig water yield, delaying yield, and maintaining ater quality. Logging forests and clearing brush- elds can result in water benefits, yet may have dverse consequences in the form of floods and edimentation.

Snow accumulation and total water yield can e increased by cutting forests. Interception and anspiration losses can be reduced without cor- esponding increases in evaporation from the snow nd soil. Water yield can be delayed by cutting forests in patterns designed to slow snowmelt—retaining the shade of trees and minimizing back radiation of trees to the snowpack. Both streamflow and sedimentation have increased after commercial timber harvesting.

Clearing brushland in converting to forest will increase water yield during the conversion period by reducing interception and transpiration losses. The pattern of the new forest can be designed and managed to give delayed water yield as compared to yield from natural brushlands.

Specific suggestions for management are given in an appendix.

Table 6. Forest and other land types of some major river basins, Cascades and north coastal California[1]

River basin	Drainage area	Forest	Brush	Grass	Urban and agric.	Barren
	Sq. miles			*Percent*		
Eel (below Van Arsdale)	2,766	61	10	22	4	3
Klamath (below Copco)	7,611	57	21	8	4	10
Mad	485	64	14	21	0	1
McCloud	606	58	31	2	--	9
Sacramento	427	51	40	0	0	9
Scott	662	41	22	11	12	12
Shasta (below Dwinoll)	657	20	34	31	12	2
Smith	613	51	32	0	0	17
Trinity	2,846	66	17	1	1	15
Van Dusen	214	64	4	26	0	6
Average		57	20	10	4	9

[1] *Compiled by James R. Wallis from timber stand maps, dated 1947 to 1958, published by the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley 1, California.*

Figure 13.—Water yield resulting from application of alternative management techniques will be tested on a dozen small watersheds with weirs.

Figure 14.—Measurement of snow water at 100 special snow courses permits evaluation of management effects on water yield.

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Appendix

Logging for Water

In forest stands of uniform size and condition:

1. Log in east-west strips (figs. 6, 7).
   a. Make strips about one-half tree height (rotation height) wide on south slopes steeper than 20 percent.
   b. Make strips about one tree height wide on all east and west slopes and on north and south slopes of less than 20 percent gradient.
   c. Make strip widths one to four tree heights across on north slopes steeper than 20 percent.

Space the first cut strips three to four stripwidths apart depending on whether you plan for three or four cutting cycles in a rotation.

2. Bulldoze or pile slash near the downhill edge of your cut strip, on all except north slopes. This arrangement will pond cold air to retain snow longer. For fire protection, make windrowed slash discontinuous at ridges and minor rises to minimize fire hazard and bulldoze a lane between the slash and the forest margin. On north slopes doze slash only to the shade line for maximum delayed water yield.

3. If you cut strips up and downhill, as on east or west slopes, "cross your T" at the bottom of the strip by having strip run along contour so as to trap the cold air drainage.

4. In subsequent cuts, cut the strips parallel to the original cut, progressing generally to the south. Thus, a wall of mature trees will always be shading the most recent cut (fig. 6).

If stands have more than 50 percent mature and over-mature trees and are a high risk, "pre-logging" will save some of the values; then:

1. Cut out the patches of decadent trees in this "pre-logging" cut, and

2. In the next cut, connect up these openings so as to make east-west strips:
   a. Make strips about one-half as wide as the rotation tree height on steep (greater than 20 percent slope) south slopes.
   b. Make strips about one tree height wide on gentle north and south slopes and on all east and west slopes.
   c. Make strip widths one to four tree heights across on north slopes steeper than 20 percent, depending on desire for delayed yield versus greater total yield.

In subsequent cuts, cut strips progressing generally southward so as to create a wall-and-step forest with the wall of mature trees facing the south and the steps toward the north.

3. On east and west slopes, connect up the openings, so as to make an uphill strip, and at the bottom of this strip "cross the T" with a strip on contour. The cutting will provide cold air drainage from the uphill cut. This cold air, caught in the contour cut, will result in maximum delay of snowmelt in the contour strip.

If individual high value or high risk trees occur scattered in the stand, take up to 25 percent of the stand volume.

Disposing Slash

Slash may be piled and burned, windrowed, lopped and scattered, or left as it falls, with different results on water yield:

1. Pile and burn slash for delayed snowmelt in spring. Unless shaded, slash if left as it falls causes melting of snow in winter and spring when the snow thinly covers the slash. Slash removal results in 3 to 4 inches more snow water in late spring, when sun reaches the snowpack.

2. Windrowing slash near the downhill wall of trees in cut strips is another way of delaying snowmelt (except on wide strips on north slopes). The slash so placed will help pond cold air near the snow and prevent snowmelt. Windrows should be discontinuous at each ridge and minor rise to reduce fire hazard. A bulldozed strip between the slash and the forest margin helps reduce fire hazard further.

3. Lop and scatter slash or chip slash for immediate soil protection on highly erodible soils and sites, where skid trails run up and downhill, where large areas are clear cut so needle fall will not protect the soil, and where steep slopes and shallow soils combine to make a runoff and erosion hazard.

Converting Brushlands for Water

To convert high elevation brushland to forest in order to achieve temporary increases in water yield and long term improvement in delayed snowmelt yield:

1. Bulldoze brush in strips approximately on contour:
   a. Make the strip width about one-half tree height across (expected height of trees at rotation age) on steep south slopes of greater than 20 percent gradient.
   b. Make the strip widths about one tree height across on north and south slopes of less than 20 percent gradient and all east and west slopes.
   c. Make strip widths one to four tree heights across on north slopes of greater than 20 percent gradient.

2. Windrow the brush on the downhill side of the cleared strips to trap cold air and intercept eroded soil. Make windrows discontinuous at ridges and minor rises to reduce fire hazard.

3. Plan cut strips in time and space for the desired cutting cycles and rotation of the forests being established. For example, space the first strips three strip widths apart for three cutting cycles in the rotation. Clear successive strips progressing generally toward the maximum solar radiation, that is, southward. This clearing and planting plan will result in a wall-and-step forest (fig. 6). Once established, management can perpetuate the forest pattern.

Preventing Floods

For prevention of rain-caused floods or rain-on-snow floods, use selection cutting or cutting in narrow strips (one-half tree height across). Strips should be on contour; selection cutting should leave trees with high vigor. For snowmelt flood prevention, cut narrow strips, which (for the amount of cut) are more effective than selection cutting. To prevent flood synchronization, cut low elevation south slopes so as to speed winter and early spring melt, such as by using wide strips, and leave high elevation north slopes uncut or cut in narrow strips. Convert brush fields to forests to slow snowmelt and hence reduce snowmelt floods.

The above suggestions are interim answers to the questions on how to log forests and convert brushlands to forests for improved water yield. They are based on research studies still in progress. The suggestions are as yet untested on whole watersheds, but they are based on sound physical principles of the disposition of heat and water on forest slopes. First results of tests indicate that the methods are performing well.

We do not expect radical changes in these suggestions because they are largely elaborations of recommendations made 40 years ago by Church and later elaborated upon by Kittredge. Refinements and specific modifications of the methods now proposed can be expected as well as information on how the patterns can be developed to meet special requirements for controlling the timing of water yield or preventing flood and sedimentation on some watersheds.

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Tractor-Logging Costs and Production in Old-Growth Redwood

Kenneth N. Boe

U. S. FOREST SERVICE RESEARCH PAPER PSW-8 1963

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Experiment Station - Berkeley, California
Forest Service - U. S. Department of Agriculture

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The Author

Kenneth N. Boe is in charge of the Pacific Southwest Station's research in the silviculture of redwood and Douglas-fir forests, with headquarters at Arcata, California. A native of Montana, he earned bachelor's and master's degrees in forestry at Montana State University. Shortly after graduation in 1946, he joined the Northern Rocky Mountain Station, spent most of the next 10 years in silvicultural research at the Upper Columbia Research Center, Missoula, Montana, and transferred to the Forest Service's experiment station in California in 1956.

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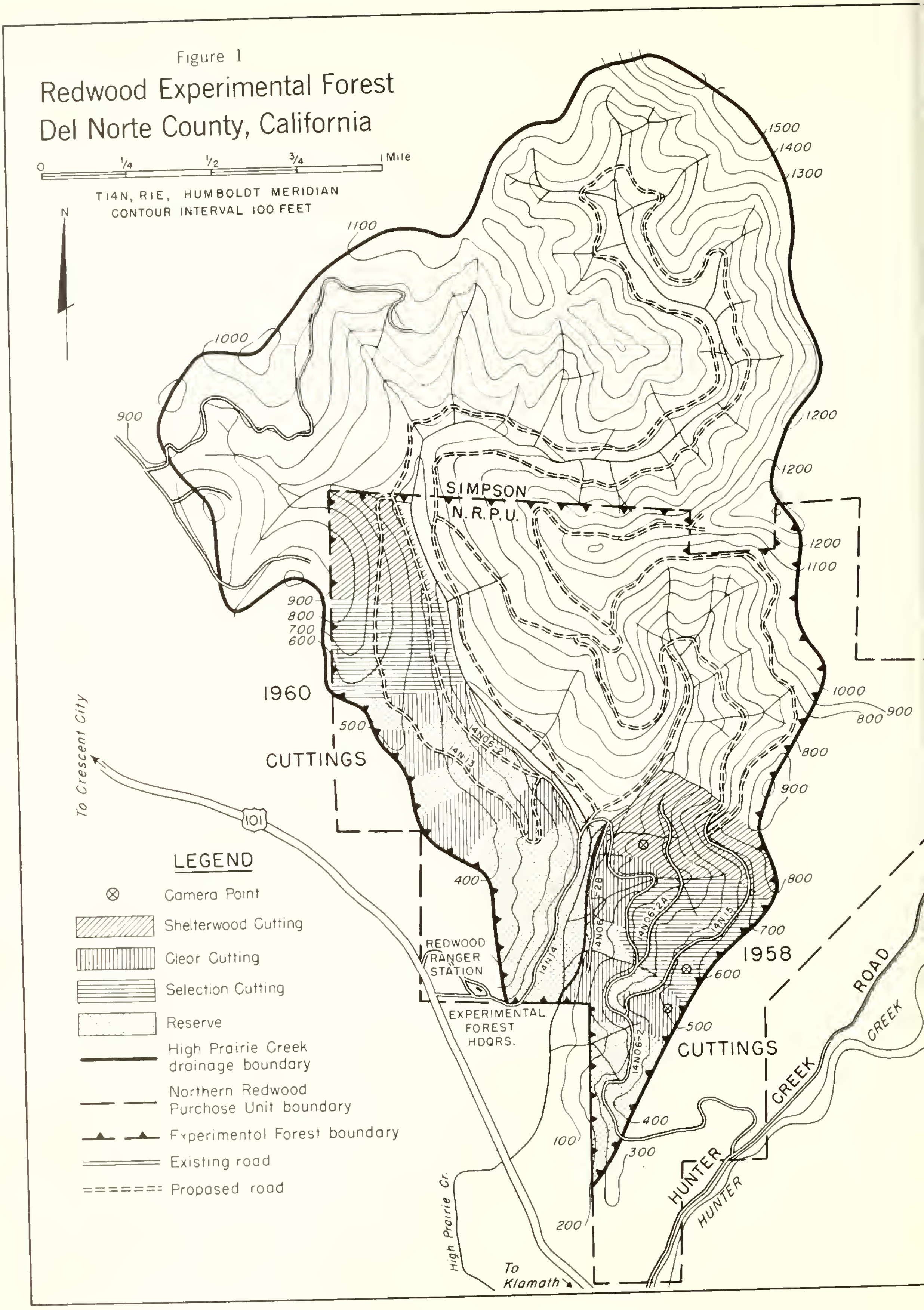

Figure 1
Redwood Experimental Forest
Del Norte County, California
0
1/4
1/2
3/4
1 Mile
T14N, R1E, HUMBOLDT MERIDIAN
CONTOUR INTERVAL 100 FEET
N
SIMPSON
N.R.P.U.
1960
CUTTINGS
1958
CUTTINGS
To Crescent City
101
REDWOOD
RANGER
STATION
EXPERIMENTAL
FOREST
HDQRS.
ROAD
CREEK
HUNTER
CREEK
HUNTER
High Prairie Cr.
To
Klamath
14N06-2
14N13
14N14
14N06-2B
14N06-2A
14N15
14N06-2
1500
1400
1300
1200
1200
1200
1100
1100
1000
900
1000
900
800
800
900
800
700
600
500
400
100
400
300
200
900
800
700
600
500
400
LEGEND
Camera Point
Shelterwood Cutting
Clear Cutting
Selection Cutting
Reserve
High Prairie Creek
drainage boundary
Northern Redwood
Purchase Unit boundary
Experimental Forest boundary
Existing road
Proposed road

The cost of harvesting old-growth redwood *(Sequoia sempervirens* [D. Don] Endl.) is of concern to logging managers, timber appraisers, forest land managers, gyppos, and others. This paper reports on a study of full-scale logging operations in heavy stand volumes of old-growth redwood in the Redwood Experimental Forest in north coastal Del Norte County, California, carried out cooperatively by the Pacific Southwest Forest and Range Experiment Station and the Simpson Timber Company.

The cost figures in published studies of old-growth redwood are essentially out-dated because of today's changes in machines, methods, and rates. But where principles are involved, some of this information is still useful.

Skidding production is affected by load per turn, distance, and gradient. Stahelin and Hallin[1] have illustrated the importance of skidding capacity loads on each turn. They found that skidding time per thousand board feet in a load less than 3,000 board feet was double or more than in loads greater than 3,000 board feet.

Person[2] reported higher yarding costs for smaller logs as compared to larger logs. He also found that costs per thousand decreased much slower and at a nearly constant rate above 4,000 board feet per log than for smaller sizes.

For tractors of 75 to 95 horsepowers, Hallin[3] found that minimum slopes for efficient skidding of logs began at 5 percent for 2,000-board-foot loads, 7 percent for 5,000-board-foot loads, and 15 percent for 8,000-board-foot loads. For combined out and in times, the most efficient slope was probably 25 to 35 percent. Output was increased by one quarter if loads of 6,000 instead of 4,000 board feet were skidded.

In the work reported here, three experimental cutting methods were studied (fig. 1). One logging side worked for 2 years (1959 to 1960) to harvest 22.5 million board feet (net Scribner scale) of timber. The experimental cuttings are still in progress.

Current costs have been tabulated for three different cutting methods and for all methods combined. Such information will be useful in appraising other timber tracts. Different dollar rates, depending on economic trends, may be applied now or in the future to the recorded work units for doing different jobs. Analysis in this report of some key-factor effects on felling-bucking, skidding, and loading production provides basic information for planning decisions by managers and appraisers.

Timber, Topography, and Climate

The old-growth redwood stand in this study is representative of the northern redwoods growing on low-elevation, medium to good sites (fig. 2). Gross volume per acre on cutting units of 13 acres and over ranged from 95,000 to 280,000 board feet (Scribner). Merchantable trees ranged in diameter from 14 to 198 inches d.b.h. The number of merchantable trees per acre ranged from 29 to 46. Snags and windfalls averaged one each per acre.

Smaller trees included all species, but the majority were the whitewoods: Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco), Sitka spruce *(Picea sitchensis* [Bong.] Carr.), Western hemlock *(Tsuga heterophylla* [Raf.] Sarg.), and Port-Orford-cedar *(Chamaecyparis lawsoniana* [A. Murr.] Parl.). The larger trees were principally redwood, although a few Douglas-fir and Sitka spruce reached 96 inches d.b.h. Above this size, all trees were redwood.

V-shaped water courses and narrowly rounded ridges dissect the Redwood Experimental Forest at many places. Slope gradients are moderate to very steep, although many small benches of gentle

[1] Stahelin, R., and Hallin, W. Importance of large loads in redwood tractor logging. West Coast Lumberman 64(2):22-23, illus. 1937.

[2] Person, Hubert L. Comparative costs for slackline, highlead and tractor yarding-redwood region. U.S. Forest Serv. Calif. Forest & Range Expt. Sta. Res. Note 15, 5 pp., illus. 1937.

[3] Hallin, William. Redwood tractor yarding costs as affected by slope gradient and load volume. U.S. Forest Serv. Calif. Forest & Range Expt. Sta. Res. Note 16, 4 pp., illus. 1937.

Figure 2.—This old-growth redwood stand is representative of the redwoods in northern California.

slopes are present. On three-tenths of the cutover stand, slopes averaged 10 to 30 percent gradient, on another three-tenths, 30 to 50 percent, and on the remaining four-tenths, 50 percent or more. On a small portion of this steep ground, slopes are 70 to 95 percent.

Soil over much of the area is deep, well-drained, moderately fine textured clay loam. Near tops of main ridges, the soil becomes somewhat shallower, is medium textured, and has a stony profile. When soil moisture was below field capacity, only short delays in logging were experienced after 1- to inch rains. Winter rains that usually began in N vember stopped tractor logging for several month

The climate is mild and humid. Rainfall h averaged 84 inches annually (19-year record The 3-month average for July, August, and Se tember—the summer fog months—is 2.7 inche Average rainfall increases to 7 inches per mon in October and 14 inches in January, then di to about 1 inch in June. Snow occurs infrequent and lasts only one or two days.

Methods[5]

The general method used in this study consisted in recording man- and machine-hours by days or fractional days for doing specific portions of t logging job. The hourly or contract labor cost f each man and machine rental cost was compile

[5] See Appendix for detailed description of methods.

These cost and production data were collected by cutting method and by landing-stage combinations within each cutting method.

Stage logging was employed primarily to learn something about the effect of tree size on logging costs. Actually stage logging—the removal of trees in successive operations over the same area—is necessary in old-growth redwoods because not enough ground space exists for all felled trees at one time. We logged trees under 6 feet d.b.h. first and called this stage "A". Trees 6 feet d.b.h. and over were logged next for stage "B". Usually this stage required more than one operation.

The three reproduction cutting methods tested were selection, shelterwood, and clear cutting. On each of the 60-acre selection, 69-acre shelterwood, and 13-, 18-, and 20-acre clear cuttings, trees of all sizes were harvested. Data on volumes harvested by cutting appear elsewhere in this report.

We used cost accounting analysis as one of two main procedures. It included computing labor- and machine-hours and costs by the different logging activities required to load logs on trucks. Log volume totals were calculated from the scale tickets for each combination of cutting method and landing stage. From these basic data, we calculated labor-hours, machine-hours, and costs per thousand board feet (gross Scribner log scale) for logs hauled.

The analysis was based on gross log scale. This long-log basis was adopted (a) to eliminate differences between cutting methods that are associated with different amounts of defect in logs hauled; and (b) to relate production output more nearly to dimensions of logs to the extent that board foot volume is correlated with diameter. Subsequently, gross log scale values may be readily converted to a net log scale basis by dividing each value by a factor. This factor is the quotient of net log volume divided by gross log volume. Similarly these costs can be easily converted to another log scale basis. For example, to convert to a Humboldt scale basis (70 percent of gross Spaulding and essentially the same percent of gross Scribner), divide costs and work units per thousand board feet by 0.70.

The second main procedure consisted of statistical analyses of the three key activities—felling-bucking, skidding, and loading—all in relation to the different factors affecting production output.

Felling-bucking[6] board-foot volume was evaluated for a 2-man crew on an 8-hour per day basis. We compiled average d.b.h. and gross Scribner volume of trees felled and bucked from random samples of daily output.

Each observation of skidding production included the volume of all logs skidded to a landing during one stage of logging. The dependent variable was expressed as average gross Scribner board-foot volume of logs skidded per tractor hour. The multiple regression and analysis included five independent variables and 30 sets of observations.

Loading production was analyzed by simple linear regression for each of two loaders and to determine significance between outputs. The independent variable was average gross Scribner volume per log, and the dependent variable was average gross Scribner volume loaded per hour. These averages were based on production for a day or fractional day for one stage-landing logging unit.

Results

Costs and Work Units to Log Redwood

The direct costs of logging old-growth redwood, excluding road construction and hauling, were less than $15 per thousand board feet (gross Scribner scale). These figures are based on 1959–1960 rates. Costs on selection cuttings were slightly lower than those on the clear cuttings (table 1; also see table 7, Appendix, for detailed costs). Costs were highest for shelterwood cuttings. When expressed on a net log scale basis, costs were lowest on the clear cuttings.

The work units by cuttings ranked similarly to costs. They were lowest by a slight margin on the selection cutting, next on clear cutting, and highest on the shelterwood cutting (table 2). Others may wish to use their own average rates with these units, or with the itemized values in table 3 and in table 7 (Appendix) to arrive at their own costs. In this study, crew organization resulted in a ratio about 4 to 1 of labor-hours to machine-hours on each cutting.

[6]The colorful regional term "chopping" is used in the redwoods to mean the same as felling and bucking.

Table 1. Cost per thousand board feet log scale to harvest old-growth redwood by three cutting methods

Basis: log rule	Direct costs loaded on trucks excluding road construction		
	Selection cutting	Shelterwood cutting	Clear cutting
	Dollars	*Dollars*	*Dollars*
Gross log scale of logs hauled:			
Scribner rule, all species	11.37	14.30	11.45
Net log scale of logs hauled: Humboldt rule, redwood;			
Scribner rule, other species	16.15	19.73	16.05
Scribner rule, all species[1]	13.13	17.02	12.92

[1] *Net log scale averaged 86.6 percent of gross on selection cutting, 88.6 percent on clear cutting, and 84.0 percent on the shelterwood cutting. By contract definition, merchantable logs scaled 50 percent or more of gross volume.*

Differences Between Cuttings

Some logging cost differences between cuttings are attributed to ordinary variation associated with difficulties of preparing to log. For example, the skidroad and landing construction costs on clear cuttings (table 7, Appendix) were only one-fourth that on the other two cuttings. Favorable terrain for the fewer landings per area resulted in low landing-construction costs. And on two of the clear cuttings, skidroad construction was easy.

Post-logging slash disposal and erosion control costs were almost twice as much on the selection as on the other two cuttings. The extra cost was caused principally by the need for more preparation before burning. On the selection area, the slash was cleared away from the reserve trees by bulldozer wherever possible and piled in openings.

Real differences appear when we consider the principal activities in logging—felling-bucking, skidding, and loading. But such other cost variables as construction or slash disposal costs, plus Social Security-payrolling, supervision, transportation, felling and bucking unmerchantable trees, layout construction, and woods scaling tend to conceal the differences, if any, due to cutting methods.

Table 2. Work units to harvest each thousand board feet (gross Scribner scale) of logs in old-growth redwood by three cutting methods

Item	Work to get logs on trucks, excluding road construction		
	Selection cutting	Shelterwood cutting	Clear cutting
	Hours	*Hours*	*Hours*
Labor	1.36	1.78	1.39
Machines	.33	.40	.32

Weighted Costs and Work Units

For appraisal and other purposes, the weighted costs and work units listed in table 3 may be particularly useful. The values are expressed on a gross Scribner scale basis. Conversion to a net log scale basis has been previously described.

Logging Roadways

The cost of logging the roadway timber was essentially the same as that for logging clear cuttings. For five identical cost items, roadways totaled $10.46 and clear cuttings $10.74 per thousand (tables 7 and 8, Appendix). Only selected cost items were compared because some items either did not apply to roadway logging or they appeared in other road construction costs. It is not surprising that the costs were similar because roadway logging is simply clear cutting a narrow strip. Apparently the narrowness of the strip did not increase these costs.

Tree Size, Methods, and Costs

Felling and bucking costs were particularly variable between broad tree sizes and methods (tables 4 and 9, Appendix), although within respective cuttings it cost more to log the smaller than the

Table 3. Average weighted cost and hours per thousand board feet (gross Scribner log scale) to harvest old-growth redwood

Cost items[1]	Work units and direct costs for logs loaded on trucks[2]		
	Labor	Machines	Cost
	Hours	*Hours*	*Dollars*
Felling-bucking	0.31	--	2.89
Scaling (woods)	.06	--	.15
Skidroad-landing construction	.02	0.01	.18
Layout construction (redwood)	.12	.07	1.39
Skidding (D-8 tractor)	.64	.16	3.88
Loading	.17	.07	1.44
Felling-bucking unmerchantable	.02	--	.15
Slash disposal-erosion control	.07	.03	.61
Supervision-transportation	.09	--	.42
Social Security-payrolling	--	--	1.13
Total	1.50	.34	12.24

[1] *Cost of peeling redwood has been omitted because only part of the volume was peeled, and the trend is now to peel at the mill instead of in the woods.*

[2] *Excluding road construction.*

arger trees. This work was all contract chopping, or payment on the basis of volume of trees cut. However, we also recorded man-hours for the work record listed in table 9, Appendix. Hence the cost difference when respective hours were nearly the same is attributable to the fact that this was contract work. The higher costs for similar hours reflect a different combination of breakage, total cull portions of otherwise merchantable trees, and bucking of windfalls—each paid at a differ-

Table 4. Cost per thousand board feet (gross Scribner log scale) to harvest old-growth redwood, by cutting methods and tree-size classes

Cost items	Selection cutting	Shelterwood cutting	Clear cutting
TREES UNDER 6 FEET D.B.H.			
	Dollars	*Dollars*	*Dollars*
Felling-bucking	3.25	3.24	2.49
Skidding	4.31	6.61	4.10
Loading	1.37	1.85	1.56
Total	8.93	11.70	8.15
TREES 6 FEET D.B.H. AND OVER			
Felling-bucking	2.48	3.08	3.19
Skidding	3.18	3.96	2.78
Loading	1.23	1.70	1.25
Total	6.89	8.74	7.22

ent rate. The variation between the woods-scale volume and gross volume of logs actually hauled also contributed to these erratic differences.

The most significant comparisons between methods and broad tree sizes are shown by the skidding and loading costs (table 4). Costs were higher for the smaller trees within respective cuttings. And in relation to methods, the shelterwood ranked highest and the selection and clear cuttings were essentially the same.

That cost differences between shelterwood and the other cuttings may be partly attributable to average volume of logs is indicated as follows:

	Less than 6 ft. d.b.h.	6 ft. or more d.b.h.
	(bd. ft. gross Scribner)	
Cutting method:		
Selection	1,700	2,631
Shelterwood	980	2,248
Clear cutting	1,290	2,917

The higher costs in each tree category for shelterwood logging are associated with average smaller logs. Although the relationships between the other two methods and log sizes were not as closely correlated, they were judged to be within the variation range.

Two other direct costs (table 9, Appendix) contribute to differences between methods and tree sizes, but their effects are variable. The cost of woods scaling is a minor item and variable. Cost comparisons that include constructing layouts are unproportional. Layouts are constructed for most of the better quality redwoods between 4 and 6 feet d.b.h. and almost all redwoods over 6 feet d.b.h. Hence this work is related to only a small fraction of the smaller trees. Therefore, cost differences between the two size-groups do not measure difficulty but rather lack of work.

Costs and Work Units to Build Roads

The main road cost almost $54,000 per mile and the secondary road more than $25,000 per mile (table 5 and table 10, Appendix). Most operators would rate these costs rather high. But when evaluated in relation to the road specifications, topography, and size of cull material removed in clearing, the cost items will be more meaningful and useful to compare to other jobs.

Road Specifications and Quantities

The main road is single lane, 18 feet wide including ditch, with intervisible turnouts averaging 10 per mile. Alignment specified minimum curve radius of 100 feet. Cut slopes were mostly three-quarters to one in earth with very little one-half to one in loose rock. Fill slopes were one and one-half to one. Rock and gravel surfacing combined was at least 12 inches deep, and 14 feet or more wide. The amount of corrugated metal pipe used per mile was approximately: (a) 18 inch diameter—180 feet, (b) 24 inch—350 feet, (c) 36 inch—370 feet, and (d) 48 inch—75 feet. Excavation of about 60,000 cubic yards of earth was required per mile.

Secondary roads are single lane, 16 feet wide if ditch was needed, otherwise 14 feet wide. Align-

Table 5. Cost per mile to construct main and secondary roads in old-growth redwood

Cost items	Main road		Secondary roads	
	Dollars	*Percent*	*Dollars*	*Percent*
Clearing, stumping, slash disposal	18,012	34	4,212	16
Excavation, grading, drainage	20,556	38	10,189	40
Surfacing, grading	10,322	19	8,876	35
Supervision, transportation	2,235	4	1,136	4
Social Security, payrolling	2,833	5	1,170	5
Total	53,958	100	25,583	100

ment, turnouts, and cut and fill slopes are the same as for the main road. However, the secondary roads tended to follow topography somewhat more than on the main roads, with more grade changes and less excavation. For an average mile of secondary road, about 11,000 cubic yards of excavation were required. Rock and gravel surfacing was at least 12 inches deep, and about 12 feet wide. Length of corrugated metal pipe per mile by diameter classes was: (a) 18-inch diameter—350 feet, (b) 24-inch—135 feet, (c) 30-inch —100 feet, (d) 36-inch—20 feet, (e) 48-inch—20 feet.

Topography and Soil

Both topography and soil affected road construction costs. The sandstone bedrock usually could be ripped by a bulldozer. Infrequent blue-clay intrusions caused only minor construction difficulties, but later becomes expensive maintenance problems. The main road crossed two particularly steep side slopes of 80 to 90 percent, each about two-tenths mile long. These sections contributed materially to expensive excavation. They are also evidence of the necessity for thorough reconnaissance before beginning a road survey. If such steep areas can be avoided, a substantial saving in construction and maintenance can be achieved.

We encountered short sections of expensive excavation and fill on two of the secondary roads. But these high costs were somewhat counterbalanced by other inexpensive sections. Therefore, average secondary road costs may be considered representative for the class of road, soil, and topography encountered on the Redwood Experimental Forest.

Clearing and Slash Disposal

In old-growth redwood, the broken, rotten chunks and tops, many of which are 4 to 8 feet in diameter, are difficult to move, pile, and destroy by burning. Stumps vary in diameter, ranging up to 18 feet. An average of about 32 stumps per acre in the sizes 2 feet and over were removed in road clearing.

Table 5 shows a clearing-cost difference of $13,800 per mile between the main and secondary roads. Some of this difference is attributable to wider clearing on main roads. However, the principal reason is that about one-third of the mileage of main road traversed reserved stands with relatively few places available to pile the debris. The waste material had to be moved considerable distances at extra cost. In contrast, all of the secondary roads were within cutting units. Hence, after clearing, the roadway slash burning job and costs were included with the cutting-units slash disposal.

Development Costs per Timber Volume

The road development costs for 1.5 miles of main road and 2.1 miles of secondary roads were $5.19 per M board feet (gross Scribner log scale) for all timber hauled. The road system made accessible the entire block comprised of the three cutting methods. Therefore, the average development charge is made to all cuttings alike.

Factors Affecting Key Logging Activities

Felling-Bucking

The over-all cost per thousand board feet of logs hauled for felling and bucking varied between cutting methods and for different size-groups of trees. Among the factors affecting these differences were (a) difficulty of terrain and brush affecting movement of men, (b) differences between woods scale and truck scale because of breakage, defect, and incomplete utilization, (c) amount of bucking in defective logs and breaks that result in no merchantable volume, and (d) size of trees and logs. We studied the latter factor only in this project.

These results are for contract (gyppo) felling and bucking by 2-man crews. The independent variable is average tree d.b.h., computed for a day or sometimes fractional part of a day. The dependent variable is average gross Scribner board foot volume per tree including the break and defect bucking cuts as part of the volume. Days on which more than two windfalls were bucked were not included in this analysis because the stump cutting time would be disproportionately small compared to the felling time of a standing tree.

Average volume that could be felled and bucked per day depends partly on the size or d.b.h. of the trees. The relationship, although not strongly correlated ($r = 0.360$), is significant at the 5 percent level. The equation for the linear regression is:

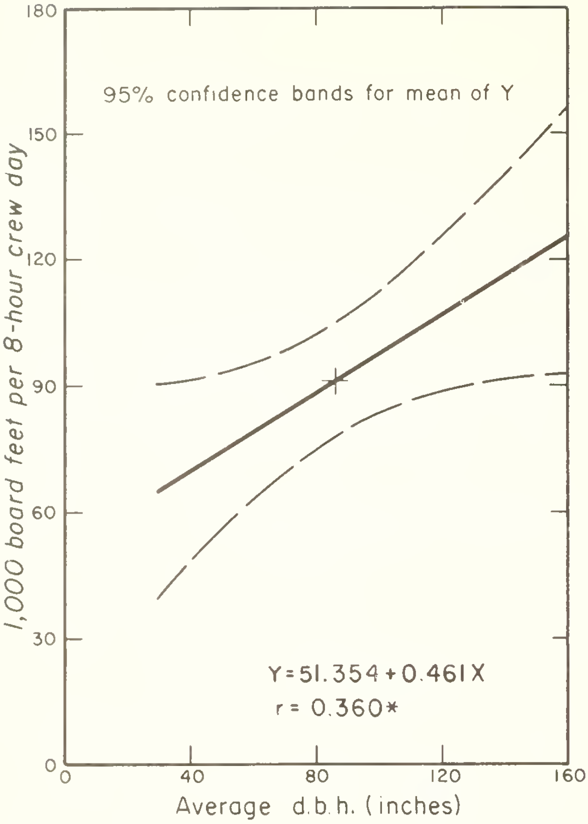

Figure 3.—Volume of logs in thousand board feet gross Scribner volume felled and bucked by 2-man gyppo crews during 8-hour days as related to average d.b.h. of trees.

$$Y = 51.354 + 0.461\,X$$

in which Y = M bd. ft. (gross Scribner log scale) felled and bucked per 8-hour day by a 2-man crew
and X = average d.b.h. of trees felled and bucked

The 95 percent confidence belt plotted in figure 3 shows the range in values for predicting felling-bucking mean volumes for trees of a given average diameter. For example, if trees average 40 inches d.b.h., output will average between 48,000 and 91,000 bd. ft. Nearer the mean of sample tree d.b.h., predictions will have less variation. If trees should average 90 inches, the expected output 95 times in 100 chances would fall between 79,000 and 106,000 bd. ft. In the upper range of tree sizes as in the lower, expected output will vary widely (fig. 4.)

Skidding

Skidding production, expressed in average volume gross Scribner log scale skidded per tractor hour, varied significantly only by average volume per log. The other factors, such as gradient of skid roads, skidding distance, and volume skidded per acre, did not materially affect production within the range and the combination of variables measured in this study.

As described elsewhere, the 30 sets of observations were made on a landing-stage basis. The variables had the following values:

Figure 4.—Daily production may be low and at other times very high when felling huge redwoods.

	Range	Average
Variable:		
Log volume in bd. ft. (gross Scribner scale)	884–3,402	2,043
Main skid road gradient in percent	12–36	22
Skidding distance in feet	291–1,024	515
Volume skidded per acre in bd. ft. (gross Scribner scale)	15,457–229,896	74,492
Volume skidded per D-8 tractor hour in bd. ft. (gross Scribner scale)	2,410–11,911	6,708

The interpretation of the stepwise regression analysis is summarized below. All simple correlation coefficients are recorded in table 6.

The volume skidded per acre had no particular effect on skidding output in conjunction with the other variables. This result seemed anomalous because the simple correlation coefficient between the volume per acre and volume skidded was highly significant (table 6). However, the positive correlation of average volume per log and average volume per acre skidded was highly significant. Therefore, the real meaningful factor, as will be shown, is volume per log.

Skidding distance was not a meaningful factor in its effect on skidding production for the distances studied. This result is contrary to our practical knowledge about effects of distance. Common sense tells us that for longer average skidding distances—other factors being equal—production will diminish. Simple correlations showed significant negative relationship between distance and production; that is, for the longer distance, lower production. However, a similar negative correlation existed between average log volume and distance, indicating that smaller logs were logged on landings with greatest skidding distances. If there had been no correlation between log volume and distance, then the distance variable could have contributed useful information in the production equation. But since they were correlated, we cannot use the skidding-distance regression coefficient in estimating production.

The average gradients of main skid roads had no particular effect on skidding production for the gradients considered. Skidding distance and gradient of main skid roads were highly, significantly, and positively correlated: the longer skidding distances were associated with the steeper gradients. However, since smaller average logs were associated with the longer distance-steeper gradient variables, the stronger effect was log size.

Average volume per log is the single most important variable affecting skidding production within the value range of the variables studied in these cuttings. The regression is highly significant. About 66 percent of predicted output in skidding

Figure 5.—Skidding production may be estimated rather accurately by the average volume per log.

Table 6. Simple correlation coefficients between variables analyzed in skidding production

Variables	X_1	X_2	X_3	X_4
Y - Average volume gross Scribner per tractor hour	0.813**	0.053	-0.396*	0.601**
X_1 - Average volume gross Scribner per log	--	-.026	-.366*	.657**
X_2 - Average skidroad gradient	--	--	.510**	-.118
X_3 - Average skidding distance	--	--	--	-.351
X_4 - Average volume gross Scribner cut per acre	--	--	--	--

* *Significant at 5 percent level;* ** *significant at 1 percent level.*

production can be accounted for by average volume of logs if trees are stratified into at least broad size groups (fig. 5) and skidding distances and main skid road gradients do not exceed those encountered in these cuttings. Furthermore, the Y and X relationship is a conditional estimate applying only for data having similar correlations among variables. The equation for this regression is plotted in figure 6 and is:

$$Y = 1.394 + 2.601 X$$

in which Y = production in M bd. ft. (gross Scribner scale) per D-8 tractor hour

and X = average log volume in M bd. ft. (gross Scribner scale) of broadly stratified size groups of trees

Average skidding output for stand conditions similar to these based on average log volume of a stratified size group can be estimated reliably from figure 6. If logs average 1,000 bd. ft., skidding production will be between 3,100 and 4,900 for probabilities of 95 percent. Nearer the midpoint, the range is narrower for estimated values. For logs averaging 2,000 bd. ft., output will average 5,900 to 7,200. The range widens for the larger logs as for the smaller. If the average is 3,000 bd. ft., estimated production is 8,300 to 10,100.

Loading

The gross board-feet volume of logs loaded per hour varied significantly with average volume per log when based on a day or fractional day's production. The relationship is expressed as a simple linear regression in the following equation:

$$Y = 6.437 + 3.506 X$$

in which Y = production in M bd. ft. (gross Scribner volume) per loader hour

and X = average log volume in M bd. ft. (gross Scribner volume)

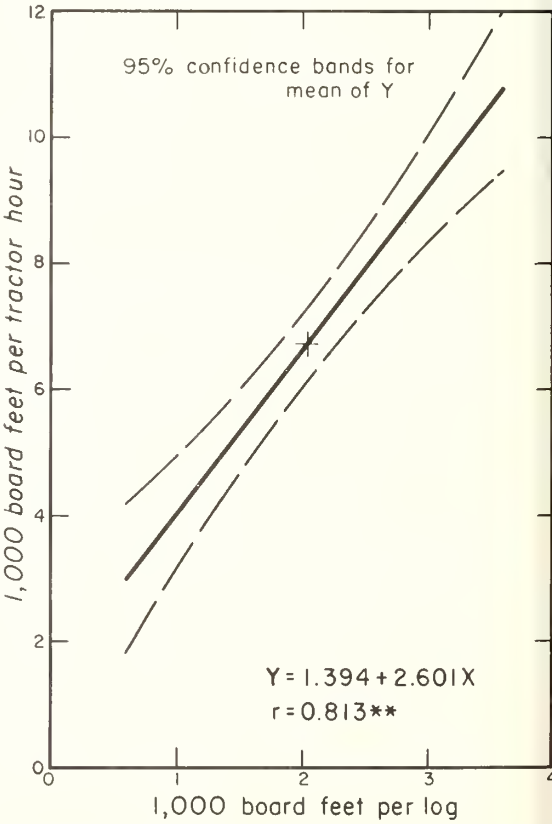

Figure 6.—Gross Scribner volume skidde[d] per tractor hour as related to average volum[e] per log.

Two loaders, a Lima[7] of 35- to 40-ton log capacity (85-ton truck crane) and an Ateco of 25-ton log capacity, were used for two seasons' logging upon which these figures are based.

Before concluding that simple linear regression was an acceptable expression of loader production, we analyzed the outputs of the two loaders separately and for several variables by multiple regression. The four independent variables were: (a) average number of logs per load, (b) average gross volume per load, (c) average log length, and (d) average gross volume per log. The dependent variable was gross board foot volume of logs loaded per hour. These variables in combination did not increase the reliability of the estimate much above that obtained by using average volume per log. Furthermore, a linear regression best expressed the relationships. Because average volume per log correlated significantly with loader output, besides being a familiar measure, it was selected for simple linear regression analysis.

The outputs of the two loaders were analyzed separately. The equations were:

Lima Loader — $Y = 6.477 + 3.347\ X$
$r = .715^{**}$
Ateco Loader — $Y = 6.534 + 3.511\ X$
$r = .824^{**}$
(Y and X have the same equivalents as before)

Covariance analysis revealed that the slope and intercept of these two regressions were not significantly different. Therefore, the single equation— $Y = 6.437 + 3.506\ X$—was calculated as the most useful expression (fig. 7).

Loading production for similar capacity loaders may be estimated from figure 7 if a reasonably accurate estimate of log volume is known. Each set of data entering the analysis had been computed for a day or fractional day's output. Log volume daily averages had a relatively low coefficient of variation because of the stratifying process of stage logging by cutting method and landing. The confidence belt demarcates the range of estimates for other averages of hourly loading production for probabilities of 95 percent. For example, if logs average 1,200 bd. ft., then hourly production will be between 10,200 and 11,200 bd. ft. Similarly, for logs averaging 3,000 bd. ft., the hourly production is 16,400 to 17,600 bd. ft.

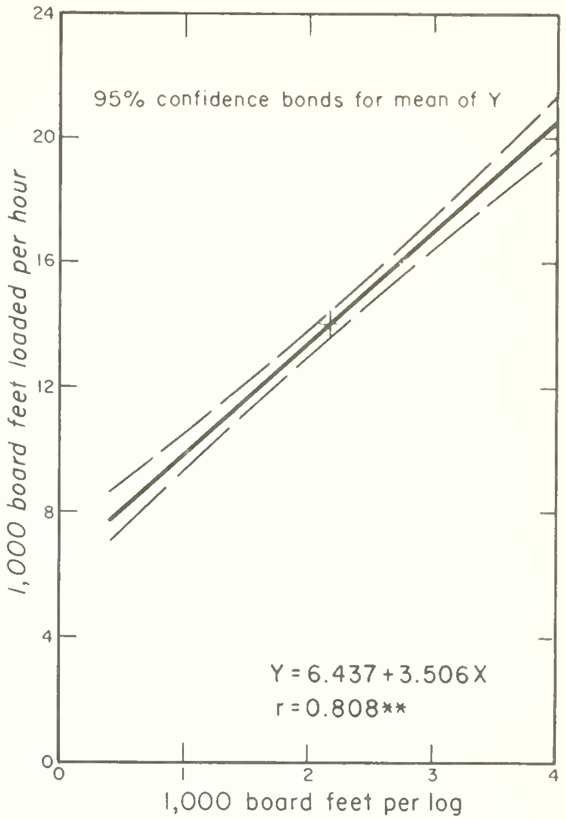

Figure 7.—Gross Scribner volume loaded per hour as related to average volume per log.

Discussion and Conclusions

Timber appraisers, logging managers, and others will find the weighted cost and production information contained in table 3 particularly useful. These figures are based on logging covering a wide variety of terrain and timber during variable weather. They include normal nonproductive time, such as waiting for trucks and changing winch lines. Therefore, they are representative average costs. However, some may wish to adjust a specific item, or all items, by a given percentage because of different experience or anticipated different output of the key logging activities in other timber stands. To convert the costs to a net log scale basis, divide by the ratio of net log volume to gross volume of logs hauled.

[7]Mention of commercial products does not constitute an endorsement by the U.S. Forest Service.

One example will illustrate a method for adjusting the weighted costs for felling-bucking, skidding, and loading:

An appraiser estimates that in a given tract, 75 percent of the volume is contained in trees averaging 48 inches d.b.h. with logs averaging 500 bd. ft., and 25 percent in trees 84 inches d.b.h. and logs 2,160 bd. ft. His calculations would be:

1. Felling-bucking
   a. Average production (fig. 3)........91,000 bd. ft.
   b. Estimated average production for given tract (fig. 3):
      (.75 x 60,000 = 45,000) +
      (.25 x 81,000 = 20,250)..........65,250 bd. ft.
   c. Weighted cost for felling-bucking (table 3)................$2.89 per M bd. ft.
   d. Adjusted weighted cost;
      91,000/65,250 x $2.89....... $4.03 per M bd. ft.
2. Skidding
   a. Average production (fig. 6)..........6,700 bd. ft.
   b. Estimated average production for given tract (fig. 6);
      (.75 x 2,700 = 2,025) +
      (.25 x 7,000 = 1,750)..................3,775 bd. ft.
   c. Weighted cost for skidding (table 3) ....$3.88 per M bd. ft.
   d. Adjusted weighted cost;
      6,700/3,775 x 3.88......... .$6.89 per M bd. ft.
3. Loading
   a. Average production (fig. 7)........13,900 bd. ft.
   b. Estimated average production for other tract (fig. 7):
      (.75 x 8,200 = 6,150) +
      (.25 x 14,000 = 3,500)...............9,650 bd. ft.
   c. Weighted cost for loading (table 3) ....$1.44 per M bd. ft.
   d. Adjusted weighted cost;
      13,900/9,650 x $1.44.........................$2.07 per M

Costs can be kept reasonably current by using the recorded work units with the present price paid per work unit. Furthermore, if different machinery rental rates are thought to be more applicable than those used in this study, then machinery costs can be adjusted accordingly. Already much of the felling and bucking is on an hourly basis so that it will be necessary to substitute current costs in this activity. These adjusted costs can be expressed on a net log scale basis as described above.

The use of road construction costs and work units for planning or appraisal would require similar procedures to those described for logging. Any adjustments would usually be based on differences such as in quantities of excavation, culverts, clearing, and applied to itemized units for the different activities recorded in table 10, Appendix.

Logging managers and foremen can use the production regressions for reaching decisions about scheduling men and equipment for a particular logging side. If contract felling and bucking are used, production estimates, although variable, are obtainable in figure 3. For similar terrain and stand conditions to those encountered in this study, skidding estimates can be reasonably accurate. If log volume for a given stage-landing is estimated to average 1,000 bd. ft., skidding production per tractor hour will be between 3,100 and 4,900 bd. ft. (fig. 6). The loader is estimated to load 9,400 to 10,600 bd. ft. per hour (fig. 7). Therefore three tractors will be needed to keep the landing supplied with logs.

Managers also can use knowledge of output related to log size to reduce costs. For example, smaller skidding tractors could be assigned to a logging side to skid all small logs, or to bunch small logs for the large tractor. Thus a different scheduling of machines offers the possibility of increasing output and lowering costs.

This study also suggests that:

- The results are most valuable as working tools. Tables and equations cannot replace the judgment and experience of the logging manager, appraiser, or foreman, but with these working tools for reference, they should do a much more efficient job.
- The two principal study procedures—cost accounting and statistical analysis of group data—provided much useful information with only minimum professional man-days required for collection of data. Now that cost relationships have been determined, future studies can concentrate on additional group data analysis of key logging activities; or on time and production studies with different machines and crews for specific jobs.
- Average gross log volume is a particularly useful variable for analyzing logging production and costs. This variable relates work to dimensions of logs. Adjustment for defect for a given stand or between stands logically are made as a last calculation.
- An unqualified conclusion that shelterwood cuttings will cost more to log than selection or clear cuttings cannot be made from this study. Costs are inversely related to log volume. The average volume of logs was lowest on the shelterwood and costs were highest. But until we complete other replications of these cuttings to determine if average log size will be consistently lower on shelterwood, we must relate costs to average log volume and not to cutting method.

Summary

The cost to tractor-log old-growth redwood averaged \$12.24 per M bd. ft. (gross Scribner log scale) loaded on trucks. Road development averaged an addtional \$5.19 per M bd. ft. These costs are based on 2 years of logging in a wide variety of terrain and timber during variable weather. They may be easily converted to a net log scale basis by dividing by the ratio of net log volume to gross volume of logs hauled.

The comparison between costs of logging on the three experimental cuttings showed that: (a) costs were highest on the shelterwood, and (b) costs were lowest and about equal on the selection and clear cuttings. On all cuttings the higher costs were associated with the smaller trees and logs. Since log volumes averaged the lowest on the shelterwood, costs were highest, but additional replications of the cuttings are needed to determine if log volume will continually average lowest on shelterwood.

Felling-bucking production as related to tree diameter was expressed as a linear regression whose equation was calculated as:

$$Y = 51.354 + 0.461\,X$$

with correlation coefficient of 0.360—significant at the 5 percent level.

In this equation, Y = M bd. ft. (gross Scribner log scale) felled and bucked per 8-hour day by a 2-man crew;

and X = average d.b.h. of trees felled and bucked.

Confidence belts that are plotted in figure 3 for predicting other average production show a rather wide dispersion because of low correlation.

Although skidding production is known to be affected by a number of variables, only the average volume per log proved to be significant in this study. The relationship was determined to be linear and its equation is:

$$Y = 1.394 + 2.601\,X$$

with correlation coefficient 0.813—highly significant at the 1 percent level. The equivalents are

Y = production in M bd. ft. (gross Scribner log scale) per D-8 tractor hour, and

X = average log volume in M bd. ft. (gross Scribner log scale) of broadly-stratified size-groups of trees.

The confidence belts that are plotted in figure 6 show a reasonably narrow dispersion for predicting average production based on mean log volume.

Loader output of heavy capacity loaders varies directly with average volume of logs. The relationship is linear as expressed in the following equation:

$$Y = 6.437 + 3.506\,X$$

and the correlation coefficient of 0.808 is highly significant at the 1 percent level. The equivalents for the variables are

Y = production in M bd. ft. (gross Scribner log scale) per loader hour, and

X = average log volume in M bd. ft. (gross Scribner log scale) of a stratified size-group of logs.

From the confidence belts plotted in figure 7, the output of similar loaders based on average log volumes can be predicted rather accurately.

Appendix

Data Collection

Logging costs and work units were collected by cutting method, stage, and landing. However, logging of the main road right-of-way was kept separate from all other logging because the road was constructed before logging of each unit began. Trees on the secondary roadways were logged with respective units through which the roads passed. Logs were branded with the cutting method, stage, and landing code before they were hauled from the woods. The scaler recorded this brand when the logs were scaled. The classification of activities was:

I. Cutting method and landing area.
   A. Stage A (trees under 6 feet d.b.h.)
      1. Log making.
         a. Felling and bucking merchantable trees and windfalls.
         b. Layout construction: This job consisted of smoothing uneven ground with a bulldozer a blade-width, then constructing loose-soil ridges crosswise in order to cushion the fall of large, quality redwoods. On some leaning trees we had to use a high-climber to attach wire rope high enough on the tree so that a bulldozer could pull the tree into its layout. Tree pulling was recorded with layout construction.
         c. Felling and bucking of total cull snags and trees.
      2. Stump to truck.
         a. Landing and skid road construction.
         b. Skidding.
         c. Loading (includes rigging time).
   B. Stage B (trees 6 feet d.b.h. and over) Costs were collected by the same categories as above.
II. Road Construction.
   A. Logging the main road right-of-way. Activities were the same as listed unde logging of units except stage logging wa omitted.
   B. Construction activities on main and se ondary roads.
      1. Stump shooting, clearing, slash di posal.
      2. Excavation, grading, drainage.
      3. Surfacing and grading.

Machines were assigned hourly rental rates th covered operation, maintenance, repair, and d preciation, but not operators' wages. The hour rates used throughout this job were:

	Hourly rate
D-8 bulldozer (old model)	$12
D-8 bulldozer (new model)	15
D-9 bulldozer	18
Lima Loader	18
Ateco	12
Scoopmobile	10
DW-20 Scraper	15
Road grader	17
Link belt shovel	12

Cutting Methods and Marking Guides

On the 60-acre selection cutting, about half th stand volume was cut, including both large an small trees. Seventy-nine percent of the merchan able volume logged was from the larger or "B trees. All windfalls and most of the snags an cull trees were cut.

About three-fourths of the stand volume wa harvested on the 69-acre shelterwood cutting. U ually well-spaced codominant trees were reserve for seed production and growth. All windfall snags, and cull trees were cut. Fifty-three percen of the merchantable volume logged was from "B trees.

All merchantable trees, snags, cull trees, an windfalls were cut on the 13-, 18-, and 20-acr clear cuttings. Of this volume 64 percent was co tained in trees over 6 feet d.b.h.

Table 7. Cost and hours per thousand board feet (gross Scribner log scale) to harvest old-growth redwood by three cutting methods

Cost items	Selection			Shelterwood			Clear cutting		
	Labor	Machines	Cost	Labor	Machines	Cost	Labor	Machines	Cost
	Hours	*Hours*		*Hours*	*Hours*		*Hours*	*Hours*	
Felling-bucking------	0.28	--	$2.65	0.36	--	$3.16	0.30	--	$2.94
Scaling (woods)------	.04	--	.12	.07	--	.18	.06	--	.15
Skidroad-landing----- construction--------	.02	0.01	.23	.03	0.01	.27	.01	0.01	.06
Layout construction (redwood only)------	.09	.07	1.31	.12	.07	1.37	.14	.08	1.48
Skidding (D-8 tractor)-------	.60	.14	3.42	.83	.22	5.20	.54	.14	3.26
Loading (Lima & Ateco)	.14	.07	1.26	.21	.08	1.77	.16	.07	1.36
Felling-bucking unmerchantable------	.01	--	.11	.02	--	.19	.02	--	.17
Slash disposal-erosion control------	.10	.04	.84	.05	.02	.47	.06	.02	.48
Supervision-transportation------	.08	--	.37	.09	--	.44	.10	--	.45
Social Security-payrolling----------	--	--	1.06	--	--	1.25	--	--	1.10
Total loaded on trucks exclusive of road construction------------	1.36	.33	11.37	1.78	.40	14.30	1.39	.32	11.45

Table 8. Cost and hours per thousand board feet (gross Scribner log scale) to harvest all timber on the main roadway

Cost items[1]	Labor	Machines	Cost
	Hours	*Hours*	*Dollars*
Felling-bucking--	0.25	--	2.36
Scaling (woods)--	.05	--	.14
Layout construction (redwood only)----------	.06	0.04	.69
Skidding--------	.71	.17	4.27
Loading---------	.17	.08	1.42
Supervision-transportation--	.13	--	.60
Social Security-payrolling------	--	--	.98
Total loaded on trucks-----	1.37	.29	10.46

1 Fewer items are listed here than in table 7 because some work was not needed or was included in the road construction activity.

Table 9. Cost and hours per thousand board feet (gross Scribner log scale) to harvest old-growth redwood, by cutting methods and tree-size classes

Cost items	Selection cutting			Shelterwood cutting			Clear cutting		
	Labor	Machines	Cost	Labor	Machines	Cost	Labor	Machines	Cost
	Hours	*Hours*		*Hours*	*Hours*		*Hours*	*Hours*	
TREES UNDER 6 FEET D.B.H.									
Felling-bucking-----	0.38	--	$3.25	0.40	--	$3.24	0.28	--	$2.49
Scaling (woods)-----	.05	--	.13	.08	--	.21	.08	--	.21
Layouts------	.07	0.05	.93	.03	0.02	.42	.09	0.04	.86
Skidding-----	.75	.17	4.31	.99	.28	6.61	.68	.17	4.10
Loading------	.17	.08	1.37	.24	.10	1.85	.19	.08	1.56
Total loaded on trucks--	1.42	.30	9.99	1.74	.40	12.33	1.32	.29	9.22
TREES 6 FEET D.B.H. AND OVER									
Felling-bucking-----	.25	--	2.48	.33	--	3.08	.30	--	3.19
Scaling (woods)-----	.04	--	.11	.06	--	.16	.04	--	.12
Layouts------	.10	.07	1.38	.14	.08	1.60	.15	.09	1.71
Skidding-----	.55	.13	3.18	.68	.16	3.96	.47	.12	2.78
Loading------	.14	.06	1.23	.18	.08	1.70	.15	.06	1.25
Total loaded on trucks--	1.08	.26	8.38	1.39	.32	10.50	1.11	.27	9.05

Table 10. Cost and hours per mile to construct main and secondary roads in old-growth redwood stands

Cost items	Main road				Secondary roads			
	Labor	Machines	Materials	Cost	Labor	Machines	Materials	Cost
	Hours	*Hours*			*Hours*	*Hours*		
Clearing, stumping slash disposal---	3,014	551	$1,904	$18,014	703	110	$900	$4,212
Excavation, grading; drainage----	1,532	688	6,640	20,556	809	312	3,555	10,189
Surfacing, grading-------------	790	759	[1]133	10,322	651	607	[1]0	8,876
Supervision-transportation---	460	--	--	2,235	238	--	--	1,136
Social Security-payrolling-------	--	--	--	2,833	--	--	--	1,170
Total----------	5,796	1,998	8,677	53,958	2,401	1,029	4,455	25,583

[1] *Rock and gravel were obtained without charge. Loading and hauling costs for delivering the surfacing appear under machines and labor.*

GPO 968-022

Robusta Eucalyptus Wood: Its Properties and Uses

Roger G. Skolmen

U. S. FOREST SERVICE RESEARCH PAPER PSW-9 1963

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Experiment Station - Berkeley, California
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CONTENTS

The Author

Roger G. Skolmen's first Forest Service assignment, in 1959, was as a member of the Experiment Station's soil-vegetation survey in Berkeley and Arcata, California. In early 1961, he joined the station's research staff in Honolulu, Hawaii, where he has been investigating the uses, properties, and processing of forest products. A native of San Francisco, he holds bachelor's and master's degrees in forestry from the University of California, Berkeley.

Robusta eucalyptus *(Eucalyptus robusta Sm.),* known as swamp mahogany in its native Australia, is a tree now common in Hawaii. First introduced in the 1880's, it has since been widely planted on several islands. The robusta resource of the State today comprises some 110 million board feet of quality sawtimber averaging about 20 inches diameter at breast height and three 16-foot logs per tree. Most of this timber is in plantations of easy access; they range in size from less than 1 acre to several hundred acres. Approximate acreages of merchantable stands by island are:

	Acres
Hawaii	4,000
Maui	1,700
Molokai	300
Oahu	2,000
Kauai	1,600

Despite the abundance of the species, only recently has a start been made towards its full utilization. Marketing of robusta products has been hindered by lack of knowledge about the wood. Many adverse opinions are expressed, such as: "Eucalyptus? it's brittle — too heavy — too weak — too hard — splits in nailing — can't be dried!" But a good deal of information is available to show that these opinions are not well founded.

Much information has been gathered about robusta recently from local milling experience and through research, at the U.S. Forest Products Laboratory, at Madison, Wisconsin, supported by the Hawaii Forestry Division. This report brings this information together.

A 40-year-old stand of robusta eucalyptus on Hutchinson Sugar Company land (Photo by Hawaiian Fern-Wood, Ltd.).

Physical Properties

Color and Figure

The heartwood of robusta eucalyptus is light red to reddish brown in color as it comes from the saw. It darkens to a rich reddish brown in seasoning. The narrow 1- to 2-inch band of sapwood is gray to pale brown in dry lumber.

The wood is moderately coarse textured with an interlocked grain which usually produces a ribbon figure of light and dark stripes on quartersawn surfaces. Light and dark areas in growth rings and large vessel elements produce a subdued figure in seasoned wood. Occasional trees yield lumber with very attractive rippled or "fiddleback" figure.

Robusta eucalyptus logs.

Weight

Robusta is a fairly heavy wood. At 46 pounc per cubic foot when air-dry, it is comparable oak and hickory (Youngs 1960). White oak, fo example, weighs 48 pounds per cubic foot ai dry. The weight, as with oak, must be considere in the use of robusta as a furniture wood. I weight is not disadvantageous in flooring, pane ing, and some construction.

Shrinkage

The wood has high shrinkage in drying, slight more than any comparable mainland hardwo (Youngs 1960). This high shrinkage, coupl with the interlocked grain, causes robusta to be wood requiring careful drying in manufacture avoid excessive loss. If put into service at close the moisture content at which it will remain service, robusta wood remains in place quite sat factorily. This is especially true in the stable H waiian climate.

Proper use and manufacture can minimi problems caused by shrinkage and swelling. The problems are not unique to robusta. For examp water-saturated soil under two new Oahu hom recently caused flat-sawn white oak flooring to raised from 9 percent moisture content to 12 pe cent. This 3 percent increase caused the floori to swell, pushing out the walls of the houses 1 inches on two sides. It was calculated from shrin age data that each 2¼-inch piece of strip floo ing had swelled 0.023 inch.

Other flooring woods would have reacted sin larly. Each piece of flat-sawn robusta floori would have swelled 0.025 inch, 0.002 inch mo than white oak. Sugar maple would have swell the same as oak: 0.023 inch. Apitong, which h a higher shrinkage (and swelling) than robus would have swelled 0.026 inch. Quarter-sav stock of all these species would have swelled mu less.

A comparison of weight and total shrinkage f robusta and seven other woods used in Hawaii given at the end of this report (table 3).

← **Milling robusta eucalyptus.**

Mechanical Properties

Strength

Robusta is a very strong wood. In strength roperties other than shock resistance and hardess, it is stronger than most mainland woods of omparable density (tables 1 and 4). Index numers (table 1) provide a convenient means of omparing properties of the various species. For xample, let us compare robusta and white oak or flooring.

Properties of importance in flooring are shrinkge, hardness, and in Hawaii, where subfloors are eldom used, stiffness. Robusta, with a shrinkage idex at 168, shrinks more than white oak at 153. obusta is about as hard as white oak (112 vs. 08) and much stiffer (203 vs. 153). Therefore, 1 Hawaii, where a stable climate minimizes hrinking and swelling of wood in place, robusta hould give service about equal to white oak. It is ossible to compare only shrinkage and strength 1 this way, not appearance or durability.

Because it is such a strong wood, robusta can e used for construction in smaller sizes or over longer spans than most of the commonly used woods. The result is a saving in wood and, at equivalent prices, a saving in cost. Recently developed nailing devices could minimize possible higher labor costs in handling and nailing this hard, heavy wood.

Basic and Working Stresses

The Forest Products Laboratory has suggested interim basic stress values for robusta in the absence of action by the American Society for Testing and Materials on Hawaii-grown species (Forest Products Laboratory 1960a). These values and the working stresses calculated from them are given at the end of this report together with a comparison of the similarly calculated stresses for Douglas-fir and redwood (table 5).

Stress Value for Poles

The Forest Products Laboratory has recommended that robusta poles be assigned a fiber-stress value of 8,400 pounds per square inch and

Table 1. Comparative shrinkage and strength ranking of some well-known woods and robusta eucalyptus[1]

Rank	Volumetric shrinkage	Bending strength	Compressive strength	Stiffness	Hardness	Shock resistance
1.	Redwood (69)	ROBUSTA (120)	ROBUSTA (118)	Apitong (220)	Sugar maple (115)	Sugar maple (137)
2.	Red lauan (121)	Apitong (114)	Apitong (108)	ROBUSTA (203)	ROBUSTA (112)	White oak (127)
3.	Douglas-fir (122)	Sugar maple (114)	Sugar maple (104)	Douglas-fir (185)	White oak (108)	ROBUSTA (103)
4.	Sugar maple (147)	White oak (102)	Douglas-fir (104)	Sugar maple (178)	Apitong (88)	Apitong (99)
5.	White oak (153)	Douglas-fir (90)	Redwood (102)	Red lauan (162)	Red lauan (59)	Douglas-fir (86)
6.	ROBUSTA (168)	Red lauan (90)	White oak (97)	White oak (153)	Douglas-fir (58)	Red lauan (82)
7.	Apitong (186)	Redwood (82)	Red lauan (86)	Redwood (136)	Redwood (54)	Redwood (66)

[1] *Strength listing based on comparative index numbers, shown in parentheses, calculated at the U.S. Forest Products Lab. by procedure outlined in U.S.D.A. Tech. Bul. 158--Comparative strength properties of woods grown in the United States (Youngs 1960). Philippine data calculated from Bellosillo and Miciano (1959).*

be used in sizes given for western larch poles in table 6 of "American Standard Specifications and Dimensions for Wood Poles," ASA Designation 05.1—1963. Though robusta is stronger than larch, use of the figures for larch, the strongest pole species listed, is recommended for ready correlation with existing standards (Forest Products Laboratory 1960b).

Round robusta posts have been pressure treat to more than acceptable standards with both o and water-borne preservatives. This work, do by a private wood treating company in Honolu indicates that poles can also be satisfactor treated with preservatives.

Durability

Heartwood of robusta eucalyptus has been tested for natural resistance to decay by the soil-block method (Clark 1961). These tests indicate that robusta is very resistant to a brown rot fungus. Compared with white oak, robusta is much more resistant to brown rot and slightly more resistant to white rot. Of four Hawaii-grown woods tested, including ohia, robusta was the most resistant to decay.

Long-term exposure tests of robusta and 14 other woods have been started in Makiki Vall Honolulu, but final results of this research are r yet available. Nevertheless, there is some eviden that robusta is durable in Hawaii. Much of t lumber now being produced is from logs that ha lain on the ground in wet forests 10 to 20 yea without deterioration of heartwood. Robus heartwood in use also shows resistance to term and other insect attack. As in other species, o the heartwood is durable, not the sapwood.

Other Characteristics

Though of concern chiefly to the primary manufacturer, certain characteristics in robusta that are not found in commonly known woods should be explained to the consumer.

Growth Stress

In common with some other eucalypts and other species (such as *Shorea* spp. and *Khaya* spp.), particularly when plantation grown, robusta wood in the tree contains internal stresses along the grain that have built up during the life of the tree. As a result of these growth stresses, wood in the outer part of the tree is in tension, and that in the inner part is in compression.

Growth stress usually shows up immediately in bucking logs to length or in sawing cants from them. During bucking, logs usually split open on the end in one or two directions. Sometimes this end splitting occurs a few hours after bucking. End splits may continue to open in stored logs and result in even greater loss of wood. As much as 10 percent of the wood in a short log may be lost in trimming lumber that contains these splits.

Growth stress is also responsible for end checks in lumber reaching the market. End checks will not open further in properly dried lumber and for certain uses are not important. They ma however, seriously limit the salability of robu lumber and should be trimmed off at the mill af drying. Hence lumber to be sold in standa lengths must be produced originally in consid ably longer lengths.

Growth stress commonly causes slight crook bow in long, large dimension pieces. The size dimension stock, therefore, may affect cert uses, as in a recent case in which a piece of bo building dimension stock was replaced by an ov size piece so that the slight bow could be adz out to make a boat stem.

Brittleheart

Another peculiarity, common to robusta a many other tropical hardwoods, is brittlehea Probably as a result of growth stresses which cau long term compression loading of the first-form juvenile wood near the pith, a central core wood, especially in butt logs, is full of micr scopic compression failures (Burgess 1957). Th wood is extremely weak in shock resistance. Br tleheart usually has a characteristic color, to fibers on end grain surfaces, or large compressi failures on lumber faces that aid in its identific tion.

Wood suspected of being brittleheart *must* be xcluded when the lumber is to be used for pur-oses requiring strength in shock resistance. This ; accomplished at present by boxing the heart in awing and segregating all lumber from the cen-ral part of the log. Lumber from the central por-ion is currently used entirely for stakes, each of vhich is strength tested during manufacture.

Unwittingly, a few pieces of brittleheart have n occasion been included in lumber shipments. These few pieces have resulted in the impression requently heard that robusta is a brash wood. It ; not, when the brittleheart portion is excluded.

Pin Knots

A third peculiarity of robusta and some other ardwoods grown in Hawaii is the frequent occur-ence of minute, knot-like growth irregularities, sually 1/16 inch or less in diameter, in otherwise lear wood (Malcolm 1961). These irregularities re caused by "dormant bud strand" tissue extend-ig radially from the log center. They appear as mall eye-shaped blotches on flat-sawn lumber, or rge medullary rays on quartered lumber (Jacobs 955). Occasionally these structures contain pith and hence can be classed as true knots.

If robusta is used in a dry climate, or if it is kiln dried to a low moisture content, these irregu-larities usually will check minutely in the direction of the grain, but the checks can be filled satisfac-torily in the finishing operation.

The smaller of these irregularities will require an exception under the standard grading rules of the National Hardwood Lumber Association if a reasonable grade recovery is to be achieved from robusta. As consumers become better acquainted with robusta lumber, these small irregularities may be found acceptable in many uses.

Tiny growth irregularities quite similar to those in robusta are frequently seen in the "Philippine mahoganies."

Drying

Drying defects are most frequently mentioned as causes of rejection of robusta lumber. But prop-erly dried robusta is not excessively warped or checked. In fact, very few pieces of dry lumber show much misalignment. Except for end splits due to other causes, robusta does not exhibit ex-cessive splitting or checking in drying.

Present Uses

The annual production of robusta lumber in [awaii is about 500,000 board feet. Lumber pro-uced is mostly of three thicknesses—1, 2, and 3 iches—and of lengths from 8 to 16 feet. This nall output is converted to several products able 2). More uses are continually being devel-ped.

Heavy duty pallets made of robusta and fas-ned with tensioned spirally grooved nails have a ng service life.In lighter pallets, robusta is ex-ellent for the edge boards that take a terrific bat-ring from forklift tines. It is now being tried for eavy sling cargo pallets by a shipping company.

Stakes, used to support irrigation ditch walls id gates, offer an excellent means of increasing ver-all utilization of logs. The durability and rength of robusta make it highly regarded for akes. Robusta stakes last a long time in the ound and can be driven repeatedly without split-ig.

One sugar mill has used robusta for several ars for flume construction and reports that it outwears steel plate in resisting the abrasion of rolling stones and mud. This abrasion resistance causes robusta to be valued for truck beds. Its strength results in its use as conveyor slats. Ranchers like robusta for corral fences and gates because it is strong and durable.

Besides excellent strength and wearing char-acteristics, robusta is a beautiful wood that takes a high polish and so makes an attractive floor. One home was built some years ago in Hilo with robusta siding that has remained in place very well and is holding its original paint satisfactorily.

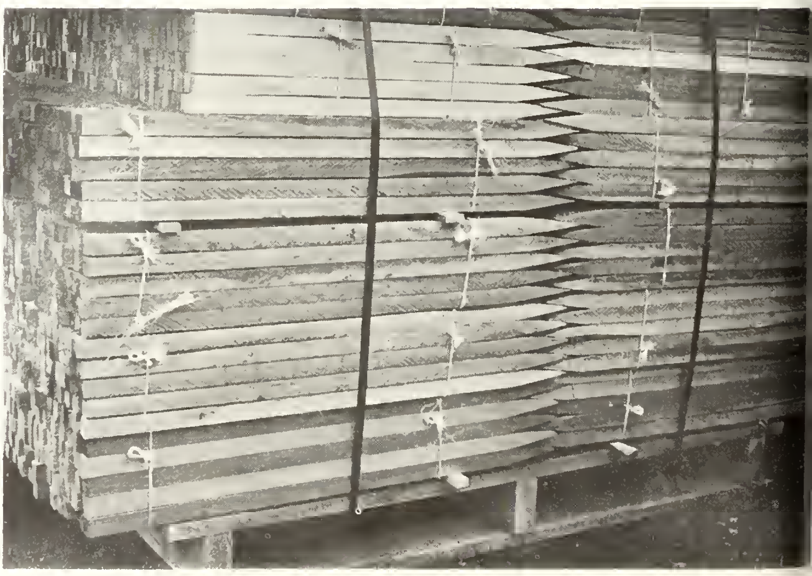
Robusta finds extensive use as both split and round posts on ranches and farms in Hawaii. A 5-inch post is estimated by ranchers to last 5 to 7 years untreated in wet areas having 100 or more inches of rain per year (Philipp 1961). In Makiki Valley, Honolulu, 3- to 5-inch posts have lasted slightly more than 2 years (Skolmen 1963). Treated with preservatives, such a post should last much longer.

Table 2. Current uses of E. robusta in Hawaii

Product	Consumers	Estimated annual production
		M board feet
Pallets	Agriculture, shipping	180
Stakes	Sugar plantations	150
Flooring	Home construction	40
Conveyor slats	Sugar mills	30
Fences and gates	Ranches	30
Truck beds	Trucking companies	20
Residue flumes	Sugar mills	10
Siding and paneling	Home construction	10
Misc. construction	(Framing, boats, etc.)	30

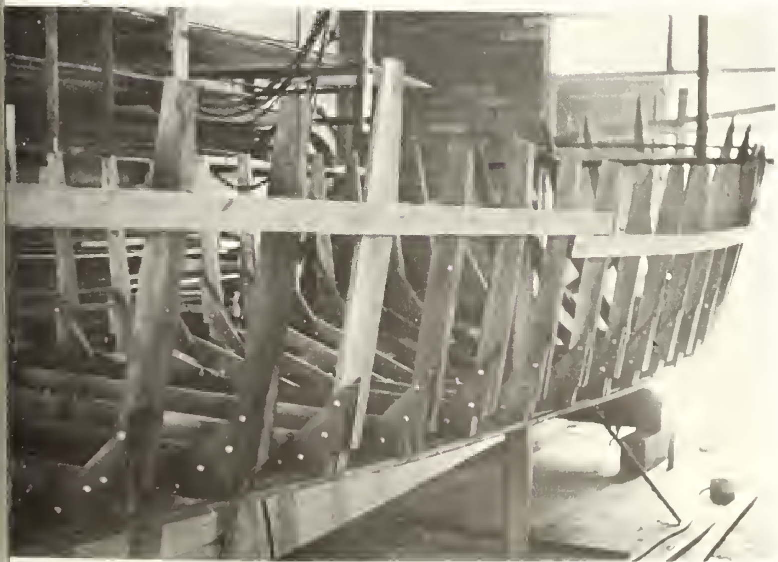
A robusta pallet, rugged and long-lived.

Irrigation stakes bundled and strapped ready for shipment.



Doors faced with robusta veneer at the Hawaii Department of Agriculture Building, Honolulu.

Robusta floor in the Board Room, Hawaii Department of Agriculture.



Robusta frames in the new Kawaihae pilot boat—one of the most critical constructional uses to which a wood can be put.

Potential Uses

Single-wall house siding is an excellent potential market for robusta. The strength and durability of the wood should suit it to this use. Thinner siding could be used if the walls were desired to be equal in strength to redwood, the most commonly used siding. If used in the same thicknesses as redwood, robusta walls would be much stiffer. But because robusta shrinks and swells more than commonly used siding woods, it may not be suitable for use in those parts of Hawaii that have large seasonal changes in atmospheric moisture.

Robusta should also produce beautiful small-membered furniture of contemporary design. It is too heavy for bulky furniture, but its high strength suits it to light construction.

The strength and durability of robusta suit it well for highway guard rails. Considerable softwood is currently imported for this use.

Sliced veneer of robusta has been produced on an experimental basis and made up into plywood by the Forest Products Laboratory (Youngs 1960) and by three private companies. None of these producers had any particular difficulty in working with the wood. Veneer sliced on the quarter works up into very attractive panels. Robusta veneer is not being manufactured commercially at present.

A veneer slicing plant would be an excellent outlet for higher grade material. Face veneer could be exported to plywood producers elsewhere or used by an Island plywood plant if one is set up. Veneer production would not necessarily preclude full utilization of logs since lower grade material unsuited for flitches could be sawed into lumber.

To sum up, *Eucalyptus robusta* wood is excellent for purposes requiring high strength and for finish work where an attractively figured, dark reddish-brown wood is desired.

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*Address requests for copies to the originating office.

Appendix

Tables of Use to Architects, Engineers, Builders, and Lumber Manufacturers

Table 3. Physical properties of robusta eucalyptus, ohia, and six woods commonly imported to Hawaii[1]

Species	Moisture content	Specific[2] gravity	Weight[3] per cubic foot	Total shrinkage (green to oven-dry)		
				Radial	Tangential	Volumetric
	Percent		*Pounds*	- - - -	- *Percent* -	- - - -
Robusta eucalyptus	88	0.60	70	6.1	10.7	--
(Eucalyptus robusta)	12	.66	46	--	--	--
Ohia	67	.70	73	6.9	12.1	19.1
(Metrosideros collina)	12	.81	57	--	--	--
Apitong[4]	80	.58	65	6.0	11.7	19.1
(Diptercarpus spp.)	12	.70	49	--	--	--
Maple, sugar	58	.56	56	4.9	9.5	14.9
(Acer saccharum)	12	.63	44	--	--	--
Oak, white	68	.60	62	5.3	9.0	15.8
(Quercus alba)	12	.68	48	--	--	--
Douglas-fir (coast type)	38	.45	39	5.0	7.8	11.8
(Pseudotsuga menziesii)	12	.48	34	--	--	--
Lauan, red[4]	65	.45	46	3.7	7.4	12.5
(Shorea negrosensis)	12	.49	34	--	--	--
Redwood (virgin)	112	.38	50	2.6	4.4	6.8
(Sequoia sempervirens)	12	.40	28	--	--	--

1 Source: Youngs (1960).
2 Based on weight when ovendry and volume at test.
3 Based on combined weight of wood and moisture and volume at test.
4 Source: Bellosillo and Miciano (1959).

Table 4. Mechanical properties of robusta eucalyptus, ohia, and six woods commonly imported to Hawaii[1]

Species	Moisture content	Static bending					Compression parallel to grain		Hardness[2]		Toughness[3]	
		Fiber stress at proportional limit	Modulus of--		Work to--		Fiber stress at P.L.	Maximum crushing strength	End	Side	Radial	Tangential
			Rupture	Elasticity	Proportional limit	Max. load						
	Percent	*Psi*	*Psi*	*1,000 Psi*	*In. lb. per cu. in.*	*In. lb. per cu. in.*	*Psi*	*Psi*	*Lb.*	*Lb.*	*In. lb.*	*In. lb.*
Robusta	88	6,500	10,400	1,780	1.38	9.2	3,560	5,260	1,100	970	260	260
eucalyptus	12	8,200	15,600	2,200	1.77	14.5	4,150	8,200	1,670	1,330	270	280
Ohia	67	6,000	10,100	1,800	1.18	10.6	3,090	4,720	1,340	1,270	410	410
	12	10,700	18,300	2,370	2.75	16.7	5,270	8,900	2,390	2,090	330	390
Apitong[4]	80	5,200	8,890	1,710	.88	7.5	2,680	4,320	790	800	-----250-----	
	12	10,100	16,700	2,500	2.40	15.3	4,790	8,840	1,600	1,410	-----290-----	
Sugar maple	58	5,100	9,400	1,550	1.03	13.3	2,850	4,020	1,070	970	-------------	
	12	9,500	15,800	1,830	2.76	16.5	5,390	7,830	1,840	1,450	(190)	(190)
White oak	68	4,700	8,300	1,250	1.08	11.6	3,090	3,560	1,120	1,060	-------------	
	12	8,200	15,200	1,780	2.27	14.8	4,760	7,440	1,520	1,360	-------------	
Douglas-fir	38	4,500	7,600	1,570	.75	7.6	3,130	3,860	570	500	150	200
	12	7,800	12,200	1,950	1.77	9.8	5,850	7,430	900	710	140	200
Red lauan[5]	65	4,700	7,700	1,380	.81	6.4	2,490	3,800	590	610	-----310-----	
	12	7,100	11,500	1,700	1.70	10.7	3,410	6,020	780	740	-----240-----	
Redwood	112	4,800	7,500	1,180	1.18	7.4	3,700	4,200	570	410	(60)	(110)
	12	6,900	10,000	1,340	2.04	6.9	4,560	6,150	790	480	(50)	(80)

[1] *Source: Youngs (1960).*

[2] *Load required to imbed a 0.444-inch ball to half its diameter.*

[3] *Specimen size 0.79- by 0.79-inch tested over 9.47-inch span, except values indicated by ( ), which are based on 5/8- by 5/8-inch specimen tested over 8-inch span.*

[4] *Averages of 19 green and 9 air-dry average tree values of 6 (5 air-dry) Dipterocarpus spp. listed by Bellosillo and Miciano (1959).*

[5] *Averages of 7 green and 5 air-dry average tree values listed by Bellosillo and Miciano (1959).*

Table 5. Basic and working stresses for robusta eucalyptus, Douglas-fir, and redwood[1]

Item	Robusta	Douglas-fir (coast type)	Redwood
	Psi	*Psi*	*Psi*
Basic stress:			
Beams (bending)			
Long-time loading	2,900	2,200	1,750
Normal loading	3,200	2,400	1,950
Columns (compression parallel)			
Long-time loading	1,900	1,450	1,350
Normal loading	2,100	1,600	1,500
Working stress:			
Beams (bending) normal loading			
High grade[2]	2,400	1,800	1,500
Medium grade[3]	1,600	1,200	1,000
Columns (compression parallel) normal loading			
High and medium grades[4]	1,500	1,200	1,100

[1] *Sources: Forest Products Laboratory (1960a); U.S. Department of Agriculture (1955).*

[2] *Assumed value 75% of basic stress as adjusted for 'normal' loading. Redwood and Douglas-fir adjusted similarly for comparison purposes. For actual working stresses of mainland woods consult National Lumber Manufacturers Association--National Design Specifications for Stress-Grade Lumber and Fastenings.*

[3] *Assumed value 50% of basic stress--also see footnote 2 above.*

[4] *Assumed value 75% of basic stress--see also footnote 2 above.*

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ABIES — a Bibliography of Literature for Tree Improvement Workers

Ronald M. Lanner

Stanley L. Krugman

U. S. FOREST SERVICE RESEARCH PAPER

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Pacific Southwest Forest and Range
Experiment Station - Berkeley, California
Forest Service - U. S. Department of Agriculture

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The Authors

Ronald M. Lanner is studying silvicultural problems of forest plantations with the Experiment Station's research staff in Hawaii. Since joining the Forest Service in 1958, he has conducted silvicultural research on the Challenge Experimental Forest in Yuba County, California, and forest genetics research at the Institute of Forest Genetics in Placerville, California. In 1962 he transferred to Hilo, Hawaii. He holds bachelor's and master's degrees in forestry from Syracuse University.

Stanley L. Krugman is conducting studies of forest tree physiology as part of the Station's research on the genetics of western conifers at Berkeley and Placerville, California. A native of St. Louis, Missouri, he did his undergraduate work in forestry at the University of Missouri. He earned a master's degree in forestry and a doctorate in plant physiology at the University of California, Berkeley, where he did research on root growth in conifers before joining the Forest Service in 1962.

This bibliography is intended to serve as a guide to botanical literature for foresters and geneticists concerned with tree improvement in the genus *Abies*. Comparatively little breeding has been done with the firs, but in recent years interest in work with this genus has increased. We hope that the references listed here will be of help to those conducting work with this circumpolar genus of the Northern Hemisphere.

Scope

Most of the articles cited were selected from references in Biological Abstracts (B.A.) and its forerunner Botanical Abstracts (Bot.A.), Bibliography of Agriculture (B.Ag.), Forestry Abstracts (F.A.), and Plant Breeding Abstracts (P.B.A.). The period 1920 to 1962 is best represented. The original document is cited unless otherwise noted. Selected references to standard and regional taxonomic works and textbooks are included, but the major emphasis is on original papers published in journals. More selectivity has been exercised with literature on common species than on some of the more obscure species, like those of the Far East and Mediterranean areas. References to insect pests and diseases have been omitted because of their great number and specialized nature.

Organization

The bibliography is arranged alphabetically by senior author. Individual entries are numbered consecutively for cross-indexing in the subject index and the index to scientific names. The classes in the subject index are in accord with the Oxford System of Decimal Classification for Forestry.

Species, varieties, hybrids, etc., are listed in the indexes as given by the publication cited. Thus, several synonyms appear, and in hybrid combinations the female (seed) parent may not always be the first species named.

Subject Index

Index to Scientific Names

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Levels and Sources of Forest Fire Prevention Knowledge of California Hunters

William S. Folkman

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Pacific Southwest Forest and Range
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The Author

William S. Folkman is responsible for studies of the sociological problems in the prevention of man-caused forest fires and in the use of forest recreation areas. He joined the Pacific Southwest Station staff in 1962 after a career in sociological research and teaching with several universities and the U.S. Department of Agriculture's Agricultural Marketing Service and Economic Research Service in Washington, D.C.

A native of Ogden, Utah, he holds a bachelor's degree in agriculture from Utah State Agricultural College, a master's degree in sociology from the University of Utah, and a doctorate in rural sociology from Cornell University. He has also studied at the American Graduate School of the University of Copenhagen in Denmark and at the University of Strasbourg in France.

Many Californians have directly experienced the power and devastation of uncontrolled fire. Dramatic television news coverage has made the ominous smoke and flame of a forest ablaze familiar to most of the others. Through such graphic experience people generally have become aware of high fire risks in the natural environment of the State. In spite of this awareness, and in spite of long and sustained efforts to make fire prevention an active part of our lives, more than 70 percent of the forest fires in California are man-caused.

This report summarizes findings from one study in a research program in forest fire prevention. The study, conducted by the School of Public Administration, University of Southern California, was sponsored jointly by the California Division of Forestry and the Pacific Southwest Forest and Range Experiment Station.

Licensed hunters of the State were chosen for study for several reasons. First, in numbers they represent an important segment of the forest-user public, nearly three-quarters of a million strong. Secondly, the major hunting season occurs during a period of the year when fire risk is generally high. The nature of hunting takes the participant away from established roadways, campgrounds, and other areas where fire-proofing efforts of various kinds can be concentrated. A final and most telling reason—the licensing process provides a convenient and inexpensive method of identifying the members of the group. Other groups are difficult to identify. Americans have a long tradition of moving freely in and out of our forests, and hence offer few points of contact for study purposes. This difficulty is a significant barrier to research.

As intimated above, we do not know much about the people who use our wildlands. However, if our fire prevention activities are to be made more effective, administrative decisions must be bolstered with a knowledge of the characteristics of these people. Efforts may be more finely focused if we know who are involved, where they come from, what use they are making of the area, as well as what they know about good fire use practices and where they get this type of information.

Specific objectives of the study were: to identify the hunter population in California; to determine the hunters' level of forest fire prevention knowledge; and to ascertain their sources of fire prevention information.

Method of Study

In the fiscal year 1959–60—the year the study was begun—California licensed about 680,000 hunters. It was decided that a mailed questionnaire to a representative sample of the total hunter population would be the most feasible means of studying such a large scattered group.

The Sampling Method

Hunters in California are required to purchase hunting licenses from the Department of Fish and Game. The Department made the hunting license stubs available for this study. These stubs, bound in books of 25, were separated into the 5 administrative regions of the Department of Fish and Game to assure a proportional geographical representation.

The first license was taken from every other book within each region to form the desired 2 percent sample. If the first license stub was illegible, incomplete, or otherwise unsatisfactory, the next one was selected. If that was unusable, the next was selected, proceeding sequentially through the book until an adequate one was located. The random nature of license procurement, and the area and sequential procedure used assured a representative sample of the hunter population.

The license stubs provided the names and addresses of the sample to whom questionnaires were mailed. In addition, the stub provided information concerning possession of a California fishing license, age, and sex. Identifying characteristics listed on the stub—height, weight, and color of hair and eyes—were not recorded.

The Questionnaire

For control purposes, two forms of the questionnaire were prepared. Each contained 16 multiple-choice questions. Six of the questions were common to both forms. The respondents were asked to indicate after each question whether they were "very certain," "fairly certain," or "uncertain" of their answer.

The two forms also included identical requests for data on source of fire safety information, possession of a fishing license, age, sex, occupation, and city and county of residence.

The questionnaires were reproduced on one of the panels of an out-size double postcard of the "Business Reply Card" type (appendix 1). Mailing of the questionnaire was preceded by a conditioning letter requesting participation. Pretests had indicated that, within budget limitations, this was the most feasible method of insuring a large response.

Questionnaires were mailed to 10,542 licensed hunters. Thirty-one percent (3,260) of these hunters returned usable forms. These respondents were compared with those in the original sample by age, sex, size of city of residence, and region where license was purchased. They were found to correlate highly, lending strong support to acceptance of the respondent sample as representative of the population.

A preliminary analysis of data from the respondents was submitted to the Station by the School of Public Administration, University of Southern California.[1] This report differs from the earlier one in some detail. Two major changes are in the analyses by regions and by size of city of residence. In the USC report, hunters were included in the region in which they purchased their hunting license. In this report they are reported in the region in which they reside. Figures from the 1960 Census of Population, which were unavailable earlier, are used in reporting size of city of residence in this report. The two reports also differ in orientation and emphasis.

[1]Administrative Dynamics Research Program. The California Hunter: Levels and sources of forest fire prevention knowledge. Univ. S. Calif. School Pub. Admin. 225 pp., 1963.

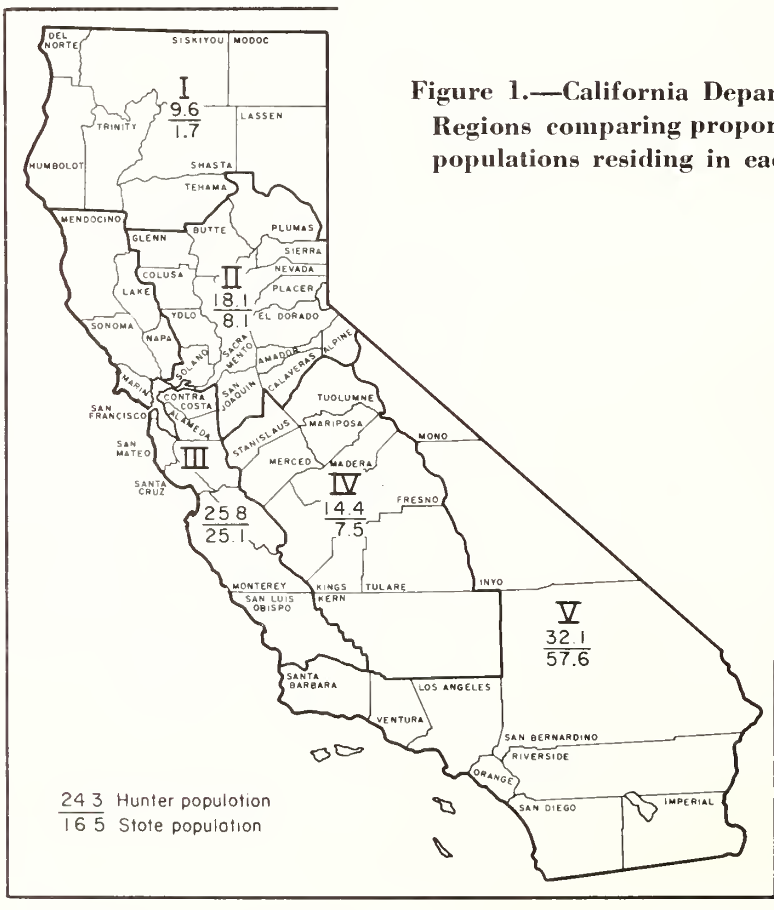

Figure 1.—California Department of Fish and Game Regions comparing proportions of State and hunter populations residing in each region.

Characteristics of the California Hunter

A study for the Outdoor Recreation Resources Review Commission reveals some of the characteristics of hunters.[2] We learn that hunting, like other vigorous outdoor activities, is most attractive to young men. Few women hunt, and many men stop hunting as they grow older. Unlike some outdoor activities, however, hunting appeals to people in all income, occupational, and educational groups. These characteristics represent national averages. But the report also shows considerable regional variation in the characteristics of the hunter population. For this reason it is somewhat hazardous to generalize too freely from the ORRRC statistics to a particular locality.

Sex Distribution

Licensed hunters in California represent a sizable army: 6.1 percent of the total 1960 population of the State 14 years of age or older, and in California, as in the Nation as a whole, hunting is almost exclusively a male sport. Only 7.1 percent of the State's licensed hunters were women.[3] Because of this imbalance, licensed hunters amount to about 1 in 10 of the total male population and less than 1 in 100 of the women of the State. An earlier on-the-ground survey of deer hunters in northern California found 144 women to 330 men. Evidently, few women purchase a hunting license, but many of them enjoy the camping experience.

The national study reported that 13 percent of the total U.S. population, 12 years of age and over, went hunting during September to November 1960—25 percent of the males and 2 percent of the females.[4] But the populations in the two studies are not exactly comparable. The California study refers to the population buying hunting licenses, some of whom may not use them. The national survey reports all those doing any hunting, whether licensed or not.

By Department of Fish and Game regions (fig. 1), the proportions of women hunters varied from

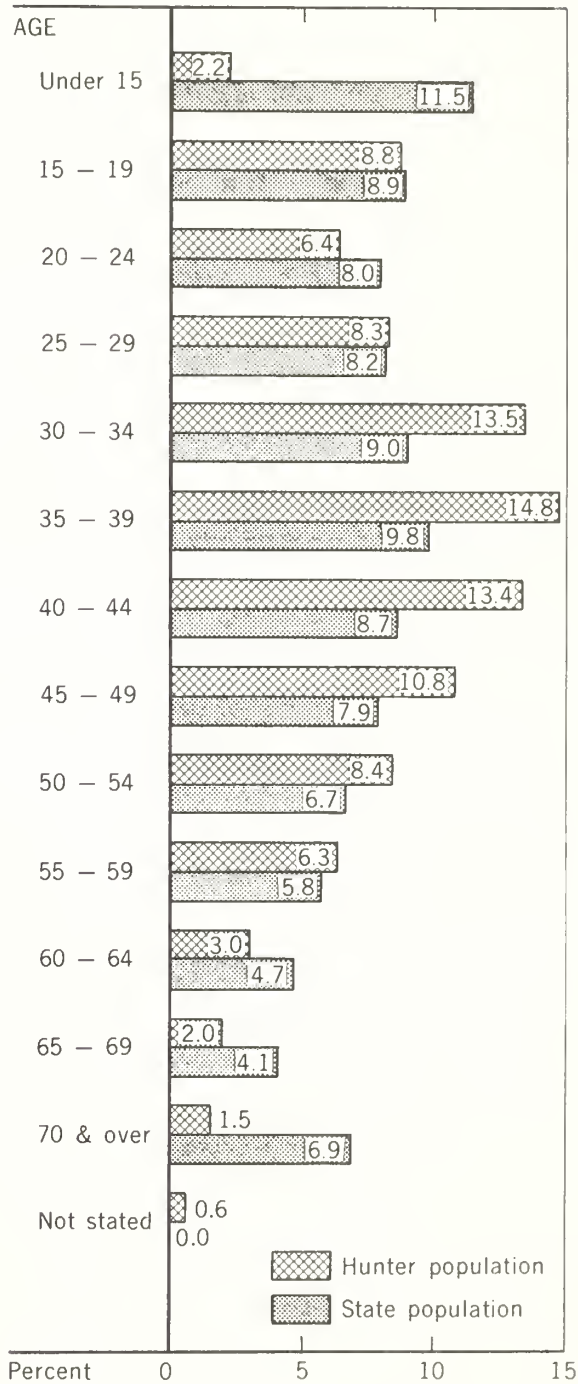

Figure 2.—Percentage distribution of licensed hunters and total population of California by age. (Youngest age group in total population includes only those 10-14 years old.)

[2]Outdoor Recreation Resources Review Commission. National recreation survey. Study report 19. Washington, D.C., 394 pp., 1962.

[3]These data were obtained from the information on the license stubs and concerns the original sample of 10,542 hunters. Women were slightly more inclined to answer the questionnaire, and their proportion among the respondents was 8.1 percent.

[4]ORRRC, *op. cit.*, Table 2.02.11, p. 209.

6.8 percent in Region IV to 13.8 percent in Region I. In Regions II, III, and V, 8.7, 7.1, and 7.4 percent, respectively, of the hunters were women.

Age Characteristics

The average age of the hunters was 37.1 years. The women, on the average, were about one year younger than the men.[5] The hunters tended to be concentrated in the middle ages (fig. 2). Those 25 to 50 years of age were considerably overrepresented, while each age group after 60 years was underrepresented. Still, 1.5 percent of the hunters were 70 or more years of age.

There was some variation in average age among the different regions. Hunters from Region I had a mean age of 36.4 years; those from Regions III and IV averaged 3 years older (39.3 years in each Region). Regions II and V fell in an intermediate position with average ages of 38.0 and 37.9 years, respectively.

The data in this study show underrepresentation among the younger age groups. One cause is a failure of the younger hunters to respond to the questionnaire at the same rate as the older hunters. However, this failure accounts for only a small part of the variance. In contrast, the national study showed the youngest age group, 12 to 17 years, to have the highest proportion of all participating in hunting.[6] The discrepancy between the two studies would seem to indicate that many younger hunters are unlicensed. The alternative explanation—that California youths are less interested in hunting—seems hardly tenable.

Residence Characteristics

According to the 1960 census, 28.6 percent of all Californians reside in cities of 250,000 or more population. Only 12 percent of the hunters in the State are from cities of this size. At the other end of the scale, 26 percent of the population live in cities under 5,000 population, or are rural residents. These persons account for just about their proportionate share of the hunters: 25 percent. Both in actual numbers and relatively, most of the hunters come from the medium-sized urban centers. In fact, cities of 5,000 to 25,000 persons account for over twice their proportional number of hunters (fig. 3).

Only 1.7 percent of the population of the State resides in the eight northern counties comprising the Department of Fish and Game's Region I (headquarters in Redding). However, nearly one-tenth (9.6 percent) of the licensed hunters are from that Region (fig. 1). The proportions of hunters in Region II (Sacramento) and IV (Fresno) are about double the proportions of the State's population residing in these two Regions, 18.1 percent compared to 8.1 percent and 14.4 percent compared to 7.5 percent, respectively.

Region III (San Francisco) is a long narrow region extending from Mendocino on the north to San Luis Obispo on the south. The proportion of the State's hunters in this Region closely matches the proportion of the total population found within its boundaries, 25.8 percent and 25.1 percent, respectively.

The ten counties in Region V (Los Angeles) contain 57.6 percent of the population of California, but their residents account for only about one-third (32.1 percent) of the license purchases in the State.

Fire control officers should find these figures especially significant in planning their fire prevention programs. They should be aware that many non-resident hunters may be unaffected by any local preseason prevention efforts. Our data do not provide direct evidence of the size of this interregional movement of hunters, but they do give some indication of its variation from area to area. In Region I, which encompasses one of the most popular deer hunting parts of the State, about 35 percent of the licenses sold were issued to non-residents of the region. For Regions II, III, IV, and V, these proportions were 15 percent, 8 percent, 4 percent, and 1 percent, respectively.

These figures in no way represent the total number of migrant hunters. Most undoubtedly buy their license before leaving home. In a rough way, though, the data do give some indication of where the mobile hunters come from and where they go. About 8 percent of all hunters in the State purchased their license outside of the region in which they reside. The highest proportion to do so were

[5]Again, these observations are from the data obtained from the original sample of license stubs. The older male hunters, as were the women, were somewhat overrepresented among the respondents to the questionnaire. The average age of respondents was 38.4 years, and the women among them averaged about one year *older* than the men.

Only these figures on sex distribution and average age of the total hunter population were derived from the license stub data. All other statistics in this report, including those on region breakdowns, were obtained from the questionnaire data.

[6]ORRRC, *op. cit*, p. 209.

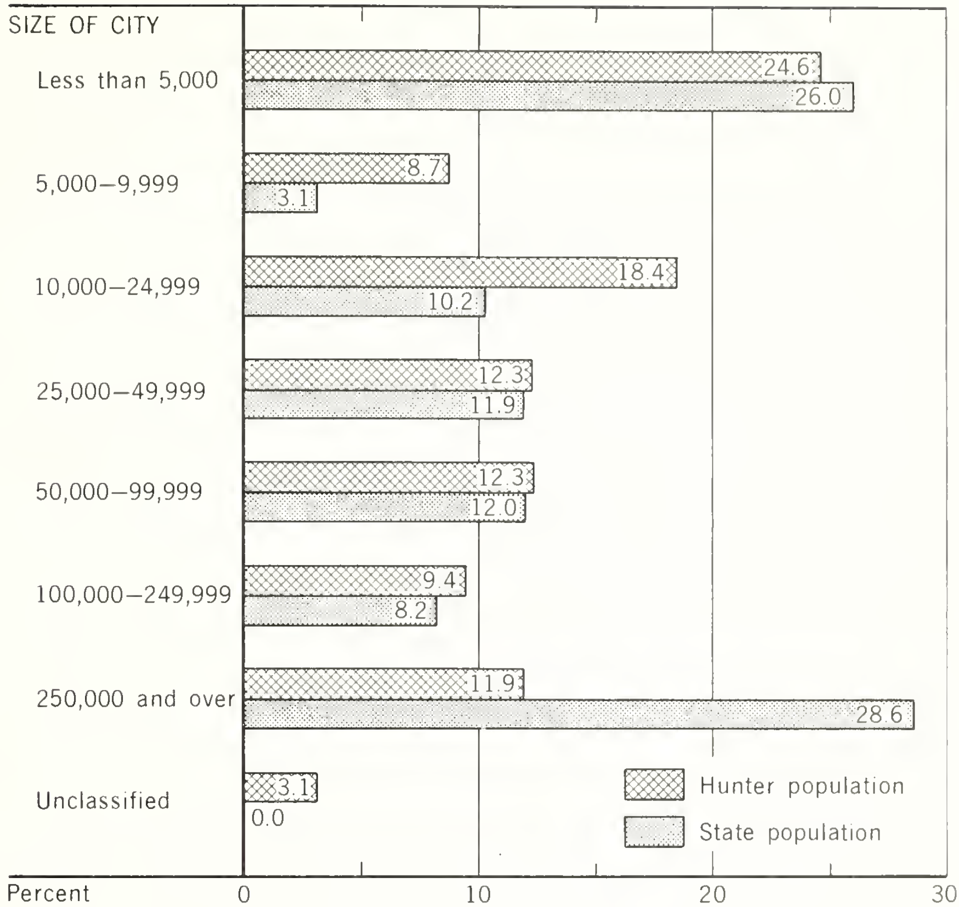

Figure 3.—Percentage distribution of licensed hunters and total population of California by size of city of residence.

from Region II. Twenty-three percent of the hunters from this region bought licenses outside of the region, primarily in Region I. Among the other Regions, the proportions were considerably smaller, varying from 9 percent in Region IV to less than 2 percent in Region I.

On the basis of these figures, the Sacramento area (Region II) would appear to furnish approximately two-thirds of the nonresident hunters in the northern region. Most of the remainder were from the metropolitan counties of the central coast and southern California, each of which accounted for about 5 percent of all purchases in the region. San Joaquin Valley hunters accounted for about half this proportion of the total of license purchasers in the northern California region. In Region II, the bulk of the purchases from out of the region were made by hunters from the central coast and southern California. Out-of-region purchases by San Joaquin Valley hunters were about equally divided between northern and Sacramento Valley regions. All other out-of-region purchases were small and widely distributed.

Occupational Characteristics

Occupations of the hunters cover a wide spectrum. Individual reports include such exotic sounding occupations as choker setter and seaweed inspector. However, when grouped in the customary broad categories, a majority is clustered in the skilled-semiskilled (36 percent) and professional-managerial (18 percent) classifications. A sizable proportion (19 percent) is not in the labor force. Most of the hunters in this latter category are students (fig. 4).

These figures do not take into account the relative size of the different occupation groups in the base population. When considered in terms of the proportion of each occupational group buying a license to hunt, the picture is quite different.

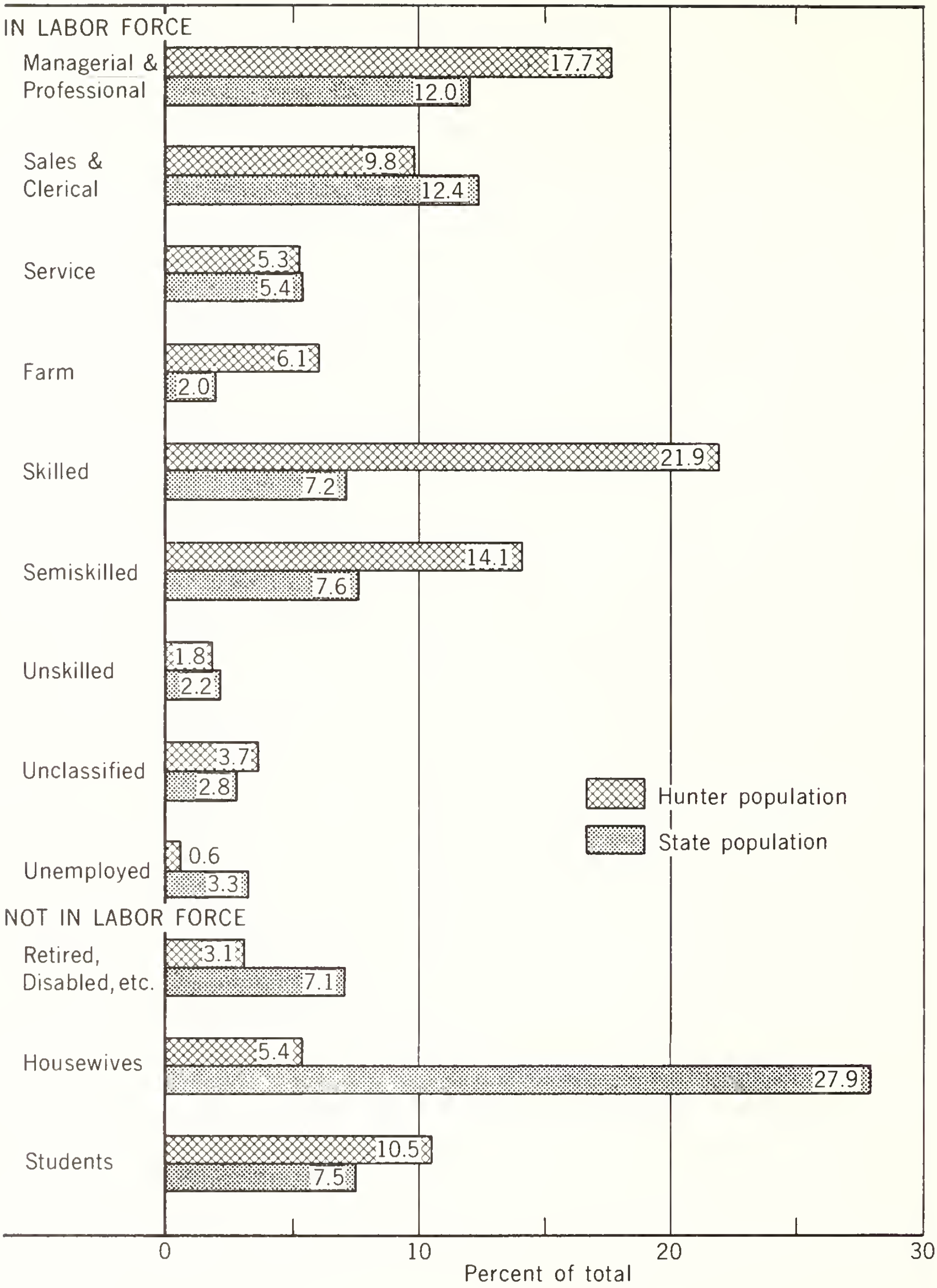

Figure 4.—Percentage distribution of licensed hunters and total population of California by major occupation groups. (Total population includes those 14 years and older.)

The skilled and farm groups rate highest: nearly 1 in 5 of those in each of these occupations purchased licenses. Those in the clerical and sales, unskilled, and service occupations, as well as those unemployed or not in the labor force (except for students) were poorly represented among the licensed hunters in proportion to their numbers in the total population.

The professional-managerial and skilled occupational groupings are highly represented among the hunters from the more urban parts of the State, i.e., Regions III and V. The professional-managerial group is particularly low among the hunters from Region I. Region IV has a high representation of farmers in its hunter population. Housewives and students seem to be influenced more than other groups by their proximity to the better hunting areas of the State. Women from Region I and students from Regions I and II are especially well represented in contrast to other regions.

In summary, hunting is largely a male sport. Residence and age also affect participation. Some types of occupations supply much more than their proportionate share of the hunters.

Knowledge About Fire Prevention

Levels of Knowledge

In general, California hunters appear to be quite well informed about forest fire prevention. The average (mean) score on the two 16-question tests was 78.9 percent correct. The range was from all correct responses to answering 12 out of 15 scorable questions incorrectly.

When scores were grouped by age, residence, and occupation, no significant differences were observed. Educational level, usually a significant variable in questionnaires concerned with knowledge levels, was not known. But educational and occupational levels are usually highly correlated, and consequently one may presume that education would also have shown little relationship to fire-prevention knowledge. Differences among the regions of the State were similarly slight. Region V had the best showing, with an average score of 80.5 percent correct. Region IV's average score of 76.8 was the lowest in the State.

One can only speculate on the reasons for the failure to find a knowledge differential among these groupings. One might presume, for example, that although hunting attracts individuals from all ages and walks of life, this common interest has a leveling effect in selecting out from the general population those who are similarly woodswise. In support of this presumption is the fact that most of the hunters had urban, "indoor" occupations in which no meaningful on-the-job contact with wildland fire-prevention problems or practices could be expected. Their interest in hunting was the one tie they shared in common, and this tie may account for their similar orientation toward uncontrolled wildland fire.

However, one might also question the test instrument. The mean score for all groups, on an absolute basis, was quite high. On a test having 15 scorable items, the *mean* number correct was about 12 items (11.85 percent). It seems reasonable to suppose that one factor limiting the difference between groups of different socio-economic characteristics is the arbitrary ceiling of the test itself. That is, we may have used a test which is too easy and hence does not allow "true" differences to show. Clearly, this cannot be demonstrated to be the case, but the distribution of scores makes the argument plausible. For example, the scores of 21 percent of the professional-managerial group were suppressed by the test ceiling in that they achieved a perfect, or near perfect(got one item incorrect) score, as compared to 15 percent of the semiskilled group.

Specific Items of Knowledge

The two 16-item forms of the questionnaire used in measuring fire prevention knowledge included 26 different questions, with 6 of these occurring in both forms. An item analysis of these questions reveals some of the specific strengths and weaknesses of the hunters' knowledge of fire behavior and good fire safety practice. The questions actually cover several areas of knowledge. They seek to assess the hunters' understanding of fire behavior characteristics, safety practices in the use of fire, and laws regulating use of fire, the importance of fire prevention, and terminology pertaining to fire behavior and prevention.

An examination of the test results indicates that hunters are generally aware of the proper precautions to take with fire. They know that windy weather makes greater wariness of fire necessary; that the surest way to put out a campfire is to cool it with water and bury it with dirt (but there was some indecision as to whether embers should first be drawn together or spread out); that lighted matches require special care in their disposal; and that extra gasoline for the camp stove should be carried in a safety can. They also know that driving a car off the road into dry grass is hazardous and that the combination of high temperature and low humidity increases the need for fire caution.

In contrast, there was considerable confusion as to the amount of forest land in California and the ownership of it. The general opinion was that the State contains more forest land than actually exists and that it belongs mostly to the Federal Government. About 27 percent did not know that the green trees and shrubs of California burn readily. There was also uncertainty over the time of day that forest fires spread most rapidly; and among those who gave the correct answer, 60 admitted they had guessed.

More than 95 percent of the respondents know that individuals who start forest fires as a result of personal negligence have a civil liability for their action, but only 73 percent know there is any criminal liability for such an act.

Although most hunters are familiar with the term "humidity," about one hunter in five doesn't know what the term "closed area" means. A similar proportion does not know what California foresters mean by "watershed."

Two-thirds of the hunters picked smokers' cigarettes and matches as the principal cause of forest fires. About 20 percent selected lightning as the principal cause.

When presented with several choices including "more men and equipment" and "better fire prevention techniques," 98 percent of the respondents recognized that the prevention of man-caused forest fires ultimately depends on public cooperation and personal responsibility.

The question concerning the most important reason for fire prevention has no one "right" answer. In one section of the State "regulation of the flow of water" is of transcendent importance; in another, "conservation of forests for wood products" takes precedence over any other reason. The hunters appeared to be influenced by the situational nature of the question. An analysis of their opinions revealed that choice of alternative was closely related to the hunter's place of residence. Those living in areas where commercial lumbering is a major industry by and large picked the alternative referring to utilization of wood products. Those from the larger population centers and the more arid areas were most likely to feel regulating water flow was of major importance.

Only 8 percent of the hunters selected "protection of wildlife" as the most important reason for fire prevention. One might have expected hunters to have a special concern for this alternative. Their response may, of course, reflect the current controversy regarding the use of burning in wildlife habitat management.

"Preservation of recreation areas" did not rank high in any area, but it was given more importance in metropolitan areas than it was in rural areas.

Distribution of responses to individual questions from both test forms are found in Appendix 2.

In general, the responses of the hunters in this study were similar to those found in previous studies of other forest-using groups.[7]

Sources of Knowledge

One of the objectives of this study was to determine where the respondents obtained their knowledge of forest fire prevention. Following the questions testing the respondents' knowledge, there appeared on the questionnaire the question, "Where did you get your principal fire safety information?" A list of 12 possible sources of information followed this question, and the respondents were requested to check one or more sources. The specific sources were derived from free responses to pretest questions. The 12 sources listed were: forest ranger, newspaper, magazine, school, friend or relative, scouting, laws, signs, television, radio, Smokey Bear, and business establishment. Provision was also made for "other" responses.

One of the most obvious and significant observations from the analysis of the sources of fire prevention knowledge is that most hunters recognize a number of sources. On the average, the hunters checked between three and four different sources of fire safety information. Less than two percent (61 persons) failed to indicate a source and only 16 percent checked a single source. Eleven persons (representing less than one-half of one percent of the respondents) indicated a possible lack of discrimination by checking all of the sources.

In an earlier study, an attempt was made to determine sources of knowledge through the use of a non-directive, or free response, type of question. This resulted in a high incidence of non-definitive responses—that is "common sense" and "experience" accounted for 50 to 70 percent of the total sources mentioned.[6] By providing a check list of

[7]Chandler, Craig C., and Davis, James B. What do people know about fire prevention? U.S. Forest Serv. Pacific SW. Forest & Range Expt. Sta. Misc. Paper 50, 4 pp. 1960.

[6]Herrmann, W. W. Progress report on research activities relevant to human behavior aspects of forest fire prevention. Univ. S. Calif. 188 pp., 1959.

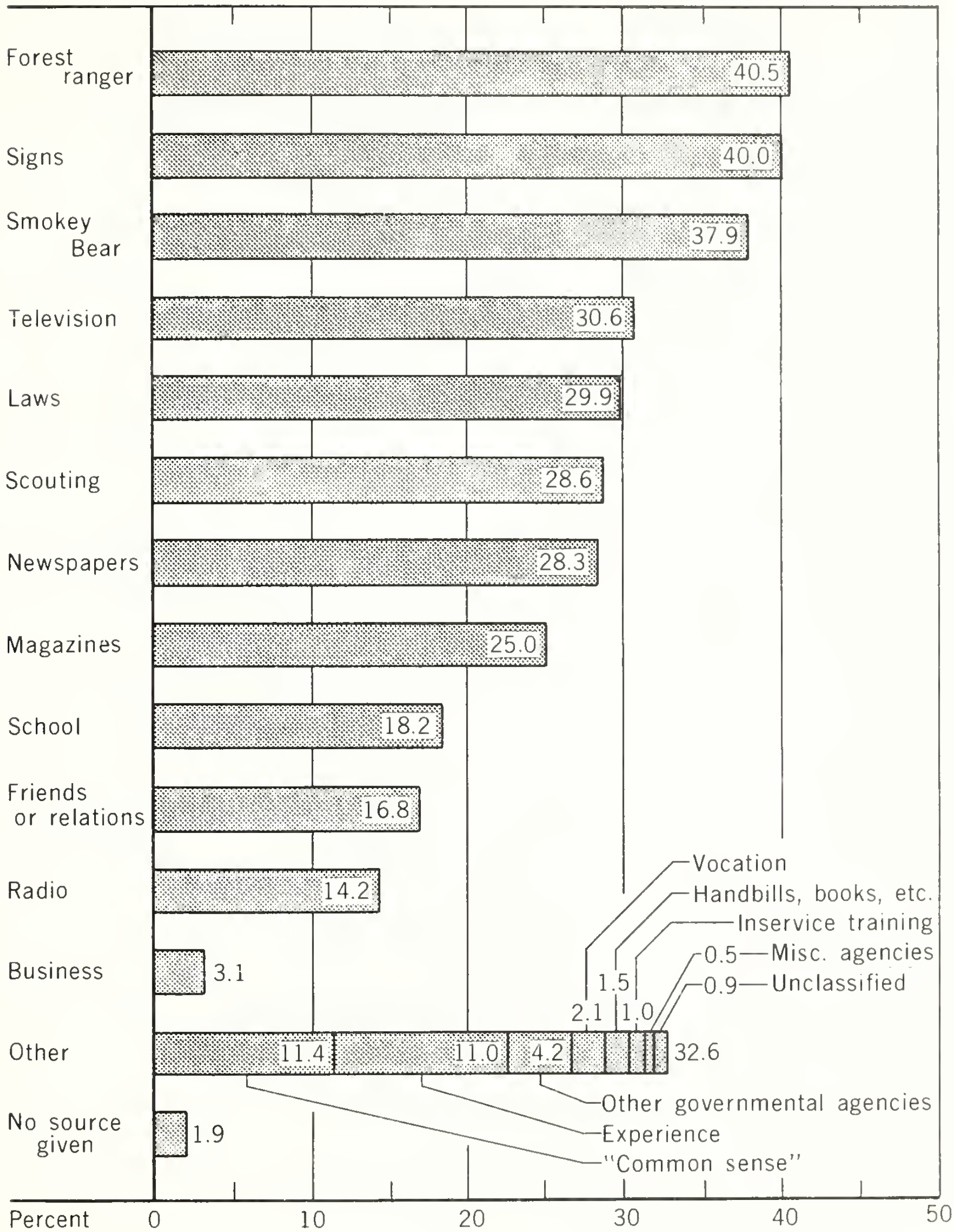

Figure 5.—Percentage distribution of sources of forest fire safety information reported by licensed hunters in California. Percentages do not add as multiple responses were possible.

specific sources from which to choose, the incidence of such non-definitive responses was reduced to less than 6.5 percent of the total sources mentioned.

"Forest ranger," "signs," and "Smokey Bear" were the most frequently reported sources of fire safety information (fig. 5). About 2 out of 5 hunters reported each of these sources. Together, these three sources accounted for a third of the total number of sources reported.

Each of the mass media (television, newspapers, and magazines), along with scouting experience and laws pertaining to fire prevention, were credited about equally as sources of information about fire safety. Together, these sources accounted for about 40 percent of the selections.

The school with its conservation programs might be expected to have been identified as a significant source of fire safety information. That it was so identified by so few hunters in this study should not be interpreted to discount its role in establishing positive knowledge and attitude levels regarding fire prevention. For most hunters, this exposure has not been recent. More immediate exposure to other information sources may tend to stand higher in conscious awareness but may not have actually effected as profound or lasting changes in basic knowledge and attitude levels. On the other hand, the contrast between the frequency of choice of schools and scouting, both essentially equal in terms of chronology of exposure, indicates that conservation played a much stronger role in the scouting program than it did in the school curriculum at the time these hunters were being exposed to both.

The influence of friends and relatives in disseminating fire safety information was checked fewer times than schools. Radio does not share the importance attributed to the other mass communications media. Business establishments do not serve as principal sources of fire safety information for many hunters.

Since most of the respondents (72.3 percent) checked more than one of the sources of information on the questionnaire, this limits somewhat the discreet measurement of the relative significance of the individual sources. This comparative analysis of the sources has, of necessity, been in terms of the *relative frequency* with which the various sources were checked.

When forest ranger, school, friend or relative, scouting, and business were grouped together as sources suggesting face-to-face contact with another person, they constituted 69.4 percent of the total selected. In contrast, the mass communication media (newspaper, magazines, television, and radio) accounted for 51.1 percent of the total. The relationship remained constant for all regions. This difference between the face-to-face and more diffuse sources takes on added significance when it is recognized that studies in communication have been consistent in demonstrating the primacy of face-to-face contact in influencing human behavior.

Although not studied in this phase of the project, the credibility of various sources also plays an important part in the extent to which information is accepted. This is an area of study that must be considered in future research.

The various sources maintained about the same rank order when the data were examined by regions (table 1). Generally, such changes as did occur represent transpositions of adjacent items. At most, there were differences of only two positions from that of the total. For example, the three sources of knowledge—forest ranger, signs, and Smokey Bear—led all other sources in frequency of mention in all five regions, with forest ranger ranked first in Regions I and II, and second in the other three regions. Signs ranked first in Regions IV and V, second in Region II, and third in Regions I and III. Smokey Bear ranked first only in Region III, second in Region I, and third in the other regions.

Laws as a source of knowledge ranked fourth in Region IV, but dropped to seventh in Regions II and III. Scouting was tied for fourth place with TV in Region III, but ranked only sixth in the other regions. Newspapers ranked fifth as a source in Region II, in contrast to seventh in all other regions. On the other hand, magazines, which ranked eighth among all the other regions, dropped to tenth place in Region I.

There was considerable variation among regions as to the proportions indicating specific sources. In Region IV, for example, 46.5 percent of the hunters chose the first ranked source—signs. In contrast, only 37.1 percent of the hunters in Region I chose their first ranked source — forest ranger (table 1).

Summary of Conclusions

Personal Characteristics of the California Hunter

Hunting is essentially a male sport. Only seven percent of the California hunter population are women. Residence and age also affect participation. Over half of the hunters (52 percent) live in places under 25,000 in population and only 12 percent live in cities of 250,000 or more.

The average age of the hunters in the State is 37.1 years; about 4 out of 5 are under 50 years of age. Female hunters average about a year younger than their male colleagues, and hunters who come from urban areas are on the whole slightly younger than those who are rural residents.

A wide variety of occupations are represented among the hunter population, but some types are more highly represented than others. More than one-fifth are in the skilled labor class, and only slightly less are professionals or in management positions. The semi-skilled and the students are other highly represented groups.

Most hunters buy their hunting license close to home, but many wait until they go to the more popular deer hunting areas. Most hunters (67 percent) also purchased fishing licenses in 1960.

Level of Knowledge

In general California hunters know quite a lot about forest fire prevention. The average score achieved on the questionnaire was 79 percent. The test instrument did not reveal any significant

Table 1. Rank order of sources of knowledge by regions[1]

Rank order of mention	Region I	Region II	Region III	Region IV	Region V	Total
1	Forest Ranger (37.1)	Forest Ranger (38.6)	Smokey Bear (41.1)	Signs (40.9)	Signs (46.5)	Forest Ranger (40.6)
2	Smokey Bear (34.2)	Signs (36.6)	Forest Ranger (40.3)	Forest Ranger (39.7)	Forest Ranger (43.4)	Signs (40.3)
3	Signs (32.6)	Smokey Bear (32.9)	Signs (37.8)	Smokey Bear (36.5)	Smokey Bear (41.7)	Smokey Bear (38.5)
4	T. V. (32.0)	T. V. (31.2)	Scouting (28.9)	T. V. (31.6)	Law (33.0)	T. V. (31.1)
5	Law (31.6)	Newspaper (29.3)	T. V. (28.9)	Law (29.4)	T. V. (32.3)	Law (30.0)
6	Scouting (26.5)	Scouting (27.5)	Newspaper (28.4)	Scouting (25.6)	Scouting (31.3)	Scouting (28.7)
7	Newspaper (25.9)	Law (27.0)	Law (28.3)	Newspaper (25.4)	Newspaper (29.9)	Newspaper (28.4)
8	School (23.3)	Magazine (19.8)	Magazine (28.1)	Magazine (23.0)	Magazine (29.0)	Magazine (25.1)
9	Friends (19.5)	Friends (18.8)	School (19.4)	School (19.2)	School (16.6)	School (18.2)
10	Magazine (17.6)	School (15.9)	Friends (16.6)	Radio (16.2)	Friends (15.4)	Friends (16.8)
11	Radio (15.6)	Radio (14.4)	Radio (14.4)	Friends (15.8)	Radio (14.6)	Radio (14.8)
12	Business (4.1)	Business (2.7)	Business (3.7)	Business (3.2)	Business (2.4)	Business (3.1)

[1] *Figures in parentheses represent percent indicating this source. Percentages do not add as multiple responses were possible.*

differences between the knowledge levels of the different age, sex, residence, and occupation classifications studied. This may mean that hunters are actually quite homogeneous in their understanding of fire prevention matters. Although they come from varied backgrounds, this common interest may serve to select out those who are similarly woodswise.

Although their answers revealed a rather high awareness of the proper precautions to be taken with fire in the woods, they also showed considerable confusion concerning other related areas of knowledge. The flammability of green plant materials and the time of day when forest fires spread most rapidly are examples of items about which a significant number of hunters were uninformed. Technical terms, such as "closed area" and "watershed" were unfamiliar to about one-fifth of the hunters.

Sources of Information About Fire Prevention

The California hunter receives information on forest fire prevention from a variety of sources, the most frequently reported being forest rangers, signs, and Smokey Bear. But no single source stands out as the most generally selected; most hunters recognized several sources from which they receive this type of information. They checked sources requiring face-to-face contact more frequently than the more impersonal sources involving the mass communications media or reading ability.

Recommendations

1. With 93 percent of the hunter population male, major prevention efforts should be framed to appeal to male interests and directed through channels serving men. At the same time, the women, who may represent a sizable minority in hunting camps, should not be wholely ignored in planning prevention programs.

2. Programs through civic and service clubs probably reach a significant number of hunters from the professional and managerial occupations. Greater effort would appear desirable in attempting to establish closer contact with the skilled and semiskilled workers who make up such a large proportion of the hunter population in the State. Labor union meetings and industry-sponsored employee activities are possible means of directly approaching these people.

Union, as well as professional magazines, and industrial house organs may be useful additional media through which to present fire prevention messages. High school and college newspapers should be considered as channels for reaching the significant student segment of the hunter population. Study of the reading habits of these young people, and other groups, is needed to determine other promising outlets for fire prevention messages.

3. In general, the hunters know most of the information tested in this study. However, in addition to teaching *what* is adequate caution with fire, perhaps more emphasis should be placed on *how* this care is to be taken. It is apparent, also, that greater attention should be given to the wording of fire prevention messages. If terms more familiar to the layman cannot be found, then more effort must be made to acquaint him with the terms that are used.

If it is deemed operationally desirable, it appears fire prevention messages should stress the following specific points:

a. *Spreading* of embers before cooling with water and covering with dirt.
b. How much of California is forest land.
c. Green trees and shrubs of California burn *readily*.
d. Fires spread most rapidly from 10:00 a.m. to sundown.
e. *Criminal liability* of individuals who are negligently responsible for a forest or wildland fire.
f. The definition of the term "watershed."
g. The chief causes of man-caused forest and wildland fires are smokers' cigarettes and matches.
h. The meaning of the term "closed area."

4. Choice of the "most important" reason for preventing fire varied geographically. This suggests that fire prevention appeals can be slanted to conform with local values in this matter. If this were done, fire prevention messages in northern California (Region I) should stress the importance of

protecting forest areas to prevent loss of wood products, and messages elsewhere in the State (Regions II, III, IV, and V) should highlight loss of water. Protection of wildlife, as a primary purpose of fire prevention, does not appear promising as a message for use among hunters.

5. Failure to know who owns forest land in California may affect understanding and identification with the seriousness of fire loss; ownership should be communicated to hunters.

6. Since many of those who hunt in Region I do not live there, fire prevention efforts relative to the region must cover a broader geographical area or must be intensive during the hunting season, when hunters are present within the region, to reach those who hunt there. This is also true in other regions but to a lesser degree.

7. The role of man as a primary cause in forest and wildland fires should continue to be stressed in fire prevention messages. One hunter in five listed lightning as the primary causative agent. Some persons have difficulty rejecting this idea because their point of reference is to a limited, specific area, such as the higher elevations of the Sierra, where human use is not intense, but summer thunderstorm activity is frequent. Here lightning *is* the major cause of fire. Explicit recognition of this situational variability in major cause of forest fires may increase the credibility of the overall program.

INSTRUCTIONS—
Check the one most appropriate answer for each question and whether *very certain, fairly certain* or *uncertain* of your answer.
Please detach this portion and mail. No postage is required. Thank you.

1. "A fire is more apt to start where there is:
   a ☐ low temperature and low humidity
   b ☐ high temperature and low humidity
   c ☐ high temperature and high humidity
   d ☐ low temperature and high humidity."
☐ Very certain ☐ Fairly certain ☐ Uncertain

2. "The time of day that forest fires typically will spread most rapidly is:
   a ☐ sundown to midnight
   b ☐ Midnight to sunrise
   c ☐ 10:00 a.m. to sundown
   d ☐ Sunrise to 10:00 a.m."
☐ Very certain ☐ Fairly certain ☐ Uncertain

3. "Fire prevention efforts in the forests:
   a ☐ are everyone's business
   b ☐ are money well spent
   c ☐ are necessary
   d ☐ all of these are correct."
☐ Very certain ☐ Fairly certain ☐ Uncertain

4. "The term, 'forest fire,' means a fire which is burning out of control on lands covered wholly or in part by:
   a ☐ timber and brush only
   b ☐ timber only
   c ☐ timber, brush and grass only
   d ☐ timber, brush, grain, or other flammable vegetation."
☐ Very certain ☐ Fairly certain ☐ Uncertain

5. "How does fire burn in the rotten vegetation found on the forest floor?
   a ☐ it burns very rapidly—almost like a dry gunpowder train
   b ☐ it smolders slowly as in 'punk' or 'cotton' with little or no visible smoke
   c ☐ it burns slowly along the top of the ground with easily detected production of smoke
   d ☐ it will not burn at all."
☐ Very certain ☐ Fairly certain ☐ Uncertain

6. "Watersheds are:
   a ☐ Areas where rain falls or snow melts to supply water to springs and creeks
   c ☐ Covered reservoirs
   c ☐ Buildings with gutters that run water to a cistern
   d ☐ Lakes and reservoirs which collect the water run-off from forests."
☐ Very certain ☐ Fairly certain ☐ Uncertain

7. "Where you drive your car off the road in dry grass areas:
   a ☐ exhaust sparks can cause fire
   b ☐ sparks made by contact of metal parts of the car and rocks can set fires
   c ☐ both a and b are correct
   d ☐ it cannot start a fire."
☐ Very certain ☐ Fairly certain ☐ Uncertain

8. "Prevention of forest fires is important to all of the following. In this area the most important is the:
   a ☐ Conservation of forest for wood products
   b ☐ Protection of wildlife
   c ☐ Regulation of flow of water
   d ☐ Preservation of recreation areas."
☐ Very certain ☐ Fairly certain ☐ Uncertain

9. "If you take extra gasoline for your camp stove, you should carry the gasoline in:
   a ☐ glass jar or jug
   b ☐ safety can
   c ☐ container in which flammable liquids were purchased
   d ☐ plastic containers such as used in the kitchen."
☐ Very certain ☐ Fairly certain ☐ Uncertain

10. "Which of the following is ordinarily the slowest burning material?
   a ☐ dry grass
   b ☐ dead leaves
   c ☐ brush
   d ☐ logs."
☐ Very certain ☐ Fairly certain ☐ Uncertain

11. "If you are negligent with your campfire or warming fire and it escapes to the property of another, whether privately or publicly owned, you are:
   a ☐ Not liable for damages
   b ☐ Criminally liable, but no civil liability
   c ☐ Civilly liable, but no criminal liability
   d ☐ Both criminally and civilly liable."
☐ Very certain ☐ Fairly certain ☐ Uncertain

12. "The best place to inquire about areas where campfires may be built in our forests is a:
   a ☐ sheriff's substation
   b ☐ service station
   c ☐ ranger station
   d ☐ camp store."
☐ Very certain ☐ Fairly certain ☐ Uncertain

13. "Having in your possession, on or firing across brush covered or forest lands, a tracer bullet or tracer charge:
   a ☐ is not against the law
   b ☐ is unlawful and punishable by a fine
   c ☐ is unlawful and punishable by a jail sentence
   d ☐ is unlawful and punishable by both a fine and a jail sentence."
☐ Very certain ☐ Fairly certain ☐ Uncertain

14. "Prevention of man-caused fires ultimately depends upon:
   a ☐ More men and equipment
   b ☐ More and better equipment
   c ☐ Public cooperation and recognition of personal responsibility
   d ☐ Better techniques of fire fighting with the equipment we have."
☐ Very certain ☐ Fairly certain ☐ Uncertain

15. "A sign in a National Forest that reads 'Closed Area' means:
   a ☐ that you may enter, but not smoke in the area
   b ☐ you may enter, but not build any camp fires in the area
   c ☐ you may not enter the area
   d ☐ no hunting or shooting within the area."
☐ Very certain ☐ Fairly certain ☐ Uncertain

16. "The safest method for lighting cigarettes in the forest area is to use:
   a ☐ book type safety matches
   b ☐ the strike anywhere stick type matches
   c ☐ stick type safety matches
   d ☐ a cigarette lighter."
☐ Very certain ☐ Fairly certain ☐ Uncertain

Where did you get your principal fire safety information: Check 1 or more.

☐ Forest Ranger
☐ Newspaper
☐ Magazine
☐ School
☐ Friend or relative
☐ Scouting
☐ Laws
☐ Signs
☐ Television
☐ Radio
☐ Smokey Bear
☐ Business establishment
☐ Other (specify)............

Did you also have a 1959-1960 California Fishing License? ☐ Yes ☐ No

For purposes of classification of your replies please supply the following information:

Age............Sex............

Occupation............

....

City of residence

....

County of residence

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School of Public Administration
Forest and Range Research Project
University Park
Los Angeles 7, California

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To

AN INVITATION TO PARTICIPATE IN RESEARCH AT USC

UNIVERSITY OF SOUTHERN CALIFORNIA
SCHOOL OF PUBLIC ADMINISTRATION
FOREST AND RANGE RESEARCH PROJECT

California Sportsman:

Did you know that nine out of ten forest fires in the State of California are caused by people? As one of the 680,000 licensed hunters who enjoy and use hunting areas in California, *YOU* have a direct and personal interest in the conservation of forest and wildland regions within this State. The University of Southern California is cooperating in a program of research aimed at preventing the needless destruction of our valuable forest areas. A limited number of sportsmen are being requested to participate in this research.

You can help the University by completing and returning the attached form. By doing so, *YOU* will be taking an active part in assuring better hunting in the future. You will also be contributing your knowledge to the search for solutions to the critical problem of forest fire prevention. In this case, haste does *not* make waste—please answer and return the questions today.

Thank You,

Dr. W. W. Herrmann
Director
Forest and Range Research Project

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APPENDIX 2

Table 2. Percentage distributions of responses to individual questions, Test Form A and B

Question	Percent
Form A(n = 1690)	
1. (Form B – #8) Prevention of forest fires is important to all of the following. In this area the most important is:	
a. Conservation of forest for wood products	24.1
b. Protection of wildlife	8.1
c. Regulation of flow of water	53.3
d. Preservation of recreation areas	7.7
Other	7.4
Very certain correct response	--
2. Humidity is a measure of:	
a. Temperature of the air	2.2
b. Amount of rainfall that has fallen in the last 24 hours	.4
c. Percentage of cloudiness during the daylight hours	.2
*d. Amount of moisture in the air	96.3
Other	1.0
Very certain correct response	90.7
3. The surest way to put out a campfire, assuming all these 'methods' are available, is:	
*a. Spread out the embers, cool with water, and cover with dirt	74.0
b. Pull the embers together, cool with water, and cover with dirt	24.9
c. Spread out the burning embers and let it burn itself out	.6
d. Let it alone and it will burn itself out	.1
Other	.4
Very certain correct response	85.5
4. Windy weather:	
a. Tends to put out campfires	.3
b. Affects only poorly built campfires	.1
*c. Makes necessary more precautions with campfires	99.2
d. Has little or no influence on campfires	.1
Other	.3
Very certain correct response	96.2
5. (Form B – #14) Prevention of man-caused fires ultimately depends on:	
a. More men and equipment	.4
b. More and better equipment	.2
*c. Public cooperation and recognition of personal responsibility	97.5

Table 2. Percentage distributions of responses to individual questions, Test Form A and B, continued

Question	Percent
d. Better techniques of fire fighting with the equipment we have	1.5
Other	.5
Very certain correct response	93.3
6. The chief cause of forest fires in California is:	
a. Lightning	20.5
b. Campfires	7.0
c. Children with matches	.5
*d. Smoker's cigarettes and matches	66.3
Other	5.7
Very certain correct response	34.6
7. (Form B – #6) Watersheds are:	
*a. Areas where rain falls or snow melts to supply water to springs and creeks	81.1
b. Covered reservoirs	2.5
c. Buildings with gutters that run water to a cistern	1.6
d. Lakes and reservoirs which collect the water run-off from forests	13.4
Other	1.4
Very certain correct response	75.7
8. (Form B – #2) The time of day fires typically will spread most rapidly is:	
a. Sundown to midnight	11.3
b. Midnight to sunrise	3.3
*c. 10:00 a.m. to sundown	79.5
d. Sunrise to 10:00 a.m.	4.1
Other	1.9
Very certain correct response	43.2
9. In areas where open fires are permitted, campfires or warming fires are less dangerous when built:	
a. Against a log	.5
*b. In a cleared-off area	99.0
c. At the base of a tree	.1
d. On the crest of a hill	.3
Other	.1
Very certain correct response	90.6
10. (Form B – #11) If you are negligent with your campfire or warming fires and it escapes to the property of another, whether privately or publicly owned, you are:	
a. Not liable for damages	.5
b. Criminally liable, but no civil liability	2.1
c. Civilly liable, but no criminal liability	25.6
*d. Both criminally and civilly liable	70.2
Other	1.7

Table 2. Percentage distributions of responses to individual questions, Test Form A and B, continued

Question	Percent
Very certain correct response	36.3
11. Green trees and shrubs of California:	
a. Are very difficult to burn	6.6
b. Will not burn at all	.1
*c. Will catch fire and burn very rapidly	72.8
d. Will burn only in the hot summer months	19.3
Other	1.3
Very certain correct response	60.0
12. When you are in a National Forest area, the law permits you to:	
a. Never smoke or build campfires	.8
b. Smoke but never build campfires	.5
*c. Smoke and build campfires, but only in areas so designated	97.6
Other	.5
Very certain correct response	83.4
13. The poorest way to put out a match is:	
a. Blow it out and break it in half	9.2
b. Spit on it	.5
*c. Throw it out the car window and let the wind blot it out	48.9
d. Throw it on the ground	39.0
Other	2.4
Very certain correct response	81.2
14. (Form B – #4) The term 'forest fire' means a fire which is burning out of control on lands covered wholly or in part by:	
a. Timber and brush only	17.4
b. Timber only	3.1
c. Timber, brush and grass only	22.6
*d. Timber, brush, grass, grain, or other flammable vegetation	56.3
Other	.6
Very certain correct response	50.7
15. If all the forests in the State should burn, what percentage of the State's area do you think would be burned?	
a. 40 percent	.7
b. 8 percent	3.4
*c. 20 percent	32.1
d. 32 percent	62.1
Other	1.8
Very certain correct response	2.6
16. Who owns this forest land?	
a. No one	.5

Table 2. Percentage distributions of responses to individual questions, Test Form A and B, continued

Question	Percent
b. Mostly large lumber companies	1.2
c. Mostly the Federal government	48.0
*d. About half Federal and half private	48.5
Other	1.9
Very certain correct response	12.2
Form B (n = 1570)	
1. A fire is more apt to start where there is:	
a. Low temperature and low humidity	1.1
*b. High temperature and low humidity	81.7
c. High temperature and high humidity	15.8
d. Low temperature and high humidity	.6
Other	.9
Very certain correct response	73.2
2. (Form A – #8) The time of day that forest fires typically will spread most rapidly is:	
a. Sundown to midnight	8.5
b. Midnight to sunrise	2.4
*c. 10:00 a.m. to sundown	83.9
d. Sunrise to sundown	3.0
Other	1.7
Very certain correct response	47.9
3. Fire prevention efforts in the forests:	
a. Are everyone's business	15.4
b. Are money well spent	0
c. Are necessary	1.0
*d. All of these are correct	77.2
Other	--
Very certain correct response	90.8
4. (Form A – #14) The term 'forest fire' means a fire which is burning out of control on lands covered wholly or in part by:	
a. Timber and brush only	16.4
b. Timber only	4.3
c. Timber, brush, and grass only	24.0
*d. Timber, brush, grain, or other flammable vegetation	53.6
Other	1.7
Very certain correct response	56.7
5. How does fire burn in the rotten vegetation found on the forest floor?	
a. It burns very rapidly--almost like a dry gunpowder train	14.5
*b. It smolders slowly as in 'punk' or 'cotton' with little or no visible smoke	61.7

Table 2. Percentage distributions of responses to individual questions, Test Form A and B, continued

Question	Percent
c. It burns slowly along the top of the ground with easily detected production of smoke	21.7
d. It will not burn at all	.3
Other	1.8
Very certain correct response	44.5
6. (Form A — #7) Watersheds are:	
*a. Areas where rain falls or snow melts to supply water to springs and creeks	85.7
b. Covered reservoirs	1.4
c. Buildings with gutters that run water to a cistern	1.4
d. Lakes and reservoirs which collect the water run-off from forests	9.9
Other	1.7
Very certain correct response	79.4
7. Where you drive your car off the road in dry grass areas:	
a. Exhaust sparks can cause a fire	14.8
b. Sparks made by contact of metal parts of the car and rocks can set fires	2.3
*c. Both a and b are correct	74.1
d. It cannot start a fire	2.2
Other	6.6
Very certain correct response	75.8
8. (Form A — #1) Prevention of forest fires is important to all of the following. In this area the most important is:	
a. Conservation of forest for wood products	26.9
b. Protection of wildlife	5.8
c. Regulation of flow of water	46.9
d. Preservation of recreation areas	6.9
Other	13.5
9. If you take extra gasoline for your camp stove, you should carry the gasoline in:	
a. Glass jar or jug	.3
*b. Safety can	88.2
c. Container in which flammable liquids were purchased	10.5
d. Plastic containers such as used in the kitchen	0
Other	1.0
Very certain correct response	86.4

Table 2. Percentage distributions of responses to individual questions, Test Form A and B, continued

Question	Percent
10. Which of the following is ordinarily the slowest burning material?	
a. Dry grass	.6
b. Dead leaves	9.4
c. Brush	1.1
*d. Logs	88.0
Other	.8
Very certain correct response	70.0
11. (Form A — #10) If you are negligent with your campfire or warming fire and it escapes to the property of another, whether privately or publicly owned, you are:	
a. Not liable for damage	.3
b. Criminally liable, but no civil liability	1.7
c. Civilly liable, but no criminal liability	23.6
*d. Both criminally and civilly liable	72.8
Other	1.6
Very certain correct response	43.1
12. The best place to inquire about areas where campfires may be built in our forests is a:	
a. Sheriff's substation	.1
b. Service station	.1
*c. Ranger station	99.4
d. Camp store	.2
Other	.3
Very certain correct response	92.5
13. Having in your possession, on or firing across brush covered or forest lands, a tracer bullet or tracer charge:	
a. Is not against the law	1.0
b. Is unlawful and punishable by a fine	11.9
c. Is unlawful and punishable by a jail sentence	1.5
*d. Is unlawful and punishable by both a fine and a jail sentence	83.7
Other	1.9
Very certain correct response	43.2
14. (Form A — #5) Prevention of man-caused fires ultimately depends upon:	
a. More men and equipment	.8
b. More and better equipment	.3
*c. Public cooperation and recognition of personal responsibility	96.4
d. Better techniques of fire fighting with the equipment we have	1.0

Table 2. Percentage distributions of responses to individual questions, Test Form A and B, continued

Question	Percent
Other	1.6
Very certain correct response	89.8
15. A sign in a National Forest that reads 'Closed Area' means:	
a. That you may enter, but not smoke in the area	3.1
b. You may enter, but not build any campfires in the area	6.3
*c. You may not enter the area	77.8
d. No hunting or shooting within the area	10.6
Other	2.2
Very certain correct response	59.6
16. The safest method for lighting cigarettes in the forest area is to use:	
a. Book type safety matches	5.7
b. The strike anywhere stick type matches	.1
c. Stick type safety matches	5.2
*d. A cigarette lighter	87.5
Other	1.5
Very certain correct response	40.2

* *Indicates correct response. Form A, question 1 (same as Form B, question 8) had no one correct answer.*

GPO 968-217

Wood Density and Growth of Some Conifers Introduced to Hawaii

Roger G. Skolmen

. S. FOREST SERVICE RESEARCH PAPER PSW-12 1963

PSW

Pacific Southwest Forest and Range
Experiment Station - Berkeley, California
Forest Service - U. S. Department of Agriculture

CONTENTS

The Author

Roger G. Skolmen's first Forest Service assignment, in 1959, was as a member of the Experiment Station's soil-vegetation survey in Berkeley and Arcata, California. In early 1961, he joined the station's research staff in Honolulu, Hawaii, where he has been investigating the uses, properties, and processing of forest products. A native of San Francisco, he holds bachelor's and master's degrees in forestry from the University of California, Berkeley.

Each year Hawaii imports 70 to 100 million board feet of lumber. Of this amount, about 92 percent is softwood.[1])bviously, locally produced softwood construc- ion lumber would find a ready market if it could ompete with imports in quality and price.

Since conifers are not native to Hawaii, the eed for a local supply of coniferous timber pecies was recognized as early as the late 1880's Territory of Hawaii 1903). During the past 80 ears many potentially suitable conifers have been ıtroduced and planted experimentally. Most trial lantings have failed, but a few species have grown vell in certain locations and some are now being lanted fairly extensively. Stands and stand rem- ants from the original plantings may be found n all the islands, but most commonly on Hawaii nd Maui.

With the growing interest in the quality of wood eing produced in Hawaii, the B. P. Bishop Es- ıte in 1952 arranged for tests of Hawaii-grown edwood *(Sequoia sempervirens)* at the U.S. For- st Products Laboratory in Madison, Wisconsin. Redwood from Hawaii was found to be very similar to second-growth redwood from California (Youngs 1960). In 1958 the Forest Products Laboratory tested wood from a slash pine *(Pinus elliottii)* grown near Olinda, Maui.[2] The wood proved to be suited for millwork and pattern stock, but not for construction—the main use of softwood in Hawaii. It resembled sugar pine *(P. lambertiana)* or eastern white pine *(P. strobus)*, rather than normal slash pine, both in appearance and in strength properties. Its specific gravity was 0.35—an excellent indicator of low strength properties. Mainland slash pine has a specific gravity of 0.56; sugar pine, 0.35; and eastern white pine, 0.34.

The exploratory tests of slash pine indicated that growth conditions in Hawaii might produce unusual variations in wood quality. It was necessary to determine the extent of these variations as a guide to forestation programs.

This paper reports on a study of the specific gravity and growth characteristics of 14 coniferous species under several site conditions in Hawaii.

Effects of Environment

Many aspects of the environment in Hawaii re quite different from those of the temperate egions from which most conifers were introduced. he State has a semitropical climate. It is warm ıroughout the year at low elevations and cool ıroughout the year at higher elevations. Forests ınge in elevation from sea level to about 8,000 et. Seasonal and diurnal temperature fluctua- ons are small. Daylength (sunlight) varies only bout 2 hours from winter to summer. Strong winds are common in many locations throughout the year. Rainfall is extremely variable. Some areas receive 400 inches annually, others less than 20. Some areas are almost constantly shrouded in mist so that sunlight seldom reaches the forest. Soils usually exhibit phosphate deficiency. Potash is also often unavailable owing to a high exchangeable magnesium content. Highly exchangeable manganese may interfere with iron uptake by plants.

Under these variable conditions, many species planted have developed unusual forms. Some are greatly deformed (fig. 1), some have oddly shaped crowns and branching habit, but may still be considered potential timber trees (fig. 2), and others have normal form and grow as well as or better than in their native habitat (fig. 3).

[1] Lucas, E. Evaluation of market data as a guide for orest development in Hawaii. 1963. (Unpublished mas- r's thesis on file at Dept. Agr. Econ. Univ. Hawaii, onolulu.)

[2] Bohr, A. W. A few strength tests on *Pinus elliottii* om Hawaii. 1958. (Unpublished report on file at Forest od. Lab., U.S. Forest Serv., Madison, Wis.)

Because environment affects tree growth, it probably also affects wood quality. Wood within the live crown portion of stems has a lower specific gravity than wood near the base of high-crowned trees (Larson 1962). Thus, the wood of open-grown trees, with live crowns extending to the ground, will have a lower specific gravity at breast height than the wood of short-crowned trees in dense stands. Crown size and vigor also affect specific gravity; thus, dominant trees generally produce less dense wood than somewhat suppressed trees.

Intraspecific variation within the wide ranging species brought to Hawaii is an important factor. For example, lowland variants planted at higher elevations will have a longer growing season than trees native to the higher elevation, and thus will produce weaker wood (Larson 1962). In Hawaii, records of seed source for the older plantings, many of which were of species with very broad ranges, are not available.

Figure 1.—Longleaf pine at Keanakolu, island of Hawaii. Forty-two feet of clear stem in 28 years. Heredity or environment?

Specific Gravity and Wood Density

Why Measure Specific Gravity?

Specific gravity provides a simple and useful index to several qualities of wood. It is closely related to the mechanical strength of wood—so closely in fact that several strength properties can be estimated from specific gravity alone, at least for well known and thoroughly tested species (U.S. Forest Products Laboratory 1941). Specific gravity also provides some indication of how well wood will perform when painted or glued. Use of specific gravity to compare wood strength between species can only be general.

Wood density has long been the primary criteria in grading southern pine and Douglas-fir *(Pseudotsuga menziesii)* structural lumber. Density is even more important in determination of pulp yields. For every 2-pound increase in wood density, about 1 pound more of Kraft pulp per cubic foot of wood is produced (Mitchell and Wheeler 1959).

To convert specific gravity measurements into density (lbs./cu. ft.), multiply by 62.4 (weight in pounds of a cubic foot of water). The density figure derived from specific gravity measurements made by using the green volume and oven-dry weight is the dry weight of the wood.

Increment Core Measurement

Measurement of specific gravity by use of increment cores is a system developed in recent years that is now being more and more widely used. Several workers have correlated measurements from cores with those made by conventional methods and found the accuracy of the method to be within acceptable limits when many trees were sampled.[3] The Forest Survey in Mississippi used

[3] Fielding and Brown 1960; Markwardt and Paul 1946; Spurr and Hsiung 1954; Tackle 1962; Wahlgren and Fassnacht 1959.

Figure 2.—Monterey pine at Keanakolu, island of Hawaii. The oddly mis shapen crowns are typical of the species in Hawaii. →

Figure 3.—Shortleaf pine at Olinda, Maui. At 14 years these trees are far outstripping their mainland counterparts—both in height and in diameter growth. ↓

the method and gathered valuable data on four pine species growing there (Mitchell and Wheeler 1959). Several studies of wood density in southern pines have been made using core measurements (Larson 1957; Zobel and McElwee 1958; Zobel and Rhodes 1955). Cores have been used in Australia for studies of Monterey pine density (Fielding and Brown 1960). They are being used in the western wood density survey to determine density variation in all the more important conifers of the Western United States. A survey of Monterey pine by increment cores is also underway in New Zealand (New Zealand Forest Service 1962).

Specific gravity based on one increment core taken at breast height is not necessarily a true measure of the average specific gravity of the whole stem. The relationship between specific gravity of an increment core at breast height and of the tree has been worked out only for the southern pines (Wahlgren and Fassnacht 1959) and lodgepole pine (Tackle 1962) to date. For other species, core specific gravity merely indicates trends in tree specific gravity. But it is satisfactory for comparing trees of the same species and about the same age. Core specific gravity is closely correlated with tree age so that age must always be considered in comparing trees or stands (Wheeler and Mitchell 1962).

The Study

Procedures

Specific gravity measurements were made by using increment core samples taken at breast height. Only trees 10 years old and older were bored because wood of very young trees is known to be of atypically low specific gravity. To avoid compression wood, we made borings on the uphill side of trees on slopes or on the side opposite the direction of lean on leaning trees. Cores were trimmed in the field to include a length from cambium to pith. Immediately after cores were extracted, measurements of core length, growth ring width, and amount of summerwood were made in the field.

Standard (0.16–0.18-inch diameter) increment borers calibrated to 0.001 inch were used. This calibration was used as the diameter measurement of the cores in obtaining volume measurements. Length of the cores was measured immediately after extraction to 0.01 inch. In the laboratory, the cores were oven-dried to constant weight and weighed to 0.001 gram. We used individual desiccator bottles to avoid picking up moisture during cooling and weighing. The desiccator bottles were weighed before and after weighing each core.

The distance from the start of springwood of the fifth ring from the pith to the end of summerwood of the tenth ring, and similar distances for rings 15-20, 25-30, and so forth were measured to 0.01 inch. These distances were divided by five to arrive at rings-per-inch. Thus, for trees less than about 20 years old, rings-per-inch measurements were averages of only five rings. In most species these rings were not necessarily annual rings because the total number of rings often exceeded the known age of the trees. With all sampled Jeffrey pine and cluster pine, however, the rings were apparently truly annual.

Percent summerwood was calculated from measurements of summerwood contained within each 5-ring segment to .01 inch. Summerwood boundaries were determined with a 10 X lens, but the cores had not been stained so that measurements were not highly accurate. When we saw compression wood in the fresh cores, we recorded it.

Because few trees were available, we attempted to bore a sample of only 10 trees of a species at each location. In many instances we found fewer than 10 trees owing either to the small number originally planted or, more often, to poor survival. In some cases only one or two trees were bored at a location. This procedure was followed to obtain an indication of wood quality for the species at a particular site, although we recognized that the results would in all likelihood be statistically inadequate.

At each location visited, we noted all coniferous species present. Only species that had produced a form generally acceptable for sawtimber were bored. Site factors, including elevation, precipitation, slope, and aspect, and soil texture, depth, and pH, were recorded for each location. Data recorded for each sample tree included diameter at breast height, total height, height of clear stem (if unpruned), age, spacing, general tree form, crown class, and vigor.

Species and Locations

The age limitation that the trees must be at least 10 years old excluded many recent plantations from consideration. Most *Pinus* spp. plantings in the State known to contain several surviving trees over 10 years old were visited. These plantings are mostly in arboretums containing a few trees of each species, usually in single isolated rows. Often the pines were planted in mixture with other conifers or hardwoods. Five representative stands of the more widely planted Norfolk-Island-pine *(Araucaria excelsa)* were chosen for sampling. Douglas-fir was sampled at two locations where trees of reasonably acceptable form were found.

The species included in the survey were:

Common name	*Scientific name*
Douglas-fir	*Pseudotsuga menziesii*
Norfolk-Island-pine	*Araucaria excelsa*
Pine, cluster	*Pinus pinaster*
Pine, eastern white	*P. strobus*
Pine, jelecote	*P. patula*
Pine, Jeffrey	*P. jeffreyi*
Pine, loblolly	*P. taeda*
Pine, longleaf	*P. palustris*
Pine, Luzon	*P. insularis*
Pine, Masson	*P. massoniana*
Pine, Monterey	*P. radiata*
Pine, shortleaf	*P. echinata*
Pine, slash	*P. elliottii*
Pine, Yunnan	*P. yunnanensis*

Statistical Analysis[4]

An analysis of variance between different locations was made of the relationships between specific gravity, percent summerwood, and rings-per-inch for each species that had been sampled at two or more locations with five or more observations at each location. Scheffe's test was used to compare the location means because it allowed compensation for unequal sample size.

In a second analysis, by multiple weighted regression, the relationship between the dependent variables of specific gravity, percent summerwood, and rings-per-inch were compared with the independent variables of age, elevation, and annual rainfall. This analysis was made only for Monterey pine, jelecote pine, and Norfolk-Island-pine.

A third analysis, also by weighted regression, was made of the correlation between specific gravity, percent summerwood, and rings-per-inch for the six species: Norfolk-Island-pine, slash pine, jelecote pine, cluster pine, Monterey pine, and loblolly pine. No significant correlation was found for any species except cluster pine. Lack of significant correlation may just reflect the small number of locations sampled, although the correlations were generally of the level found in similar studies. Or, it may be that the sample of rings-per-inch and percent summerwood taken for each core did not truly represent all rings in the core.

Wood Quality and Tree Growth

All specific gravity values reported in this study were based on green volume and oven-dry weight.

Table 1 (appendix) lists information on environment for each location together with average values obtained for each species. Standard deviations for rings-per-inch and percent summerwood were usually very large. The faith that should be placed in the figures on specific gravity, rings-per-inch, and percent of summerwood should be governed by the number of trees sampled to obtain the data. Figures that are averages of numerous trees are more likely to be valid estimates than those that are based on only 20 or 30 cores—or in some cases only one or two cores—because of the large possibility of error induced by the increment core sampling method used. Thus, the Statewide averages are better estimates than the averages for one location.

Norfolk-Island-Pine

(Araucaria excelsa)

Locations: 5 **Trees:** 50

Hawaii core specific gravity (25-50 years)—

Average: 0.434

Range: 0.371–0.537

Wood Quality

Norfolk-Island-pine wood has not been used to any large extent anywhere in the world. Several other species of the genus *Araucaria* are more widely used, notably parana-pine *(A. angustifolia)*, Klink araucaria *(A. klinkii)*, hoop-pine *(A. cunninghamii)*, and bunya-bunya *(A. bidwillii)*.

The core specific gravity of Hawaii-grown Norfolk-Island-pine is close to that of hoop-pine (0.437) (Kingston and Risdon 1961). Assuming the core specific gravity is not greatly different from tree specific gravity, this species is not as dense as parana-pine (0.53) (Kukachka 1962), though denser than Klink araucaria (0.38) and bunya-bunya (0.38) (Kingston and Risdon 1961). Norfolk-Island-pine is probably suited to structural use, but physical and mechanical property tests will be required to establish this. Moreover, compression wood, observed in several rings of almost every sample core, may cause seasoning difficulties and problems in use.

Growth

The species grows well in areas below 2,000 feet and having 50 or more inches of rainfall. The Hawaii Forestry Division reports that the trees require tending for 1 to 3 years after planting before they are safely above competing vegetation. Norfolk-Island-pine is subject to epicormic sprouting if the stems are opened to light. Survival as indicated by the plantations examined seemed excellent.

[4] I am indebted to Mrs. R. R. Taylor, geneticist on the staff of the Pacific Southwest Forest and Range Experiment Station, for developing the analytical systems used and for interpreting the machine-processed data.

Figure 4.—Norfolk-Island-pine. An unmanaged 27-year-old plantation at Kukuihaele, Hawaii.

Self-pruning in stands spaced even as widely as 12 by 12 feet is more rapid than with any of the introduced true pines. At 10- by 10-foot spacing and 27 years of age, the length of clear stem of the Kukuihaele stand averaged 10 feet, and height to the first live branch 51 feet. At 12- by 12-foot spacing and 50 years, the Haiku stand had self-pruned to an average of 14 feet and averaged 32 feet to the first live branch.

Slash Pine (Pinus elliotii)

Locations: 4 **Trees:** 23
Hawaii core specific gravity (20-29 years, 2 locations)—
Average: 0.423
Range: 0.388–0.522
Native habitat core specific gravity (20-30 years): 0.51 (Mitchell and Wheeler 1959)

Wood Quality

Core specific gravity at the two locations wher the species grew in acceptable form was low fc the age of the trees. Analysis of variance indicate no significant difference in specific gravity betwee the two stands.

The strength of the wood can be estimated fror available literature (U.S. Forest Products Labor atory 1941; fig. 1). Since green slash pine has modulus of rupture of 8,900 pounds per squar inch at a specific gravity of 0.56, it would be ex pected to be about 6,200 psi at 0.42. The Hawaii grown wood is so different from mainland-grown wood that its suitability for structural use shoulc be determined by mechanical property tests at a early date.

Trees at Kalialinui and Keanakolu were toc poor in form for sawtimber. The two Keanakolu trees also had wood of extremely low density for this species. The sampled trees at Puu Ohu, a very windy area, had all developed compression wood on their leeward sides.

Figure 5.—Slash pine. Thirty-year-old trees at Olinda, Maui. Jelecote pine is in the back ground.

Growth

Height growth of dominants at Olinda equaled or excelled growth of the best slash pine sites on the mainland (Barnes 1955; U.S. Department of Agriculture 1929). At Puu Ohu, dominants had grown at a rate equal to better mainland sites. Diameter growth at both locations was quite good.

At Puu Ohu, slash pine exhibited fewer forked tops than loblolly pine, but must still be considered highly susceptible to wind deformation. Self-pruning of the Olinda stand averaged 5.4 feet high. Though good for this age, this was poor when related to diameter, for the trees were mostly already of merchantable size.

Survival of slash pine has varied. It was very good at Puu Ohu and fair at Olinda. These stands were probably never tended. Elsewhere in the State, slash pine has usually failed when grown above 4,000 feet elevation. At lower elevations, such as on Molokai and near the Volcano Road on Hawaii, young slash pine has shown excellent survival in untended stands.

Jeffrey Pine (Pinus jeffreyi)

Locations: 3 **Trees:** 30

Hawaii core specific gravity (51 years)—
Average: 0.472
Range: 0.417–0.542

Native habitat tree specific gravity (all ages):
0.37 (Markwardt and Wilson 1935)

Wood Quality

Wood density was high for this species at all three locations. On the basis of its core specific gravity, the wood should be better suited for structural use than that of mainland-grown Jeffrey pine.

The Hosmer Grove stand lies in an area of much higher rainfall than the other two stands, yet the analysis of variance indicated no significant difference in core specific gravity.

Growth

In comparison with Jeffrey and ponderosa pines in their native habitat, the sampled trees had from average to poor height growth (Dunning and Reineke 1933; Meyer 1938). As would be expected, average height growth was best in the most closely spaced stand, although the open-grown Hosmer Grove trees did almost as well as the closely

Figure 6.—Jeffrey pine. A 51-year-old plantation at Puu Laau, Hawaii, fenced against feral sheep.

spaced Puu Laau trees. This may have been a reflection of the better site afforded by the lower elevation and higher rainfall at Hosmer Grove.

Form was good except for excessive taper. The species resisted wind deformation very well. Self-pruning was very poor at 51 years, even at close spacing. Survival seemed satisfactory, though it was not known whether the original seedlings survived or were replaced one or more times after failure.

Jelecote Pine (Pinus patula)

Locations: 6 **Trees:** 52

Hawaii core specific gravity (12 years)—
Average: 0.357
Range: 0.311–0.403

Hawaii core specific gravity (18-30 years)—
Average: 0.438
Range: 0.314–0.540

South Africa tree specific gravity (8 years):
0.380; (30 years): 0.496 (Scott 1953)

New Zealand tree specific gravity (37 years):
0.370 (Entrican et al. 1957)

Figure 7.—Jelecote pine. A 30-year-old unmanaged plantation at Olinda, Maui. The steep branch angle is typical of the species in Hawaii.

Wood Quality

Wood density of this species in Hawaii is somewhat lower than that grown in South Africa, but higher than that grown in New Zealand.

Probably because of their young age, trees at Keanakolu differed significantly in mean specific gravity from those at all the other locations.

An analysis of specific gravity, rings-per-inch, and percent summerwood on age, elevation, and rainfall showed significant (5 percent) correlation of age both with specific gravity and with rings-per-inch.

Growth

Height growth of 95-foot dominant trees 28 and 29 years old in the closely spaced stands at Makawao and Poli poli excelled that of trees from New Zealand where a 40-year-old stand achieved 104 feet (Fielding and Brown 1960). The species in Hawaii is extremely susceptible to wind deformation; height growth was good only in areas well sheltered from the wind. Forked and multiple tops were common in all stands, particularly so in windy areas.

Branching habit is very poor. Branches are very steeply angled. Their tips keep up with the tree leader so they are not shaded out even in denser stands. Form is usually very poor because these large, live, steeply angled branches are included in the stem close to the ground.

Survival of this species was quite good in all areas, whether of high or low rainfall, high or low elevations, and tended or untended stands.

Cluster Pine (Pinus pinaster)

Locations: 4 **Trees:** 38

Hawaii core specific gravity (12 years)—
- Average: 0.401
- Range: 0.370–0.443

Hawaii core specific gravity (24–32 years)—
- Average: 0.489
- Range: 0.401–0.549

South Africa tree specific gravity (age not given): 0.576 (Scott 1953)

Australia tree specific gravity (age not given): 0.490 (Kingston and Risdon 1961)

Wood Quality

Core specific gravity of the older trees indicated that the wood being produced should be acceptable for structural and other uses. Significant differences in specific gravity are probably related to the age of the trees. Well defined growth rings were produced at all locations. Compression wood may be a problem as the species often produces crooked stems in Hawaii.

Growth

Height growth of this species was less than several other pines in Hawaii (Monterey, jelecote, slash, loblolly), but compares favorably with the superior Leiria (Portuguese) race growing in South Africa. The Leiria had a mean height on 14 plots at 43 years of 71 feet (Scott 1962).

Tree form is acceptable for sawtimber, though slightly crooked stems are common—even in closely spaced stands. Knot swellings are large at the branch whorls and may produce distorted grain for many years after pruning. The species does not self-prune rapidly in Hawaii.

Survival has been quite variable—very good at Olinda and Keanakolu; quite poor in the other two sample locations. The tree was extensively planted at wide spacing at Kalialinui and failed badly probably because of high winds. Survival at Makawao of hundreds of trees outplanted was almost nil. The variable survival probably is not related to soil differences because this species is noted for its ability to withstand poor soils (Scott 1962).

Monterey Pine (Pinus radiata)

Locations: 13 **Trees:** 105

Tree origin:	Specify gravity of trees at— 10-20 years	20-30 years	30-40 years
Hawaii (core)	0.434	0.462	0.503
Australia	.404	—	[1].485
New Zealand	—	[1].400	—
South Africa (age not given)	—	[2].544	—
Native habitat (43-77 years)	—	[3].460	—

[1] Kingston and Risdon 1961.
[2] Scott 1953.
[3] Cockrell 1959.

Wood Quality

Density of Monterey pine was higher over a wider range of site conditions than that of any other species surveyed. In all locations listed except the high elevation Puu Kihe, the samples indicated that the species was producing wood of a density suited to structural purposes. Though the 12-year-old stand at Keanakolu had low density wood, a 28-year-old stand at the same location had wood with a core specific gravity equal to the tree specific gravity of wood produced by mainland trees. Compression wood may be a problem as trees are often crooked or lean. Tree form and branching habit have more effect on wood quality with this species than wood specific gravity.

A regression analysis of age, elevation, and rainfall on specific gravity, rings-per-inch, and percent summerwood and on each other showed that specific gravity, percent summerwood, and rainfall were significantly correlated with elevation. Rings-per-inch and rainfall were highly significantly correlated. All correlations other than rainfall with elevation were negative.

The negative correlation of specific gravity with elevation bears out recent findings in New Zealand where an increment core survey of Monterey pine is underway. Indications there are that highest density wood is found at low elevations and low latitudes regardless of rainfall or soil type—presumably indicating that temperature has a major influence on specific gravity (New Zealand Forest Service 1962, p. 62)—and that wood from phosphate deficient sites is much denser than from nearby normal sites. This relationship might be applicable in Hawaii, where phosphate is often low, and may help explain the high specific gravity found for many of the very fast grown trees.

From these correlations, these conclusions can be drawn: wood grown at lower elevations will have higher density and a higher percent summerwood than that grown higher. Diameter growth (rings-per-inch) will increase (fewer rings-per-inch) as rainfall increases, but there will not necessarily be any connection between faster growth, percent summerwood, and specific gravity, although rainfall increases as elevation increases.

Growth

Height growth at Kalialinui, in a wind sheltered gulch, was superior to the best sites in the Canterbury Plains, New Zealand (Gorman 1933). Trees at Kapaakea (upper), Olinda, Keanakolu (12 years old), Lalakea, Honuaula, and Poli poli (lower) all also had outstanding height growth. A 34-year-old tree at Poli poli (lower) stood 147 feet tall, with a 36.3-inch d.b.h.; another, 142 feet,

Figure 8.—Cluster pine. A 32-year-old plantation at Olina, Maui. Pruned in 1945, many trees still show knot bumps.

Figure 9.—Monterey pine at Poli Poli, Maui. At 34 years, the seven trees at this site average 37 inches d.b.h. and 142 feet in height.

with 45.6-inch d.b.h. A 23-year-old tree at Honuaula (lower) was 141 feet, with 28.7-inch d.b.h.

Though its growth rate is excellent, the species leaves much to be desired as to form and branching habit (fig. 2). Even in closed stands branches are steeply angled and light-seeking, and live for many years. Multiple tops are usual, though two 16-foot logs are usually produced before the tree forks. Stems sprout after pruning even in low rainfall areas.

Most plantings are small remnants of .original plantings of hundreds of trees. This is especially true in those plantations that were not tended for the first few years. Survival with this species is thus highly questionable. At Poli poli, for example, the seven remaining trees are the only survivors of several early plantings that totaled 563 trees.

Loblolly Pine (*Pinus taeda*)

Locations: 4 **Trees:** 38

Hawaii core specific gravity (19–25 years)—
Average: 0.419
Range: 0.333–0.524

Native habitat core specific gravity (19–25 years): 0.48 (Mitchell and Wheeler 1959)

Figure 10.—A 4-year-old mixed planting of loblolly and slash pines on Molokai. The island contains many acres of these young, vigorous stands.

Wood Quality

Only the trees at Aina Hou have produced wood that nearly matches the density of loblolly pine in its native habitat. The specific gravity of trees at Aina Hou was not significantly different from trees at Honuaula and Lalakea. Therefore the wood from sampled trees of this species at the four locations all may be less dense than wood from trees grown in their native habitat and perhaps may not be suitable for structural purposes. This suitability should be determined by mechanical property testing at an early date. Compression wood formation was pronounced at Puu Ohu and will probably be a problem with all trees from windier sites.

Growth

Height growth of dominants and co-dominants at Aina Hou and Lalakea indicated sites equal to the better sites in the Southeastern States (Allen 1960; Czarnowski and Burns 1960). It was slightly lower at Puu Ohu, probably due to wind, and was somewhat below the mainland average at Honuaula (upper). In the windiest area, Puu Ohu, almost every tree was badly forked at 12 to 20 feet, indicating susceptibility of the species to high wind. At Lalakea the trees had been pruned. At the three other locations, the height of limb-free stem averaged 3 feet, with no apparent difference due to spacing difference.

Survival of this species was good except at Honuaula, which is much higher than the other three locations. Loblolly pine has been tried at several areas of 5-6,000 feet elevation in Hawaii and Maui, but has failed almost completely except at Honuaula.

Other Species

Several species were not available in enough numbers or locations to provide more than an indication of trends. Limited data were obtained for seven species (table 9).

Of the seven species, shortleaf pine is the most promising; both wood density and growth were quite good for this species. Though growth was very good for longleaf pine at Olinda, core specific gravity was low. Masson pine also showed excellent growth, but had wood of somewhat low density, steeply angled branches, and rather crooked stems. Although wood density of Douglas-fir was in the range for Douglas-fir from the Rocky Mountains, its height growth in Hawaii was comparable only to the poorest mainland sites.

Other species have had varying success. Luzon pine has been planted extensively in Hawaii and has generally shown very poor survival. Eastern white pine does well and reproduces naturally at Hosmer Grove, but the wood from two trees resembled that from the species in its native habitat. This wood is not particularly well suited for structural use. Yunnan pine may be solely an ornamental; its form and branching habit make it unsuited for sawtimber at the one location where it was observed.

Summary and Conclusions

The results, though based on a limited sample, suggested that Norfolk-Island-pine, cluster pine, and Monterey pine were producing at good growth rates wood that should be suitable for structural use. Although slash pine and loblolly pine were growing well, the few trees available for sampling indicated that they were not producing at the sites occupied wood of a density suited for structural use. Jelecote pine had such poor form in most areas and was producing such low density wood that it is probably unsuited to timber production.

On the basis of this study, shortleaf pine, longleaf pine, Masson pine, and Douglas-fir showed some promise and deserve further trial in Hawaii. Not sampled sufficiently were Luzon pine, eastern white pine, and Yunnan pine. The poor survival of the Philippine pine, the normally rather low density of white pine, and the form of the Chinese pine in Hawaii suggested that there are more suitable species for future trials.

Species requiring tests of mechanical properties to determine how well their wood is suited for structural use are Norfolk-Island-pine, slash pine, cluster pine, Monterey pine, and loblolly pine.

Based on observations in the study, a number of suggestions for management can be given. Early mechanical pruning is essential with all true pine species in order to produce clear wood at the commonly used plantation spacings on the short rotations indicated by the rapid growth rate. But the economic feasibility of this requirement is, of course, questionable. Early high pruning may also reduce too rapid growth where it is limiting to wood density. Closer spacing of planted trees may improve self-pruning.

Protective measures would help plantation establishment. All true pines, except possibly Jeffrey pine, should be shielded from strong winds by natural barriers, close spacing, or planting windbreaks of more vigorous species, such as saligna eucalyptus *(Eucalyptus saligna),* when plantations are established. Planting in areas with a large feral pig population should be avoided. These animals, when in large numbers, were observed to have girdled and killed longleaf pine and to have damaged Monterey pine and loblolly pine.

The success of softwood plantations in Hawaii as a means of watershed protection is quite evident, but their success as a source of timber will remain uncertain for many years to come. Not enough information is available from previous experimental plantings to provide sound guideposts. As a first step in future research, stands should be established from seed selected from trees of superior wood density.

Several important questions directly bearing on the feasibility of softwood production in Hawaii need to be answered. Site selection can be critical because even though most species surveyed were doing well at one or two locations, the same species were doing very poorly at others. Also, most land best suited to conifers is even better suited to one or more quality hardwood species. Not to be ignored is the matter of marketing conifer products.

The basic questions remain: Can Hawaii produce a significant volume of coniferous timber that will compete successfully with the higher grades of softwood lumber from the mainland? Can Hawaii's sawmills produce softwood lumber that will be competitive in price with lumber produced by the large volume mills of the mainland?

I hope this report will contribute some guides to help in making the difficult policy decision of how much money and effort should be put into planting conifers now for future timber production in Hawaii.

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Appendix

Table 1. Stand descriptions and specific gravity data of Hawaii conifers

Island	Location	Elevation	Annual precipitation	Spacing	Trees sampled	Age	D.b.h.	Height	Rings-per-inch	Standard deviation	Summer-wood	Standard deviation	Core specific gravity	Standard deviation
		Feet	*Inches*	*Feet*	*Number*	*Years*	*Inches*	*Feet*			*Percent*			
ARAUCARIA EXCELSA (NORFOLK-ISLAND-PINE)														
Hawaii	Kukuihaele	1,800	77	10 x 10	10	27	15.5	106	--	--	--	--	.417	.012
Maui	Mahinahina	2,040	95	12 x 12	10	25	13.3	54	4.3	1.37	37.0	20.28	.445	.028
Maui	Haiku	1,000	50	10 x 14	10	50	21.1	121	5.4	.60	30.1	12.07	.438	.042
Oahu	St. Louis Hts.	1,060	60	12 x 12	10	27	14.0	60	3.1	.65	17.8	8.34	.462	.017
Oahu	Nuuanu	760	95	10 x 10	10	27	13.1	61	3.6	.61	24.95	16.05	.410	.026
PINUS ECHINATA (SHORTLEAF PINE)														
Maui	Olinda	3,620	50	8 x 8	10	13	8.7	47	5.2	1.40	27.7	9.40	.466	.031
PINUS ELLIOTTII (SLASH PINE)														
Hawaii	Keanakolu	5,500	110	(1)	2	28	13.8	37	3.7	--	22.8	--	.340	--
Hawaii	Puu Ohu	3,280	40	8 x 8	10	20	12.5	52	5.0	1.23	35.0	8.57	.419	.028
Maui	Olinda	3,620	50	8 x 8	10	29	14.7	84	5.5	1.62	26.0	10.13	.426	.040
Maui	Kalialinui	6,730	104	(1)	1	15	5.6	23	3.5	--	11.3	--	.429	--
PINUS INSULARIS (PHILIPPINE PINE)														
Hawaii	Keanakolu	5,500	110	(1)	1	21	6.5	32	--	--	--	--	.364	--
Oahu	Round Top Drive	1,400	120	(1)	2	40	32.7	70	--	--	--	--	.539	.109
PINUS JEFFREYI (JEFFREY PINE)														
Hawaii	Puu Laau	7,500	20	7 x 7	10	51	11.4	48	9.1	2.24	23.1	8.47	.464	.049
Hawaii	Puu Ulaula	9,000	18	12 x 12	10	51	16.1	38	5.5	1.40	22.6	8.35	.469	.032
Maui	Hosmer Grove	6,730	104	(1)	10	52	14.6	47	7.5	2.47	25.6	6.99	.484	.040
PINUS MASSONIANA (MASSON PINE)														
Maui	Olinda	3,620	50	8 x 8	10	13	10.0	62	3.9	.97	15.2	4.11	.429	.031
PINUS PALUSTRIS (LONGLEAF PINE)														
Hawaii	Keanakolu	5,500	110	(1)	3	28	8.6	47	8.5	1.87	13.6	1.06	.421	.035
Maui	Olinda	3,620	50	(1)	6	13	10.2	54	3.4	.85	27.5	5.81	.425	.025

Table 1. Stand descriptions and specific gravity data of Hawaii conifers, continued

Island	Location	Elevation	Annual precipitation	Spacing	Trees sampled	Age	D.b.h.	Height	Rings-per-inch	Standard deviation	Summerwood	Standard deviation	Core specific gravity	Standard deviation
		Feet	*Inches*	*Feet*	*Number*	*Years*	*Inches*	*Feet*			*Percent*			
					PINUS PATULA (JELECOTE PINE)									
Hawaii	Puu Ohu	3,280	40	10 x 10	2	20	12.9	27	3.3	0.40	39.2	9.10	.395	.012
Hawaii	Keanakolu	5,500	110	10 x 12	10	12	8.5	35	2.4	1.36	17.6	3.92	.357	.030
Maui	Poli poli (lower)	5,280	42	6 x 8	10	28	13.9	85	8.2	2.48	23.9	7.31	.419	.031
Maui	Olinda Road	2,630	75	7 x 7	10	18	11.7	53	4.1	1.61	23.6	10.24	.423	.052
Maui	Olinda	3,620	50	8 x 8	10	30	13.8	77	6.5	1.77	30.9	8.50	.437	.044
Maui	Makawao	2,200	100	6 x 8	10	29	13.6	89	5.0	2.37	26.8	6.86	.472	.051
					PINUS PINASTER (CLUSTER PINE)									
Hawaii	Keanakolu	5,500	110	10 x 12	10	12	7.4	36	2.3	.56	30.1	14.49	.397	.017
Hawaii	Honuaula (upper)	6,250	50	10 x 20	8	12	6.7	26	2.4	.29	19.5	4.36	.404	.021
Maui	Poli poli (upper)	6,200	42	(1)	10	24	14.8	56	3.8	1.50	10.3	3.12	.464	.041
Maui	Olinda	3,620	50	8 x 10	10	32	13.6	70	6.5	1.42	28.3	8.80	.514	.034
					PINUS RADIATA (MONTEREY PINE)									
Hawaii	Keanakolu	5,500	110	(1)	10	28	22.9	75	2.6	.95	16.3	5.80	.466	.028
Hawaii	Keanakolu	5,500	110	10 x 12	10	12	7.1	42	2.1	.39	13.4	8.40	.340	.024
Hawaii	Honuaula (lower)	5,200	60	10 x 20	10	23	19.7	100	3.5	1.79	23.9	8.99	.458	.029
Hawaii	Puu Kihe	7,800	45	(1)	5	16 & 30	12.7	40	3.5	.92	10.0	4.90	.377	.107
Hawaii	Lalakea	2,750	70	(1)	2	25	19.4	90	2.1	.40	18.2	2.29	.480	.013
Hawaii	Aina hou	2,900	84	10 x 12	1	19	9.5	44	2.8	--	15.5	--	.500	--
Maui	Kailua gulch	2,320	40	8 x 12	10	35	23.4	102	4.2	1.26	25.2	6.76	.552	.053
Maui	Poli poli (lower)	5,280	42	15 x 20	7	34	37.2	142	2.6	.64	13.9	5.49	.459	.015
Maui	Olinda	3,620	50	12 x 12	10	12	9.5	48	2.7	1.37	16.0	7.00	.442	.042
Maui	Kalialinui	6,730	104	12 x 12	10	14	13.2	70	2.2	.69	16.0	7.10	.425	.029
Molokai	Kapaakea (upper)	2,450	45	9 x 9	10	13	8.1	55	4.1	1.35	26.9	7.20	.478	.031
Molokai	Waikolu	3,550	67	10 x 10	10	14	12.4	49	2.3	1.07	32.7	19.81	.462	.029
Molokai	Kapaakea (lower)	1,950	35	10 x 10	10	13	7.3	32	4.2	.99	17.6	6.36	.454	.022
					PINUS STROBUS (EASTERN WHITE PINE)									
Maui	Hosmer Grove	6,730	104	6 x 6	2	52	13.7	70	5.6	3.35	12.6	6.52	.370	.019
					PINUS TAEDA (LOBLOLLY PINE)									
Hawaii	Aina hou	2,900	84	10 x 12	10	19	11.9	52	2.8	.54	23.9	11.75	.460	.036
Hawaii	Honuaula (upper)	6,250	50	10 x 20	10	19	9.6	40	3.0	.75	22.3	5.55	.415	.040
Hawaii	Lalakea	2,750	70	(1)	8	25	21.3	68	2.3	1.05	34.5	10.37	.404	.055
Hawii	Puu Ohu	3,280	40	10 x 10	10	20	11.6	41	3.1	.63	32.8	7.28	.394	.018
					PINUS YUNNANENSIS (YUNNAN PINE)									
Hawaii	Keanakolu	5,500	110	(1)	2	28	10.8	48	4.1	.10	9.9	1.10	.388	.007
					PSEUDOTSUGA MENZIESII (DOUGLAS-FIR)									
Hawaii	Puu Kihe	7,800	45	10 x 20	4	25	14.0	38	2.8	.10	20.6	5.85	.419	.018
	Kaluakauka	5,950	105	10 x 12	10	27	13.2	54	5.2	2.89	41.7	16.34	.398	.020

[1] Open.

Table 2. Characteristics and stand means of Norfolk-Island-pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp.gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
St. Louis Heights	12 x 12	14.0	60	27	0.462	
Mahinahina	12 x 12	13.3	54	25	.445	
Haiku	10 x 14	21.1	121	50	.438	
Kukuihaele	10 x 10	15.5	106	27	.417	
Nuuanu	10 x 10	13.1	61	27	.410	

[1]Brackets group specific gravity means not significantly different at 5 percent level.

Table 3. Characteristics and stand means of slash pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp.gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
Kalialinui	(2)	5.6	23	15	0.429	1 tree only[3]
Olinda	8 x 8	14.7	84	29	.426	
Puu Ohu	8 x 8	12.5	52	20	.419	
Keanakolu	(2)	13.8	37	28	.340	2 trees only[3]

[1]Brackets group specific gravity means that are not significantly different at 5 percent level.

[2]Open.

[3]Not tested owing to sample size, included here only to show range.

Table 4. Characteristics and stand means of Jeffrey pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp.gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
Hosmer Grove	(2)	14.6	47	52	0.484	⎤
Puu Ulaula	12 x 12	16.1	38	51	.469	⎥
Puu Laau	7 x 7	11.4	48	51	.464	⎦

[1]Brackets group specific gravity means not significantly different at 5 percent level.

[2]Open.

Table 5. Characteristics and stand means of Jelecote pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp.gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
Makawao	6 x 8	13.6	89	29	0.472	⎤
Olinda	8 x 8	13.8	77	30	.437	⎥
Olinda Road	7 x 7	11.7	53	18	.423	⎥
Poli poli (lower)	6 x 8	13.9	85	28	.419	⎥
Puu Ohu	10 x 10	12.9	27	20	[2]/.395	⎦
Keanakolu	10 x 12	8.5	35	12	.357	]

[1]Brackets group specific gravity means not significantly different at 5 percent level.

[2]Not included in the analysis owing to the small sample size. Shown here only to show place in range.

Table 6. Characteristics and stand means of cluster pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp. gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
Olinda	8 x 10	13.6	70	32	0.514	]
Poli poli (upper)	(2)	14.8	56	24	.464	]
Honuaula (upper)	10 x 20	6.7	26	12	.404	]
Keanakolu	10 x 12	7.4	36	12	.397	]

[1]Brackets group specific gravity means not significantly different at the 5 percent level.

[2]Open.

Table 7. Characteristics and stand means of Monterey pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp. gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
Kailua Gulch	8 x 12	23.4	102	35	0.552	]
Aina hou	10 x 12	9.5	44	19	[2].500	]
Lalakea	(3)	19.4	90	25	[2].480	]
Kapaakea (upper)	9 x 9	8.1	55	13	.478	]]
Keanakolu	(3)	22.9	75	28	.466	]
Waikolu	10 x 10	12.4	49	14	.462	]
Poli poli (lower)	15 x 20	37.2	142	34	.459	]
Honuaula (lower)	10 x 20	19.7	100	23	.458	]
Kapaakea (lower)	10 x 10	7.3	32	13	.454	]
Olinda	12 x 12	9.5	48	12	.442	]
Kalialinui	12 x 12	13.2	70	14	.425	]
Puu Kihe	(3)	12.7	40	16, 30	.377	]
Keanakolu	10 x 12	7.1	42	12	.340	]

[1]Brackets group specific gravity means not significantly different at 5 percent level.

[2]Not included in the analysis owing to small size of sample. Shown here only to indicate place in range.

[3]Open.

Table 8. Characteristics and stand means of loblolly pine sampled

Location	Spacing	D.b.h.	Height	Age	Core sp.gr.	Comparison of means[1]
	Feet	*Inches*	*Feet*	*Years*		
Aina Hou	10 x 12	11.9	52	19	0.460	
Honuaula (upper)	10 x 20	9.6	40	19	.415	
Lalakea	(2)	21.3	68	25	.404	
Puu Ohu	10 x 10	11.6	41	20	.394	

[1]Brackets group specific gravity means not significantly different at 5 percent level.

[2]Open.

Table 9. Stand means of other species sampled

Species	Location	Trees	Age	Av. height dominants	Av. d.b.h.	Av. core sp.gr.
		Number	*Years*	*Feet*	*Inches*	
Douglas-fir	Puu Kihe	4	25	38	14.0	0.419
	Kaluakauka	10	27	54	13.2	.398
Pine, eastern white	Hosmer Grove	2	52	70	13.7	.370
Pine, longleaf	Olinda	6	13	54	10.2	.425
	Keanakolu	3	28	47	8.6	.421
Pine, Luzon	Keanakolu	1	21	32	6.5	.364
	Round Top Drive	2	40	70	32.7	.539
Pine, Masson	Olinda	10	13	62	10.0	.429
Pine, short-leaf	Olinda	10	13	47	8.7	.466
Pine, Yunnan	Keanakolu	2	28	48	10.8	.388

GPO 968-581

STX—FORTRAN 4 PROGRAM
---for estimates of tree populations from 3P sample-tree-measurements

L. R. Grosenbaugh

U. S. FOREST SERVICE RESEARCH PAPER PSW-13 1964

PSW

Pacific Southwest Forest and Range
Experiment Station - Berkeley, California
Forest Service - U. S. Department of Agriculture

NCTICE

THIS COMPUTER-PRODUCED PUBLICATICN IS AN EXPERIMENTAL EFFORT TO PUBLISH MORE RAPIDLY, MORE EFFICIENTLY, AND MORE COMPACTLY, INFORMATION ON COMPUTER-ORIENTED TECHNIQUES IN WHICH LUCID EXPLANATION MAY REQUIRE VOLUMINOUS DETAILS OR EXAMPLES IN APPENDICES.

AT THE SAME TIME, WE ARE TRYING TO IMPROVE SUSCEPTIBILITY OF THE INFORMATION TO AUTOMATED SEARCH AND RETRIEVAL. THE INITIAL SUMMARY AND THE ENTIRE TEXT OF THE PAPER ARE IMMEDIATELY SUITABLE FOR COMPUTER SEARCH BY VIRTUE OF ALREADY BEING ON PUNCHED CARDS. ON A MORE ELEMENTARY LEVEL, H. P. LUHN'S INGENIOUS 11-CHARACTER DOCUMENT IDENTIFIER (FAMILIAR TO USERS OF PERMUTED 'KWIC' INDICES) PROVIDES AN EXCELLENT TOOL FOR VISUAL, MECHANICAL, OR ELECTRONIC RETRIEVAL BY AUTHOR, YEAR, OR INITIALS OF THE FIRST THREE NON-TRIVIAL WORDS IN THE TITLE. THIS IDENTIFIER ALSO SERVES TO MATCH ANY PAGE WITH ITS APPROPRIATE DOCUMENT IN THE EVENT OF SEPARATION OR MIXUPS. SUCH A SYSTEM IS MUCH BETTER ADAPTED TO CUMULATIVE UPDATING OF INDICES THAN IS ANY ARBITRARY LOCAL SERIES OF NUMBERS THAT MUST BE RECYCLED PERIODICALLY.

FINALLY, COMPUTER-PROCESSED TEXT IS EASILY REVISED AND REPUBLISHED IN TOTO THROUGH THE MEDIUM OF MICROFORMS. RAPID CHANGES AND NEW DEVELOPMENTS IN COMPUTER-ORIENTED TECHNIQUES MAKE THIS AN IMPORTANT CONSIDERATION. DESPITE THE SATISFACTORY PERFORMANCE OF IMPROVED PORTABLE OR LIBRARY-TYPE MICRO-READERS, WE INTEND TO FOLLOW THE PRACTICE OF SIMULTANEOUSLY REPRODUCING THE TEXT (NOT THE APPENDICES) OF MOST OF OUR MICROFORM PUBLICATIONS IN LETTER-SIZE FOR THE CONVENIENCE OF THE MORE-THAN-CASUAL USER.

APPENDICES A, B, AND C ARE INCLUDED ONLY IN THE MICROCARD EDITION OF THIS PAPER OBTAINABLE ON REQUEST FROM THE PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, BOX 245, BERKELEY, CALIFORNIA 94701.

CONTENTS

THE AUTHOR

L. R. GROSENBAUGH JOINED THE U. S. FOREST SERVICE IN 1936 AFTER RECEIVING HIS MASTER OF FORESTRY DEGREE FROM YALE UNIVERSITY. HE SPENT 25 YEARS WITH THE SOUTHERN REGION AND THE SOUTHERN FOREST EXPERIMENT STATION, AND IN 1961 STARTED THE FOREST SERVICE'S FIRST PIONEERING RESEARCH UNIT (IN FOREST MENSURATION) AT THE PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION.

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PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, BERKELEY, CALIFORNIA
FOREST SERVICE, U.S.DEPARTMENT OF AGRICULTURE

STX--FORTRAN 4 PROGRAM FOR ESTIMATES OF TREE POPULATIONS FROM 3P SAMPLE-TREE-MEASUREMENTS

L.R.GROSENBAUGH

==================================SUMMARY==================================

PROGRAM 'STX' (WRITTEN IN FORTRAN 4) PROCESSES SAMPLE-TREE-MEASUREMENTS AS TAKEN IN THE FIELD AND COMPUTES FINAL POPULATION ESTIMATES IN TERMS OF WHATEVER VARIABLES ARE DESIRED. INPUTS ARE TREE-STEM MEASUREMENTS WITH QUALITY ASSESSMENTS, PLUS SUCH WHOLE-TREE AND PRODUCT-OUTTURN DATA AS ARE DEEMED APPROPRIATE. VARIOUS DENDROMETERS, TAPES,OR CALIPERS CAN BE USED TO MEASURE TREES. TREE SELECTION MAY BE WITHOUT UNCERTAINTY (ALL TREES OF INTEREST), WITH PROBABILITY PROPORTIONAL TO PREDICTION ('3P'SAMPLING), OR WITH SOME OTHER FORM OF PROBABILITY SAMPLING IF USERS MODIFY THE PROGRAM SLIGHTLY. PROVISION CAN BE MADE TO INCLUDE OR EXCLUDE BARK AND/OR USABLE MATERIAL ABOVE HIGHEST MEASURED DIAMETER.

THE PRINTED OUTPUT PRODUCED FROM ORIGINAL DATA INPUT HAS 4 MAJOR SECTIONS PLUS CERTAIN DATA-PROCESSING STATISTICS. OPTIONAL CARD OUTPUT FOR INDIVIDUAL LOGS OR TREES IS ALSO POSSIBLE. A SKELETAL SUBROUTINE CAN BE EXPANDED BY USERS DESIRING GRADE-YIELD, REALIZATION, OR APPRAISAL COMPUTATIONS. ADDITIONAL DUMMY SUBROUTINES ARE INCLUDED IN THE PROGRAM TO ALLOW USERS WIDE LATITUDE IN CHOICE OF METHODOLOGY.

=================================GENERAL=================================

FORESTERS HAVE LONG NEEDED A BETTER WAY OF CALCULATING THE EXPECTED PRODUCT-YIELD AND REALIZATION-VALUE OF STANDING TIMBER FROM ACCURATE UPPER-STEM MEASUREMENTS OF A RELATIVELY SMALL NUMBER OF STANDING SAMPLE TREES.

A PRACTICAL, EFFICIENT TECHNIQUE IS AT LAST AVAILABLE--A COMPREHENSIVE NEW COMPUTER PROGRAM CALLED 'STX' THAT TAKES ADVANTAGE OF SEVERAL RECENT DEVELOPMENTS--NEW '3P' SAMPLING THEORY (*3), BETTER MAGNIFYING SPLIT-IMAGE DENDROMETERS (*2), TREE QUANTITIES EXPRESSED IN UNITS THAT ARE MORE FUNCTIONAL AND INVARIANT THAN 'BOARD FEET' OR 'CUBIC FEET', EXPLICIT USE OF CERTAIN IMPLICIT GEOMETRIC RELATIONSHIPS, AND WIDE-SPREAD AVAILABILITY OF LARGE HIGH-SPEED BINARY COMPUTERS.

ALTHOUGH THE PROGRAM ASSUMES USE OF 3P-SAMPLING (SAMPLING WITH PROBABILITY PROPORTIONAL TO PREDICTION), IN WHICH EVERY INDIVIDUAL TREE IN THE POPULATION IS VISITED AND ASSIGNED AN ARBITRARY RELATIVE PROBABILITY OF BEING MEASURED, ONLY MINOR MODIFICATION WOULD BE NEEDED TO ADAPT IT TO PLOT-SAMPLING, POINT-SAMPLING, OR ANY OTHER DESIRED FORM OF CLUSTER SAMPLING WITH OR WITHOUT COMPLETE KNOWLEDGE OF PROBABILITY FOR EVERY INDIVIDUAL IN THE POPULATION.

THE PROGRAM IS COMPOSED OF A MASTER EXECUTIVE ROUTINE STX, WHICH IN TURN CALLS UPON FOUR MAJOR SUBROUTINES (ST1, ST2, ST3, ST4). ALL ARE WRITTEN IN FORTRAN 4 AND LISTED IN APPENDIX A.

SUBROUTINE ST1 EDITS INPUT AND ACCUMULATES POPULATION FREQUENCY AND RELATIVE PROBABILITY FOR EACH TREE-SAMPLING CATEGORY IN EACH VALUE STRATUM. INPUT ERRORS ARE FLAGGED BY SPECIAL PRINTOUTS. THE PROGRAM ALSO COPIES

INDIVIDUAL SAMPLE TREE DATA ONTO SCRATCH TAPE JW FOR LATER PROCESSING. FINALLY, IF NO ERRORS ARE DETECTED, IT MAY PRINT OUT A PRELIMINARY REPORT ON AGGREGATE FREQUENCIES AND PROBABILITIES BY VALUE STRATUM.

SUBROUTINE ST2 FURTHER EDITS THE SAMPLE-TREE PORTION OF INPUT AND CONVERTS THE FIGURES TO LOG AND TREE VOLUMES, SURFACES, LENGTHS, FREQUENCIES, BASAL AREAS, PREDICTIONS, AND QUANTITIES NEEDED FOR ESTIMATES OF SAMPLING ERROR. RESULTS MAY BE PRINTED OUT IN A DETAILED INDIVIDUAL LOG AND TREE REPORT, WRITTEN ON SCRATCH TAPE JX FOR FURTHER PROCESSING, PUNCHED OUT ON CARDS, AND (IN THE ABSENCE OF ERROR) AGGREGATED BY VALUE STRATUM. SPECIAL DIAGNOSTIC ERROR MESSAGES ARE PRINTED WHEN INPUT ERRORS ARE DETECTED. AMONG SEVERAL MINOR SUBROUTINES THAT ASSIST IN THE PROCESS IS SBR, WHICH CONVERTS SHORTBASE-RANGEFINDER DENDROMETER READINGS TO TREE DIAMETERS AND ELEVATIONS. ALTERNATIVELY, DUMMY SUBROUTINES OCL AND OFK MAY BE USER-EXPANDED TO SIMILARLY HANDLE MEASUREMENTS MADE BY OPTICAL CALIPERS, OPTICAL FORKS, STEEL TAPES, AND VARIOUS HYPSOMETERS. SUBROUTINE GAP MAY THEN SUPPLY CERTAIN OMITTED MEASUREMENTS, MAKE REDUCTIONS FOR BARK AS DIRECTED, AND PROJECT THE UNMEASURED UPPER STEM ABOVE THE LAST MEASURED DIAMETER IF THIS UNSEEN STEM WAS DEEMED LIKELY TO CONTAIN USABLE MATERIAL. DUMMY FUNCTIONS FB3, FH3, FS3, AND FV3 MAY BE EXPANDED BY USERS NOT SATISFIED WITH THE OPTIONS BUILT INTO THE EXISTING PROGRAM TO HANDLE BARK OR UNSEEN HEIGHT, SURFACE, AND VOLUME.

SUBROUTINE ST3 APPROPRIATELY COMBINES THE AGGREGATE POPULATION ESTIMATES FOR SAMPLING CATEGORY AND STRATUM, WHILE COMPLETING COMPUTATIONS OF SAMPLING ERROR. IT MAY PRINT OUT A SUMMARY REPORT. IN ADDITION, IT PROVIDES A PAGE OF DATA-PROCESSING STATISTICS, CHECKS, ERROR COUNTS, AND A LIST OF TREES WITH SUSPICIOUS INPUT DATA.

SUBROUTINE ST4 READS AND PRINTS OUT THE BASIC APPRAISAL INFORMATION

FCR EACH INDIVIDUAL SAMPLE LCG AVAILABLE ON SCRATCH TAPE JX. IT MAY BE USER-EXPANDED INTC A CCMPLETE GRADE-YIELD, REALIZATION, AND APPRAISAL REPORT BY SUPPLYING APPRCPRIATE GRADE YIELDS, PRICES, AND COSTS. TAPE JX ALSO CONTAINS DATA NEEDED BY USERS TO CALCULATE SAMPLING ERRORS FOR WHATEVER SYSTEM OF GRADE-YIELD STRATIFICATION THEY MAY WISH TO EMPLOY. SUCH STRATIFICATION MAY BE QUITE DIFFERENT FROM THE VALUE STRATIFICATION USED INITIALLY TO CCNTROL SAMPLING INTENSITY.

THE ENTIRE PROGRAM IS DESIGNED SC THAT THE 'OVERLAY' FEATURE OF FORTRAN 4 CAN BE USED. THIS IS A VASTLY IMPROVED FORM OF CHAIN EXECUTION. ORDINARILY, THE ZERO LINK IN THE CHAIN SHOULD INCLUDE STX WITH ALL NECESSARY LIBRARY AND SYSTEM SUBROUTINES. THIS ZERO LINK IS NEVER REPLACED, SO IT RESIDES IN CORE MEMORY CONTINUOUSLY. THE FIRST REPLACEABLE LINK SHOULD INCLUDE ST1, ST2 (WITH ITS ESSENTIAL SUBROUTINES), AND ST3. THE SECOND LINK, WHICH IN DUE TIME DISPLACES THE FIRST, CONSISTS OF ST4 AND ITS AUXILIARY SUBROUTINES WHICH CAN BE EXPANDED TO TAKE ADVANTAGE OF THE MEMORY SPACE PREVIOUSLY OCCUPIED BY THE FIRST LINK. THE OVERLAY FEATURE CAN BE ACTIVATED MERELY BY ARRAYING THE BINARY DECKS IN THE NATURAL ORDER JUST DISCUSSED AND BY THEN INSERTING A CONTROL CARD PUNCHED '$ORIGIN ABLE' DIRECTLY IN FRONT OF BINARY DECK ST1, AND INSERTING A CCNTROL CARD PUNCHED '$ORIGIN ABLE, REW' DIRECTLY IN FRCNT OF BINARY DECK ST4.

THE PROGRAM HAS BEEN FURTHER DESIGNED TO TAKE ADVANTAGE OF THE 'BLOCK DATA' FEATURES CF FORTRAN 4. THE SYMBOLIC REPRESENTATICNS OF A LARGE NUMBER OF CONSTANTS HAVE BEEN COLLECTED IN BLOCK DATA SUBROUTINE BLDT SO THAT THEY CAN BE GROUPED IN A SPECIAL 'NAMED' OR 'LABELLED' FORM OF COMMON STORAGE (DENOTED BY 'CCNS' IN THE PROGRAM). SINCE ALL THEIR VALUES ARE ESTABLISHED BY THIS CNE SMALL SUBROUTINE, SUCH CONSTANTS CAN BE CHANGED

WITHOUT RECOMPILING ANY SUBROUTINE EXCEPT BLOT. THIS IS ESPECIALLY HELPFUL IN THE CASE OF INPUT-OUTPUT TAPE ASSIGNMENTS THAT MAY DIFFER IN DIFFERENT INSTALLATIONS. ADDITIONALLY, THERE IS A REAL ADVANTAGE IN BEING ABLE TO MODIFY CONSTANTS LOCALLY APPROPRIATE FOR BARK AND UPPER-STEM PROJECTIONS OR BOARD-FOOT CONVERSIONS WITHOUT TROUBLESOME RECOMPILATIONS OF NUMEROUS OR LENGTHY SUBROUTINES.

STX WILL NOT RUN EFFICIENTLY ON BUSINESS-TYPE, VARIABLE-WORD-LENGTH COMPUTERS. SCIENTIFIC-TYPE BINARY COMPUTERS WITH AT LEAST 16,000 WORDS OF CORE MEMORY AND WITH FORTRAN 4 COMPILERS ARE NEEDED. HOWEVER, EVEN SOME OF THESE MAY REQUIRE MINOR PROGRAM MODIFICATIONS BECAUSE OF LOCAL PECULIARITIES.

A FEW OF THE LOCAL MODIFICATIONS SOMETIMES NEEDED ARE DESCRIBED BELOW.

IF AN INSTALLATION DOES NOT EMPLOY SYSTEM SUBROUTINE FXEM WITH OPTIONAL ENTRYPOINT FXMSET, THEN THE FIRST TWO EXECUTABLE STATEMENTS IN ST1 AND ALSO IN ST2 SHOULD BE DELETED OR REPLACED BY 'CONTINUE' STATEMENTS. THE STATEMENTS INVOLVED ARE 'ASSIGN XXXX TO MFL' AND 'CALL FXMSET (MFL, NERR, 32, 35)'.

IF THE COMPILER LACKS THE ABILITY TO HANDLE AS MANY AS 19 CONTINUATION CARDS, THEN A 'COMMON' CARD MUST BE INSERTED BETWEEN CONTINUATION CARDS 7 AND 8 OF THE 'COMMON' STATEMENTS IN STX AND IN ALL SUBROUTINES EXCEPT THE DUMMIES AND THE SKELETON ST4.

IF THE COMPILER LACKS THE 'BLOCK DATA' FEATURE, THEN BLOT MUST BE OMITTED, AND THE VALUES FOR ALL ITS CONSTANTS MUST BE ESTABLISHED EARLY IN PROGRAM STX BY THE OLDER TYPE OF 'EQUALS' STATEMENTS.

FINALLY, INSTALLATIONS FORBIDDING DIRECT ADDRESSING OF PERIPHERAL PUNCH TAPES MUST REPLACE 'WRITE (MPU, 22) . . .' WITH 'PUNCH 22 . . .' ON CARD 186 OF ST2, AND SIMILARLY REPLACE 'WRITE (MPU, 21) . . .' WITH 'PUNCH 21 . . .' ON CARD 196 OF ST2.

==================================INPUT==================================

BEFORE PROCESSING OF ACTUAL DATA IS POSSIBLE, THE SOURCE PROGRAM LISTED IN APPENDIX A MUST BE COMPILED INTO A BINARY OBJECT PROGRAM ACCEPTABLE TO THE LOCAL MACHINE INSTALLATION. IF THE NECESSARY LOCAL PROGRAM MODIFICATIONS JUST DISCUSSED HAVE BEEN MADE WHERE NEEDED, THE ONLY PROGRAM FEATURE NEEDING ATTENTION IS TO ESTABLISH CERTAIN APPROPRIATE LOCAL CONSTANTS IN SUBROUTINE BLDT (OR IN STX IF BLOCK DATA IS UNACCEPTABLE).

CARDS 7, 8, AND 9 OF BLDT CONTAIN SPACE FOR ALL THE VALUES NEEDING INITIAL ESTABLISHMENT IN THE PROGRAM ITSELF (AS OPPOSED TO DATA-ESTABLISHED CONSTANTS).

THE POSITIVE OR NEGATIVE INTEGER FOLLOWING MRE ON CARD 7 OF BLDT SHOULD BE THE LOGICAL NUMBER OF THE SYSTEM INPUT TAPE. SIMILARLY, THE INTEGER FOLLOWING MPR SHOULD BE THE LOGICAL NUMBER OF THE SYSTEM OUTPUT TAPE, AND THE INTEGER FOLLOWING MPU SHOULD BE THE LOGICAL NUMBER OF THE SYSTEM PUNCH TAPE. INTEGERS FOLLOWING JW AND JX SHOULD BE LOGICAL NUMBERS FOR SYSTEM BCD SCRATCH TAPES.

THE DECIMAL FRACTION FOLLOWING HYPB IS A COEFFICIENT DEEMED APPROPRIATE FOR HYPERBOLIC PROJECTION OF UPPER STEM, TAKING INTO CONSIDERATION CERTAIN LOWER STEM MEASUREMENTS (*3).

THE DECIMAL NUMBERS FOLLOWING BCRD, SLAB, CLFT ARE COEFFICIENTS FOR CONVERTING CUBIC FEET OF VOLUME, SQUARE FEET OF CIRCUMFERENTIAL SURFACE, AND LINEAL FEET OF LENGTH TO UNITS OF PRODUCT-OUTTURN SUCH AS BOARD FEET (*1). SUCH ROUGH CONVERSTION IS MERELY TO FACILITATE 3P-ERROR CALCULATIONS, WHERE

PREDICTED VARIABLES SUCH AS VALUE OR PRODUCT-OUTTURN (TERMED KPI) ARE COMPARED WITH APPROPRIATELY WEIGHTED COMBINATIONS OF BASIC INSTRUMENTAL DETERMINATIONS.

THE HOLLERITH LITERALS 1H* AND 1H FOLLOWING CRIT AND BLANK ARE NEEDED FOR SORTING PURPOSES. IF THE COMPILER IS UNABLE TO HANDLE BLOCK DATA OR TO ACCEPT HOLLERITH LITERALS IN DATA STATEMENTS, THE STATEMENTS CRIT = - 1370299086 AND BLANK = - 17997958192 INSERTED AT THE BEGINNING OF SUBROUTINE STX WILL SUFFICE WHERE MACHINES SUCH AS THE IBM 7040 HANDLE SIGNED 35-BIT INTEGERS. OTHER INTEGERS WOULD BE APPROPRIATE ON MACHINES OR SYSTEMS WHERE WORDS WERE NOT 36 BITS LONG.

THE DECIMAL FRACTION FOLLOWING RCE IS THE RATIO OF D.I.B/D.O.B. AT BREAST-HEIGHT THAT WILL BE ASSUMED IF NO BARK-MEASUREMENTS HAVE BEEN RECORDED.

THE DECIMAL FRACTION FOLLOWING UCTRO IS THE ASSUMED RATIO OF D.O.B. OF UNSEEN TOP TO D.B.H., OR THE ASSUMED TAPER TO THE UNSEEN TOP IN INCHES PER FOOT. THE FRACTION IS IGNORED WHERE THE OBSERVER RECORDS SOME BETTER ESTIMATE. THE USE OF THE CONSTANT IS DISCUSSED IN MORE DETAIL LATER.

THE DECIMAL NUMBERS FOLLOWING QUAN AND DENO ARE FOR HYPERBOLIC EXTRAPOLATION OF D.I.B./D.O.B. RATIOS ABOVE BREAST HEIGHT. THE PROCESS IS DISCUSSED IN MORE DETAIL LATER.

IF THE PROGRAM HAS BEEN PROPERLY COMPILED WITH APPROPRIATE CONSTANTS AS DISCUSSED ABOVE, EXECUTION REQUIRES ONLY THAT THE BINARY DECKS BE PRECEDED AND FOLLOWED BY APPROPRIATE MONITOR CARDS AND BY ONE OR MORE SETS OF DATA. WHETHER OR NOT THE FIRST SET OF DATA MUST BE IMMEDIATELY PRECEDED BY 2 CARDS PUNCHED '$ENTRY STX' AND '$DATA' DEPENDS ON CONVENTIONS FOLLOWED AT THE PARTICULAR INSTALLATION.

APPENDIX A LISTS THE SOURCE DECKS FOR PROGRAM STX AND ITS SUBROUTINES

SUITABLY ARRAYED FOR COMPILATION ON THE IBM 7090 AT UNIVERSITY OF CALIFORNIA (BERKELEY).

APPENDIX B LISTS 5 SETS OF INPUT DATA USED IN DEBUGGING AND OBTAINING ILLUSTRATORY OUTPUT.

FIVE CONTROL CARDS MUST ALWAYS PRECEDE EACH SET OF DATA CARDS THAT IS TO BE SEPARATELY PROCESSED. THE FIELDS OF THESE CARDS ALONG WITH THE FORMAT AND LIST OF VARIABLES OCCUPYING THESE FIELDS ARE DESCRIBED IN FIGURES 1 THROUGH 3.

THE FIRST CARD IDENTIFIES THE PARTICULAR AREA OR BODY OF TREES BEING MEASURED, AND FURNISHES A SHORT 4-CHARACTER IDENTIFIER USED TO IDENTIFY PUNCHED OUTPUT AND CERTAIN ERROR DIAGNOSTICS (IF ANY).

THE SECOND CARD GIVES THE INITIALS OF THE PERSON RESPONSIBLE FOR HANDLING THE PARTICULAR SET OF DATA, AND THE DATE OF INPUT. IN ADDITION, IT FURNISHES INSTRUMENT AND SAMPLE-DESIGN PARAMETERS AND SPECIFIES A PARTICULAR JOB-PROCESSING OPTION IN EACH OF 6 DIFFERENT CATEGORIES.

THE THIRD AND FOURTH CARDS CAN BE LEFT BLANK IF THE FIRST OF THESE STX JOB OPTIONS IS LEFT BLANK, PUNCHED 0, OR PUNCHED 1. IF THE FIRST JOB-OPTION IS PUNCHED 2 OR GREATER, THE THIRD CARD MUST CONTAIN THE TOTAL NUMBER OF TREES IN EACH STRATUM, AND THE FOURTH CARD MUST CONTAIN THE AGGREGATE PREDICTED VOLUME OR VALUE OF ALL TREES IN EACH STRATUM. THESE TOTALS MUST INCLUDE NOT ONLY SURE-TO-BE-MEASURED TREES AND 3P-MEASURED TREES, BUT ALSO ALL TREES HAVING A 3P PREDICTION ONLY.

THE FIFTH CARD CONTAINS AN ARBITRARY RELATIVE VALUE PER UNIT VOLUME FOR TREES IN EACH STRATUM. ANY OR ALL STRATA LEFT BLANK WILL BE UNDERSTOOD TO HAVE A RELATIVE VALUE OF UNITY.

THE LABELS ON FIGURES 1 THROUGH 3 ARE SELF-EXPLANATORY FOR THE MOST PART WHEN COUPLED WITH THE FORMAT AND LIST SHOWN BENEATH EACH. HOWEVER, PARAMETERS B, Q, U, G, K + Z, K, Q2 ARE MORE FULLY EXPLAINED BELOW.

B IS THE SHORT-BASE-RANGEFINDER DENDROMETER OPTICAL BASE IN INCHES.

Q IS THE SINE OF 1/2 THE MAXIMUM DEFLECTION CAUSED BY COUNTER-ROTATION OF SHORT-BASE-RANGEFINDER DENDROMETER PRISMS AWAY FROM NEUTRAL POSITION.

U IS THE CONSTANT AMOUNT OF DEFLECTION (IN DEGREES) BUILT INTO A GIVEN SHORT-BASE-RANGEFINDER DENDROMETER AND ALGEBRAICALLY ADDED TO THE VARIABLE DEFLECTION CAUSED BY PRISMS' COUNTER-ROTATION.

G IS THE REFRACTIVE INDEX OF THE GLASS USED IN THE COUNTER-ROTATING PRISMS.

K + Z IS THE TOTAL NUMBER OF OPPORTUNITIES FOR SELECTION OR REJECTION SPECIFIED BY THE 3P-SAMPLING DESIGN.

K IS THE LARGEST ASSIGNABLE RELATIVE SAMPLING PROBABILITY IN A 3P-SAMPLING DESIGN (EQUIVALENT TO THE NUMBER OF NON-NULL OPPORTUNITIES SPECIFIED BY THE 3P-SAMPLING DESIGN).

Q2 IS RESERVED FOR AN INSTRUMENT PARAMETER POSSIBLY NEEDED WHEN WRITING SUBROUTINES OCL OR CFK FOR CONVERTING INSTRUMENT READINGS OF A DIFFERENT SORT TO DIAMETER, HEIGHT, AND RANGE.

REFERENCES (*2) AND (*3) EXPLAIN DENDROMETER GEOMETRY AND 3P-SAMPLING THEORY MORE FULLY.

THE SIX JOB-OPTIONS OF THE SECOND CONTROL CARD ARE SPECIFIED BY PUNCHING OF COLUMNS 66-71, THUS--

```
              (0 OR 1     INPUT CARDS MUST BE PUNCHED FOR ALL TREES (INCLUDING
              (           NON-MEASURED TREES ASSIGNED PREDICTIONS ONLY), BUT
              (           THIRD AND FOURTH CONTROL CARDS ARE LEFT BLANK.
              (
FIRST (66)    (2 OR 2+    INPUT CARDS MUST BE PUNCHED ONLY FOR MEASURED TREES,
              (           BUT AGGREGATE NUMBER OF TREES AND AGGREGATE
              (           PREDICTIONS FOR EACH STRATUM (INCLUDING SURE-TO-BE-
              (           MEASURED TREES, 3P-MEASURED TREES, AND 3P-
              (           PREDICTED-ONLY TREES) MUST BE PUNCHED ON THE
              (           THIRD AND FOURTH CONTROL CARDS.


              (0 OR 1     PROCESSING WILL CEASE AFTER ST1 HAS CALCULATED AND
              (           PRINTED PRELIMINARY REPORT.
SECOND(67)    (
              (2 OR 2+    PROCESSING WILL CONTINUE BEYOND ST1 IF NO FATAL ERRORS
              (           OCCUR.


              (0 OR 1     NO INDIVIDUAL TREE DETAIL WILL BE PRINTED.
              (
THIRD (68)    (2          INDIVIDUAL TREE DETAIL WILL BE PRINTED.
              (
              (3 OR 3+    INDIVIDUAL LOG AND TREE DETAIL WILL BE PRINTED.


              (0 OR 1     NO DETAIL CARDS WILL BE PUNCHED AS PART OF OUTPUT.
              (
FOURTH(69)    (2          TREE DETAIL CARDS WILL BE PUNCHED AS PART OF OUTPUT.
              (
              (3 OR 3+    LOG DETAIL CARDS WILL BE PUNCHED AS PART OF OUTPUT.


              (0 OR 1     NO LOG AND TREE DETAIL WILL BE WRITTEN ON TAPE JX FOR
              (           LATER GRADE-YIELD AND REALIZATION PROCESSING BY ST4.
FIFTH (70)    (
              (2 OR 2+    LOG AND TREE DETAIL WILL BE WRITTEN ON TAPE JX AND IT
              (           WILL BE PROCESSED BY ST4 IF NO FATAL ERRORS TRUNCATE
              (           PROCESSING.


SIXTH (71)    (           CURRENTLY RESERVED FOR USE WHEN ST4 IS EXPANDED.
```

IF A FATAL FLAW IS DETECTED DURING EXECUTION OF ST1, IT WILL CAUSE A DIAGNOSTIC ERROR MESSAGE TO BE PRINTED--THEN ADDITIONAL DATA WILL BE SCANNED FOR ERRORS, BUT NO SUMMARY WILL BE PRINTED. AND PROCESSING BY ST2, ST3, AND ST4 WILL BE BLOCKED. IF A FATAL FLAW IS DETECTED IN ST2, A DIFFERENT DIAGNOSTIC WILL BE PRINTED, AND ADDITIONAL INDIVIDUAL TREES WILL BE PROCESSED AND PRINTED, BUT NO MORE SUMMARIZATION OR CARD PUNCHING WILL BE ALLOWED, EXCEPT FOR THE DATA PROCESSING STATISTICS PRINTED ON A PAGE ALWAYS NUMBERED 'ZERO'.

ACTUAL DATA INPUT INVOLVES ONLY 2 CARD FORMS--TREE CARDS AND DENDROMETER CARDS. A SPECIAL FORM OF TREE CARD THAT IS BLANK EXCEPT FOR TREE NUMBER PUNCHED 9999 IS USED AS A JOB-END CARD FOR EACH OF A GROUP OF SIMILAR JOBS AND ALSO AS A FINAL SIGNAL FOR TERMINATION EXIT OF THE PROGRAM (NO MORE JOBS OR SETS OF DATA TO PROCESS). OBVIOUSLY, NO TREE NUMBER HIGHER THAN 9998 CAN BE ASSIGNED TO REAL TREES.

TREE INPUT CARD SHOWN IN FIGURE 4 IS LARGELY SELF-EXPLANATORY. COLUMN 11 DENOTES TREE SAMPLING CLASS THUS--BLANK INDICATES A 3P-PREDICTED-ONLY TREE, *INDICATES A 3P-SAMPLE TREE, AND = INDICATES A SURE-TO-BE-MEASURED TREE.

THE THREE TREE-CPTICNS CN EACH TREE-CARD ARE SPECIFIED BY PUNCHING OF COLUMNS 23-25, THUS--

```
              (C CR 1    TREE MEASURED BY SHCRT-BASE-RANGEFINDER AND SBR.
              (
              (2         TREE MEASURED BY OPTICAL CALIPERS AND OCL (OR AS
FIRST (23)    (          DESIRED).
              (
              (3 CR 3+   TREE MEASUREC BY CPTICAL FCRK ANC OFK (OR AS DESIRED).

              (C CR 1    CONSTANT   RATIO  (C.I.B.)/(D.O.B.) ASSUMED
              (          = (D.B.H.I.B.)/(D.B.H.O.B.)
              (
              (2         HYPERBOLIC RATIO  (D.I.B.)/(D.O.B.) ASSUMED
SECCNC(24)    (          = QUAN/(CENO-C.O.B./D.B.H.O.B.) ALL MULTIPLIED BY
              (            (D.B.H.I.B.)/(D.B.H.O.B.)
              (
              (3 CR 3+   VARIABLE   RATIO  (D.I.B.)/(D.O.B.) ASSUMED
              (          = FUNCTICN FB3 SUPPLIED BY USER.

              (O OR 1    UNSEEN BUT USABLE MATERIAL ABOVE LAST MEASURED SECTION
              (          CF TREE ESTIMATED BY HYPERBOLIC PRCJECTION.
              (
              (2         UNSEEN BUT USABLE MATERIAL ABOVE LAST MEASURED SECTION
THIRD (25)    (          OF TREE ESTIMATED BY CONIC PROJECTION.
              (
              (3 CR 3+   UNSEEN BUT USABLE MATERIAL ABOVE LAST MEASURED SECTION
              (          CF TREE ESTIMATED FROM USER-SUPPLIED FUNCTIONS FH3,
              (          FS3, FV3.
```

THIS THIRC SET CF OPTIONS IS IGNCRED UNLESS A FICTITIOUS SET OF DENDROMETER READINGS IS RECORCED AFTER THE LAST MEASURED SET, CR UNLESS A FICTITIOUS NEGATIVE VALUE FOR FGRADS IS RECORDED AFTER THE LAST ACTUALLY MEASURED VALUE. THE FICTITICUS SET OF READINGS SHCULD HAVE SINELV AND TGRADS EQUAL TO PRECEDING SINELV AND TGRADS, WITH FGRADS EQUAL TO TGRADS. A TERMINATING FICTITIOUS NEGATIVE FGRADS ACHIEVES THE SAME RESULT MORE SIMPLY. THE PRESENCE CF UNSEEN MATERIAL IN A TREE WILL BE FLAGGED LATER BY AN ASTERISK IN PRINTED CR PUNCHED TREE-TCTAL CUTPUT.

SOME CF THE CETAILS INVOLVEC IN THE HYPERBOLIC AND CONIC PROJECTICNS ARE DISCUSSED IN FIGURE 4 OF REFERENCE (*3). APPRCPRIATE VOLUME INTEGRALS

ARE USED FOR BOTH HYPERBOLIC AND CONIC PROJECTIONS, WHILE THE SURFACE INTEGRALS ARE CLOSELY APPROXIMATED. HYPERBOLIC ASYMPTOTES DEPEND ON TREE DBH AND THE HYPERBOLIC PARAMETER 'HYPB' IN CONS, CURRENTLY VALUED AT .62069 BUT EASILY CHANGED BY REASSEMBLING BLDT.

THE FIELDS LABELLED UMAXL AND UDORT ON THE TREE INPUT CARD ARE LEFT BLANK UNLESS A FICTITIOUS SET OF DENDROMETER READINGS IMPLYING UNSEEN USABLE MATERIAL HAS BEEN RECORDED. THEN IF THE THIRD TREE OPTION IS PUNCHED (1) OR (3), THE PROGRAM WILL COMPUTE UPPERMOST UNSEEN D.O.B. AS UDORT X DBH. IF THE THIRD TREE OPTION IS PUNCHED (2), THE UPPERMOST UNSEEN D.O.B. IS PROGRAM-COMPUTED AS THE HIGHEST MEASURED D.O.B. MINUS UDORT X UMAXL--THIS IS A STRAIGHTFORWARD CONIC PROJECTION TREATING UMAXL AS THE UNSEEN LENGTH IN FEET, AND UDORT AS THE RATE OF TAPER IN INCHES PER FOOT OF LENGTH. IF UMAXL IS LEFT BLANK OR ZERO WHEN THE THIRD OPTION IS PUNCHED (1) OR (3), THE UNSEEN LENGTH IS COMPUTED FROM HYPERBOLIC OR USER-SUPPLIED FUNCTIONS. IF A POSITIVE VALUE IS PUNCHED IN UMAXL IN THESE TWO SITUATIONS, UMAXL IS TREATED AS A MAXIMUM POSSIBLE LENGTH, AND ANY COMPUTED LENGTHS EXCEEDING IT WILL BE REDUCED TO LENGTH SPECIFIED BY UMAXL. IF UDORT IS LEFT BLANK BUT DENDROMETER READINGS IMPLY UNSEEN MATERIAL ABOVE LAST MEASURED SECTION, UDORT WILL BE SET EQUAL TO UDTRO, A PARAMETER CURRENTLY SET AT .45 BUT EASILY CHANGED BY REASSEMBLY OF BLDT. NOTE THAT UMAXL SHOULD NOT BE LEFT BLANK IF THE CONIC PROJECTION HAS BEEN SPECIFIED--IT WOULD IMPLY ZERO ADDITIONAL LENGTH.

THE FIELDS XTRA AND XTRB ARE RESERVED FOR USE AS DESIRED IN USER-SUPPLIED FUNCTIONS CCL OR CFK.

CERTAIN OTHER CONVENIENT PROGRAM FEATURES SHOULD BE DICUSSED AT THIS POINT. IF THE COLUMN FOR TOTAL NUMBER OF STRATA ON THE SECOND CONTROL CARD IS LEFT BLANK OR PUNCHED ZERO, IT WILL BE CONSIDERED TO BE THE SAME AS

HAVING A (1) PUNCHED. SIMILARLY, IF THE INDIVIDUAL TREE VALUE STRATUM IS LEFT BLANK OR PUNCHED ZERO, IT WILL BE CONSIDERED TO BE IN STRATUM (1). THUS, WHERE SAMPLING IS TO BE PROPORTIONAL TO VOLUME (RATHER THAN VALUE), NO STRATIFICATION IS NEEDED AND ALL VALUE STRATA FIELDS CAN BE IGNORED OR LEFT BLANK. A MAXIMUM OF 9 VALUE STRATA MAY BE USED IN COLUMN 10 TO FACILITATE VARYING SAMPLING INTENSITY, BUT STRATIFICATION FOR OTHER PURPOSES IN COLUMNS 12 - 16 OF THE TREE INPUT CARD IS PRACTICALLY UNRESTRICTED.

A BLANK DBH FIELD WILL CAUSE AN ESTIMATE OF D.B.H. TO BE SUPPLIED FROM THE SECOND SET OF DENDROMETER READINGS (THE SET NEXT ABOVE THE STUMP SET), AND THE NUMBER OF THE TREE WILL BE RECORDED IN THE LIST OF SUSPICIOUS TREES-- ALSO, THE TREE CARD PUNCHED FOR THIS TREE WILL SHOW ZERO BASAL AREA.

A BLANK FIELD IN ANY OF THE 3 TREE OPTIONS WILL BE TREATED AS THOUGH A (1) WERE PUNCHED.

IF ONLY ONE OF THE TWO FIELDS FOR RECORDING SINGLE-BARK THICKNESS IS PUNCHED, THE PROGRAM WILL DOUBLE THAT VALUE TO ESTIMATE TOTAL BARK THICKNESS. IF BOTH FIELDS ARE PUNCHED, IT WILL ADD THEM. IF THE SECOND TREE-OPTION (DEALING WITH PROJECTION OF BARK THICKNESS) IS LEFT BLANK AND IF THE SOLE BARK PUNCHED IS NEGATIVE (OR IF BOTH PUNCHED BARKS ARE NEGATIVE), THE PROGRAM WILL CALCULATE VOLUMES AND SURFACES OUTSIDE BARK. THE ONLY INDICATION OF BARK INCLUSION WILL BE A NEGATIVE BARK THICKNESS SHOWN ON PRINTED OR PUNCHED OUTPUT OF TREE TOTALS. IF BOTH BARKS ARE LEFT BLANK OR ARE PUNCHED ZERO, THE RATIO D.I.B./D.O.B. AT BREAST HEIGHT WILL BE SET EQUAL TO RDE, A PARAMETER CURRENTLY VALUED AT .90 BUT EASILY CHANGED BY REASSEMBLING BLDT. OMISSION OF BOTH BARKS ON THE INPUT (CAUSING USE OF RDE IN ESTIMATING D.I.B.) IS FLAGGED BY THE APPEARANCE OF A ZERO OR A MINUS ZERO IN THE BARK FIELD OF PRINTED OR PUNCHED OUTPUT OF TREE TOTALS (BLANKS ARE FLAGGED BY MINUS ZERO AT MANY BUT

NOT ALL INSTALLATIONS).

FINALLY, THE LINEAR COMPOUND USED IN THE CALCULATION OF RELATIVE ERROR OF A 3P SAMPLE SHOULD BE MENTIONED. THE PROGRAM ASSUMES THAT THE RELATIVE PROBABILITIES ASSIGNED EACH TREE ARE INTENDED TO BE PROPORTIONAL EITHER TO BOARD FOOT VOLUME OR TO BOARD FOOT VOLUME WEIGHTED BY RELATIVE VALUE. THESE AND A WIDE VARIETY OF OTHER POSSIBLE VARIABLES OF INTEREST CAN BE ESTIMATED BY FUNCTIONS OF THE TYPE DISCUSSED IN REFERENCE (*1)--(BORD X VOLUME + SLAB X SURFACE + CLFT X LENGTH) X (WV) WHERE BORD, SLAB, CLFT ARE PARAMETERS IN /CONS/ CURRENTLY ESTABLISHED AT 9.1236718, -.70845732, .042222227, AND WV IS A RELATIVE VALUE PER UNIT IN EACH STRATUM READ FROM THE FIFTH CONTROL CARD. BORD, SLAB, CLFT CAN EASILY BE CHANGED TO FIGURES MORE CONSISTENT WITH LOCAL MILLING PRACTICE BY REASSEMBLING BLDT.

AS WAS NOTED EARLIER, ONLY MINOR MODIFICATIONS IN THE PROGRAM ARE NEEDED TO ALLOW ASSIGNING RELATIVE PROBABILITIES PROPORTIONAL TO BASAL AREA, D.B.H., PLOT SIZE, ETC., BUT SUCH ASSIGNMENTS WOULD USUALLY BE MUCH LESS EFFICIENT WHERE VOLUME OR VALUE ARE THE VARIABLES OF INTEREST.

AFTER A TREE CARD HAS BEEN PUNCHED, WITH THE COLUMN FOLLOWING THE TREE NUMBER EITHER PUNCHED ZERO OR LEFT BLANK, UP TO 9 DENDROMETER CARDS (NUMBERED SEQUENTIALLY IN THE COLUMN FOLLOWING TREE NUMBER) MAY FOLLOW. THE ILLUSTRATION IN FIGURE 5 IS FOR OBSERVATIONS MADE WITH A SHORT BASE-RANGEFINDER-DENDROMETER. OPTICAL CALIPERS AND FORKS WOULD USE THE SAME FIELDS (OR LEAVE SOME FIELDS BLANK), BUT THEY WOULD REPRESENT DIFFERENT VARIABLES. EVEN MECHANICAL CALIPERS OR DIAMETER TAPES COULD BE USED. EACH SET OF READINGS WOULD BE CONVERTED TO DIAMETER, ELEVATION, AND REAL OR FICTITIOUS RANGE BY THE APPROPRIATE SUBROUTINE (SBR, CCL, CFK).

THE DENDROMETER CARD REPEATS THE TREE NUMBER AND FOLLOWS IT WITH A

WITHIN-TREE CARD SEQUENCE NUMBER STARTING WITH 1 BUT NEVER PROGRESSING HIGHER THAN 9. TRIOS OF DENDROMETER READINGS (TGRADS, FGRADS, SINELV) ARE THEN RECORDED, STARTING AT THE STUMP (OR BASE) OF THE TREE, WITH THE SECOND TRIO OF READINGS MEASURING D.B.H. REFERENCE (*2) EXPLAINS THE MEANING OF THESE TERMS FOR SHORT-BASE-RANGEFINDER-DENDROMETERS. USERS EXPANDING SUBROUTINES OCL OR OFK SHOULD ALWAYS EMPLOY FGRADS AS A VARIABLE NAME. TGRADS OR SINELV MAY BE OMITTED IF ONLY 2 VARIABLES ARE NEEDED. READINGS PROGRESS UPWARDS--NOTE THAT THIS IS OPPOSITE TO THE DIRECTION SPECIFIED IN THE SMALL EXPLORATORY COMPUTER PROGRAM OUTLINED IN REFERENCE (*2). THE UPWARD PROGRESSION HANDLES FORKED TREES MORE LOGICALLY, AND ALLOWS BETTER IDENTIFICATION OF A TREE WITH MEASURED D.B.H. ASSOCIATED WITH EACH TRIO OF READINGS IS A 2-CHARACTER FIELD TO BE USED FOR CHARACTERIZING EXTERNAL QUALITY (AND DEFECT) OF THE TREE SECTION BETWEEN THAT DIAMETER AND THE ONE NEXT BELOW IT.

IF COLUMN 72 IS LEFT BLANK ON A DENDROMETER CARD, IT IMPLIES THAT THE CARD IS COMPLETELY FILLED WITH 4 TRIOS OF DENDROMETER READINGS, AND THAT THE PARTICULAR TREE IS BEING CONTINUED ON A FOLLOWING CARD.

IF COLUMN 72 IS PUNCHED WITH AN ASTERISK (*), IT MEANS THAT THE LAST SET OF DENDROMETER READINGS OCCURS SOMEWHERE ON THAT PARTICULAR CARD, AND THAT THE NEXT CARD SHOULD BE A TREE CARD FOR A NEW TREE, OR A TERMINATING 9999.

IF COLUMN 72 IS PUNCHED WITH A PLUS SIGN (+), IT MEANS THAT A TRUNCATING SET OF DENDROMETER READINGS OCCURS SOMEWHERE ON THAT PARTICULAR CARD, BUT THAT MORE MATERIAL FOR THE SAME TREE STARTING FROM A NEW 'BOTTOM' (WHICH MIGHT, HOWEVER, BE THE SAME POINT ON THE TREE AS THE PREVIOUS TRUNCATION POINT) WILL OCCUR ON THE VERY NEXT CARD. THIS DEVICE ALLOWS CHANGING POSITION ONCE UPHILL OR DOWNHILL FOR BETTER VISIBILITY DURING THE MEASUREMENT OF A SINGLE-STEMMED TREE--HERE THE FIRST MEASUREMENTS FROM THE NEW VIEWPOINT RECORDED ON THE CARD

FOLLOWING THE CARD WITH THE TRUNCATING PLUS SIGN SHOULD BE OF THE SAME DIAMETER ON THE TREE AS THAT WHICH TRUNCATED THE PREVIOUS CARD WHEN MEASURED FROM THE OLD VIEWPOINT. THE HEIGHTS OF DIAMETERS AFTER TRUNCATION WILL ALL BE MEASURED ABOVE THE NEW 'BOTTOM' TO WHICH WILL BE ADDED THE TRUNCATING HEIGHT ON THE CARD WITH THE INITIAL PLUS SIGN. WHEN VIEWPOINT IS CHANGED ALONG THE CONTOUR (WITH NO CHANGE IN BASE ELEVATION), THE TRUNCATION AND PLUS PROCEDURE IS UNNECESSARY--THE USER GOES RIGHT ON UP THE TREE AS THOUGH HE HAD NOT CHANGED POSITION.

TREES WITH ANY NUMBER OF FORKS ABOVE BREAST HEIGHT CAN BE HANDLED BY THE TRUNCATION PROCEDURE. THE SINGLE PORTION OF THE STEM IS TRUNCATED WITH THE PLUS SIGN, THEN EACH FORK EXCEPT THE LAST IS MEASURED AND TRUNCATED WITH A PLUS SIGN. THE TALLEST FORK SHOULD ORDINARILY BE LEFT TILL LAST AND SHOULD BE TERMINATED WITH AN ASTERISK RATHER THAN A PLUS SIGN TO SHOW THAT NO MORE MATERIAL IN THAT TREE WILL BE MEASURED. FORKED TREES ARE FLAGGED BY AN ASTERISK ON PRINTED OR PUNCHED TREE-TOTAL RECORDS.

AFTER THE LAST CARD OF THE LAST TREE ON A GIVEN AREA OR JOB, A JOB-END CARD (ILLUSTRATED IN FIGURE 6) SHOULD FOLLOW, PUNCHED ONLY 9999 IN THE FIRST 4 COLUMNS.

IN ADDITION TO THIS JOB-END CARD, ANOTHER SIMILAR CARD SHOULD BE PLACED AFTER IT WHEN NO MORE SETS OF DATA FOLLOW. SUCH A PROGRAM-END CARD FOLLOWING A SIMILAR JOB-END CARD WILL TERMINATE USE OF PROGRAM STX AND WILL EXIT FROM THE COMPUTER.

FIGURE 7 ILLUSTRATES A SINGLE CARD LAYOUT THAT FACILITATES PUNCHING EITHER TREE DATA OR DENDROMETER DATA.

==========================DIAGNOSTICS AND ERRORS==============================

AN ERROR SIGNAL WILL BE PRINTED IF SUBROUTINE ST1 ENCOUNTERS ERRORS SUCH AS A WITHIN-TREE CARD SEQUENCE NUMBER THAT IS NEGATIVE, A NEGATIVE STRATUM NUMBER OR ONE EXCEEDING THE NUMBER OF STRATA SPECIFIED ON THE JOB CONTROL CARD, OR A SAMPLE-TREE PREDICTION (KPI) THAT IS BLANK, ZERO, NEGATIVE, OR LARGER THAN THE MAXIMUM (K) SPECIFIED ON THE JOB CONTROL CARD.

THE ERROR SIGNAL CONSISTS OF A PRINTOUT OF THE CURRENT CONTENT OF CERTAIN LOCATIONS IN COMMON (ILLUSTRATED IN FIGURE 8). THE FIRST LOCATION WILL ORDINARILY CONTAIN ZERO UNLESS SUBROUTINE FXMSET HAS BEEN CALLED AT THE START OF ST1, IN WHICH CASE A 32 MIGHT INDICATE THAT A CHARACTER READ VIOLATES THE FORMAT EXPECTED, AND A 35 MIGHT INDICATE A BAD TAPE OR A MACHINE ERROR. THE SECOND LOCATION WILL GIVE THE 4-CHARACTER JOB IDENTIFICATION. SUBSEQUENT LOCATIONS CONTAIN CURRENT TREE NUMBER, WITHIN-TREE CARD SEQUENCE NUMBER, SAMPLING CLASS (=, *, BLANK IMPLYING SURE-TO-BE-MEASURED TREES, 3P-MEASURED TREES, 3P-PREDICTED-ONLY TREES), TERMINAL SYMBOL (*, +, BLANK IMPLYING LAST CARD OF A GIVEN TREE, LAST CARD PRIOR TO FORKING OR ESTABLISHMENT OF NEW REFERENCE ELEVATION, AND A NON-TERMINAL CARD CONTINUED NORMALLY ON A FOLLOWING CARD). FINALLY, TREE NUMBER READ PREVIOUS TO THAT CURRENTLY STORED IS GIVEN. IF CURRENT TREE NUMBER AND PREVIOUS TREE NUMBER ARE THE SAME, IT IS LIKELY THAT BOTH REPRESENT PREVIOUS NUMBER AND THAT THE TREE CARD FOR THE CURRENT TREE CONTAINS AN ILLEGAL CHARACTER OR INVOLVES TAPE REDUNDANCY.

IF ONE OF THESE ERRORS HAS CAUSED A ONE-LINE INFORMATIONAL PRINTOUT OF THE SORT DESCRIBED, ADDITIONAL TREES ARE SCREENED FOR MORE POSSIBLE ERRORS,

BUT ALL FURTHER PROCESSING IS SUPPRESSED.

IF ST1 IS COMPLETED WITHOUT ENCOUNTERING ERRORS, AND IF THE SECOND JOB OPTION ON THE SECOND CONTROL CARD HAS BEEN PUNCHED 2 OR MORE, PROCESSING OF INDIVIDUAL TREES BY ST2 IS STARTED.

A DIFFERENT ERROR MESSAGE WILL BE PRINTED IF CERTAIN ERRORS ARE ENCOUNTERED BY ST2. THE MESSAGE IS OF THE FORM 'ERROR XXX, TREE NUMBER XXXX X XXXX', AS ILLUSTRATED IN FIGURE 9. THE FIRST VARIABLE IS A NUMERICAL CODE FOR THE PARTICULAR ERROR, THE NEXT IS THE TREE NUMBER, THE THIRD IS THE WITHIN-TREE DENDROMETER CARD SEQUENCE NUMBER, AND THE LAST IS THE NUMBER OF THE TREE PREVIOUSLY PROCESSED.

ERROR CODE IN ST2 IS AS FOLLOWS--

(1) IMPLIES A PUNCHING OR MACHINE ERROR INVOLVING NEGATIVE TREE NUMBERS OR TREE NUMBERS LARGER THAN 9999.

(2) IMPLIES A MACHINE ERROR SUCH AS FAILURE TO BRANCH PROPERLY FOR +, *, BLANK, =, OR FAILURE TO COPY THESE FROM INPUT TAPE TO TAPE JW.

(3) IMPLIES A NEGATIVE LENGTH DUE TO HAVING DENDROMETER READINGS PROGRESS FROM TOP TO STUMP. DATA MUST BE REPUNCHED SO THAT IT PROGRESSES UPWARDS.

(4) IMPLIES A DISARRANGED DATA DECK OR FAULTY PUNCHING. FAILURE TO PUNCH TERMINAL * CAN CAUSE THIS, AS CAN VARIATION IN TREE NUMBER (CAUSED BY FAULTY PUNCHING) DURING A SINGLE WITHIN-TREE CARD SEQUENCE. THE MOST COMMON CAUSE IS FAILURE OF WITHIN-TREE CARD SEQUENCE TO BE IN ARITHMETIC PROGRESSION WITH UNIT INTERVAL STARTING WITH ZERO.

(5) IMPLIES A MACHINE ERROR IN FAILING TO CONVERT ZERO, BLANK, OR NEGATIVE STRATUM NUMBER TO UNITY, OR IN FAILING TO DETECT A STRATUM NUMBER LARGER THAN THE CONTROL CARD SPECIFICATION DURING EXECUTION OF ST1.

(6) IMPLIES AN EARLIER MACHINE ERROR IN COPYING SAMPLE-TREE PREDICTION (KPI),

OR IN CONVERTING (KPI) TO FLOATING POINT, OR IN FAILING TO DETECT THAT (KPI) WAS ERRONEOUSLY OMITTED, OR ERRONEOUSLY PUNCHED AS ZERO OR NEGATIVE. (32) AND (35) IMPLY DISAGREEMENT BETWEEN DATA AND FORMAT, AND BAD TAPE. DISARRAY CAN CAUSE (32) TO BE SHOWN, AS DISARRAY MAY CAUSE THE OUT-OF-PLACE CARD TO BE SCANNED BY AN INAPPROPRIATE FORMAT. THESE TWO CODES WILL ONLY BE SHOWN WHERE SUBROUTINE FXMSET HAS BEEN CALLED AT THE START OF ST2.

AFTER PRINTING ANY ONE OF THESE 6 ERROR MESSAGES, ST2 WILL CONTINUE TO PROCESS AND PRINT INDIVIDUAL TREE DATA, BUT ADDITIONAL SUMMARIZATION AND PROCESSING WILL BE SUPPRESSED (EXCEPT FOR DATA-PROCESSING STATISTICS ON PAGE ZERO).

==================================OUTPUT==================================

THE EXAMPLES OF OUTPUT SHOWN IN FIGURES 10 THROUGH 17 ARE WELL ENOUGH LABELLED TO REQUIRE LITTLE ELABORATION.

THE PRELIMINARY PRINTCUT (FIGURE 10) IS PRODUCED WHEN ST1 HAS BEEN ABLE TO COMPLETE ITS PROCESSING OF TREE CARDS WITHOUT ENCOUNTERING A FATAL ERROR. NOTE THAT THE PAGE-HEADING FAITHFULLY REPRODUCES THE MOST ESSENTIAL INFORMATION CONTAINED ON THE FIRST TWO CCNTRCL CARDS (SHOWN IN FIGURE 1). THE SPECIFIED 3P-SAMPLING DESIGN INDICATES THAT (K + Z) IS EQUAL TO 50, WITH MAXIMUM (K) BEING 25. TWO DIFFERENT VALUE STRATA HAVE BEEN SPECIFIED, AND THE DIFFERENT NUMBERS OF TREES AND AGGREGATE PREDICTED VALUES FOR EACH ARE GIVEN. IN ADDITION, THE EXPECTED NUMBER OF SAMPLE TREES (ESN) BASED ON 3P-SAMPLING THEORY IS SHOWN FOR EACH STRATUM AND FOR THE TOTAL. THE ACTUAL NUMBER OF SAMPLE TREES (4) AGREES WELL WITH EXPECTATICN (4.04).

THE DETAILED LOG AND TREE PRINTOUT (FIGURE 11) IS PRODUCED WHENEVER THE THIRD JOB OPTICN IS PUNCHED '3' AND NO FATAL FLAWS HAVE BEEN DETECTED BY ST1. VCLUME, SURFACE, LENGTH, UPPER DIAMETER, AND CODED QUALITY OF EACH INDIVIDUAL LCG BETWEEN CONSECUTIVELY ARRAYED DIAMETERS ARE SHOWN, ALONG WITH THE COMPUTED SLANT RANGE TO EACH DIAMETER AND THE RAW DENDROMETER READINGS.

FINALLY, THE TREE IDENTIFYING NUMBER AND TOTALS FOR VOLUME, SURFACE, AND LENGTH ARE GIVEN, ALONG WITH TREE D.B.H. IN INCHES, POPULATION FREQUENCY REPRESENTED BY THE MEASURED TREE, PREDICTION FOR THE TREE (KPI), DOUBLE-BARK THICKNESS IN INCHES (0. OR -0. SIGNALS THAT NO BARK MEASUREMENT WAS RECORDED), ASTERISK DENOTING A FORKED TREE, TYPE OF DENDROMETER USED, ASTERISK DENOTING A TREE WITH UNSEEN USABLE UPPER STEM, TREE CLASSIFICATION, AND VALUE STRATUM

(APPROPRIATE LABELS WOULD BE THE SAME AS IN FIGURE 14). THUS, TREE NUMBER 21 HAD UNSEEN USABLE UPPER STEM (THE 49.1-FOOT UPPERMOST SECTION IS A PROGRAM-SUPPLIED ESTIMATE OF THIS UNSEEN PORTION, A FACT SUBSTANTIATED BY THE 0. RANGE ASSOCIATED WITH IT). TREE NUMBER 31 IS A FORKED TREE (A FACT SUBSTANTIATED BY THE OCCURRENCE OF TWO 0. LENGTHS ABOVE THE INITIAL 0. LENGTH AT THE STUMP).

THE SUMMARY PRINTOUT FOR THE TREE POPULATION (FIGURE 12) WILL BE PRODUCED BY ST3 WHENEVER THE SECOND JOB-OPTION IS PUNCHED '2' AND NO FATAL FLAWS HAVE BEEN DETECTED BY EITHER ST1 OR ST2. SEPARATE SUMMARIES WILL BE PRODUCED FOR EACH STRATUM AS WELL AS FOR THE WHOLE, BUT THE PERCENTAGE SAMPLING ERROR FOR RELATIVE VALUE WILL BE OMITTED, SINCE IT IS IDENTICAL WITH THAT FOR VOLUME IN THE CASE OF AN INDIVIDUAL STRATUM.

THE SUMMARY PRINTOUT FOR DATA-PROCESSING STATISTICS (FIGURE 13) WILL BE PRODUCED BY ST3 WHENEVER THE SECOND JOB OPTION IS PUNCHED '2' AND NO FATAL FLAWS HAVE BEEN DETECTED BY ST1. THE PAGE NUMBER OF THIS SUMMARY WILL ALWAYS BE ZERO. THE NUMBER OF INPUT FLAWS REPORTED HERE IS A COUNT OF CARDS THAT HAD TO BE IGNORED DUE TO ERROR, TO MISARRAY, OR TO FOLLOWING ERRONEOUS OR MISARRAYED CARDS. SOMETIMES AFTER SUCH ERRORS, CORRECT CARDS IN CORRECT ORDER MUST BE SCANNED AND IGNORED IN ORDER TO PROPERLY ORIENT SUBSEQUENT SCANS. DATA AND OUTPUT ASSOCIATED WITH TREE NUMBERS LISTED AS SUSPICIOUS SHOULD BE CLOSELY EXAMINED. REASONS FOR SUSPICION ARE LACK OF RECORDED D.B.H. (THE PROGRAM USES THE SECOND SET OF DENDROMETER MEASUREMENTS TO PROVIDE A SUBSTITUTE), A POPULATION FREQUENCY OF ONE OR LESS FOR ANY SAMPLE-TREE, OR AN UPPER D.O.B. MORE THAN ONE-HALF INCH LARGER THAN ITS NEXT LOWER D.O.B.

THE AMOUNTS OF INPUT AND PROCESSING DONE BEFORE ENCOUNTERING FATAL FLAWS ARE HELPFUL IN VERIFYING THAT THE SAME NUMBER OF TREE CARDS (8 IN THIS CASE) WERE READ BY ST1 AND BY ST2, AND THAT PROCESSING WAS COMPLETED FOR ALL 8 TREES.

ALSC, THE NUMBER CF TREE OR LCG CARDS PUNCHED AS OPTIONAL OUTPUT MAY BE CHECKED AGAINST THE TCTAL NUMBER OF TREES OR LCGS.

FURTHER REASSURANCE MAY BE OBTAINED FRCM A CHECK OF THE ACTUAL NUMBER OF TREES IN THE PCPULATION AGAINST THE NUMBER ESTIMATED FROM THE SAMPLE (124 VS. 125.2 IN THIS CASE). THE DIFFERENCE ORDINARILY IS A MEASURE CF THE MAGNITUDE OF SAMPLING ERROR. WITH 3P-SAMPLING, THIS NUMERICAL SAMPLING ERROR WILL USUALLY BE LARGER THAN ANY CTHER.

FINALLY, THE AGGREGATE PREDICTIONS SHOULD BE CHECKED AGAINST THE SAMPLE ESTIMATE (284 VS. 284.). THEY SHOULD CHECK EXACTLY OR ELSE ALL SAMPLE-BASED ESTIMATES MUST BE REJECTED. MACHINE ERROR, FAILURE TO DRAW AT LEAST ONE SAMPLE FROM EACH STRATUM, OR THE OCCURRENCE OF SOME FATAL FLAW DESCRIBED IN A DIAGNOSTIC ERROR MESSAGE ARE THE MOST LIKELY REASONS FOR FAILURE TO CHECK.

FIGURE 14 ILLUSTRATES A DETAILED TREE PRINTOUT (WITHOUT LOGS) THAT IS AN ALTERNATIVE PRINTCUT TO FIGURE 11. THE THIRD JOB-OPTION SHOULD BE PUNCHED '2' INSTEAD OF '3' WHEN NO LOG DATA IS DESIRED. IF THE THIRD JOB-OPTION IS LEFT BLANK, OR PUNCHED 0 CR 1, NO DETAILED INFORMATION CN EITHER LCGS OR TREES WILL PRINTOUT.

FIGURES 15 AND 16 ILLUSTRATE ALTERNATIVE PUNCHED CARD OUTPUTS THAT MAY BE OBTAINED IN ADDITION TO WHATEVER PRINTOUTS ARE SECURED. THE FOURTH JOB-OPTION SHOULD BE PUNCHED '2' TC OBTAIN THE TREE CARDS, ANC '3' TO OBTAIN THE LOG CARDS.

FIGURE 17 ILLUSTRATES THE CONSTITUENTS AND THE FORMAT OF INDIVIDUAL LOG AND TREE INFORMATION STORED ON TAPE JX AND PROCESSABLE BY ST4 WHEN EXPANDED BY THE USER. TC STCRE THE INFORMATION ON TAPE JX AND TO CALL ST4 AFTER THE SUMMARY PRINTOUTS PRCDUCED BY ST3, THE FIFTH JOB-OPTION SHOULD BE PUNCHED '2'.

DATA INPUT FCR FIVE GROUPS CF TREES (LABELLED DBUG, EXM1, EXM2, MPT3,

AND MXDB) IS LISTED IN APPENDIX B, WITH CORRESPONDING OUTPUT IN APPENDIX C.

THE APPENDICES ILLUSTRATE THE FOLLOWING UNUSUAL SITUATIONS--

DBUG (TREE 1)	SUSPICIOUS OMITTED D.B.H., SUSPICIOUS TAPER, UNMEASURED BARK, FRONT AND BACK COINCIDENCE.
DBUG (FIRST TREE 4)	UNSEEN UPPER STEM--FICTITIOUS FINAL TGRADS AND FGRADS SAME AS PRECEDING TGRADS, FICTITIOUS FINAL SINELV SAME AS PRECEDING SINELV.
DBUG (SECOND TREE 4)	UNSEEN UPPER STEM--FICTITIOUS FINAL READING MERELY A NEGATIVE FGRADS.
DBUG (LAST TREE 5)	CALCULATION OF OUTSIDE-BARK VOLUMES AND SURFACES, SIGNALLED BY USE OF NEGATIVE BARK MEASUREMENTS.
DBUG (TREE 31)	FORKED TREE.
EXM1 (TREE 9)	SUSPICIOUS SAMPLE-TREE FREQUENCY EQUAL TO OR LESS THAN 1.
MPT3 (STRATUM 1)	STRATUM UNREPRESENTED BY SAMPLE TREE--ON PAGE 0 OF SUMMARY, THE FAILURE OF SAMPLE ESTIMATE (175.) TO CHECK WITH AGGREGATE PREDICTIONS (211) IS DUE TO THIS FACT.
MPT3 (STRATUM 3)	STRATUM REPRESENTED BY ONLY ONE SAMPLE TREE (ERROR CALCULATION IMPOSSIBLE, ZERO ERROR SHOWN).
MPT3 (TREE 41)	NONFORKED TREE TRUNCATED BY CHANGE OF POSITION, WITH ESTABLISHMENT OF NEW REFERENCE ELEVATION.

DBUG AND MXDB ILLUSTRATE HOW TOTAL NUMBER AND PREDICTIONS FOR EACH STRATUM CAN BE INPUT ON CONTROL CARDS 3 AND 4, WHILE EXM1, EXM2, AND MPT3 ILLUSTRATE HOW TO HANDLE INPUTS WHERE AT LEAST ONE CARD IS PUNCHED FOR EVERY TREE IN THE POPULATION. EVEN IN THIS LAST CASE, IT MAY BE DESIRABLE TO INPUT TOTALS BY CONTROL CARD FOR ANY RUNS NECESSARY AFTER SUCCESSFULLY OBTAINING THE PRELIMINARY REPORT, SO AS TO MINIMIZE CARD-HANDLING AND CARD-READING TIME.

ORDINARILY, THE LAST PRINTOUT FOR THE LAST SET OF DATA WILL BE FOLLOWED BY THE MESSAGE 'NORMAL TERMINATION EXIT', INDICATING THAT PERIPHERAL PRINTING OF WHATEVER TAPE OUTPUT WAS SECURED IS COMPLETE AT THIS POINT.

================================LITERATURE CITED=================================

(*1) GROSENBAUGH, L. R. 1954. NEW TREE-MEASUREMENT CONCEPTS--HEIGHT ACCUMULATION, GIANT TREE, TAPER AND SHAPE. U. S. FOREST SERV. SOUTH. FOREST EXPT. STA. OCCAS. PAPER 134, 32 PP.

(*2) GROSENBAUGH, L. R. 1963. OPTICAL DENDROMETERS FOR OUT-OF-REACH DIAMETERS--A CONSPECTUS AND SOME NEW THEORY. FOREST SCIENCE MONOGRAPH 4, 47 PP.

(*3) GROSENBAUGH, L. R. 1964. SOME SUGGESTIONS FOR BETTER SAMPLE-TREE-MEASUREMENT. SOC. AMER. FORESTERS PROC. 1963. (IN PRESS).

FIGURE 1. FIRST AND SECOND CONTROL CARDS.

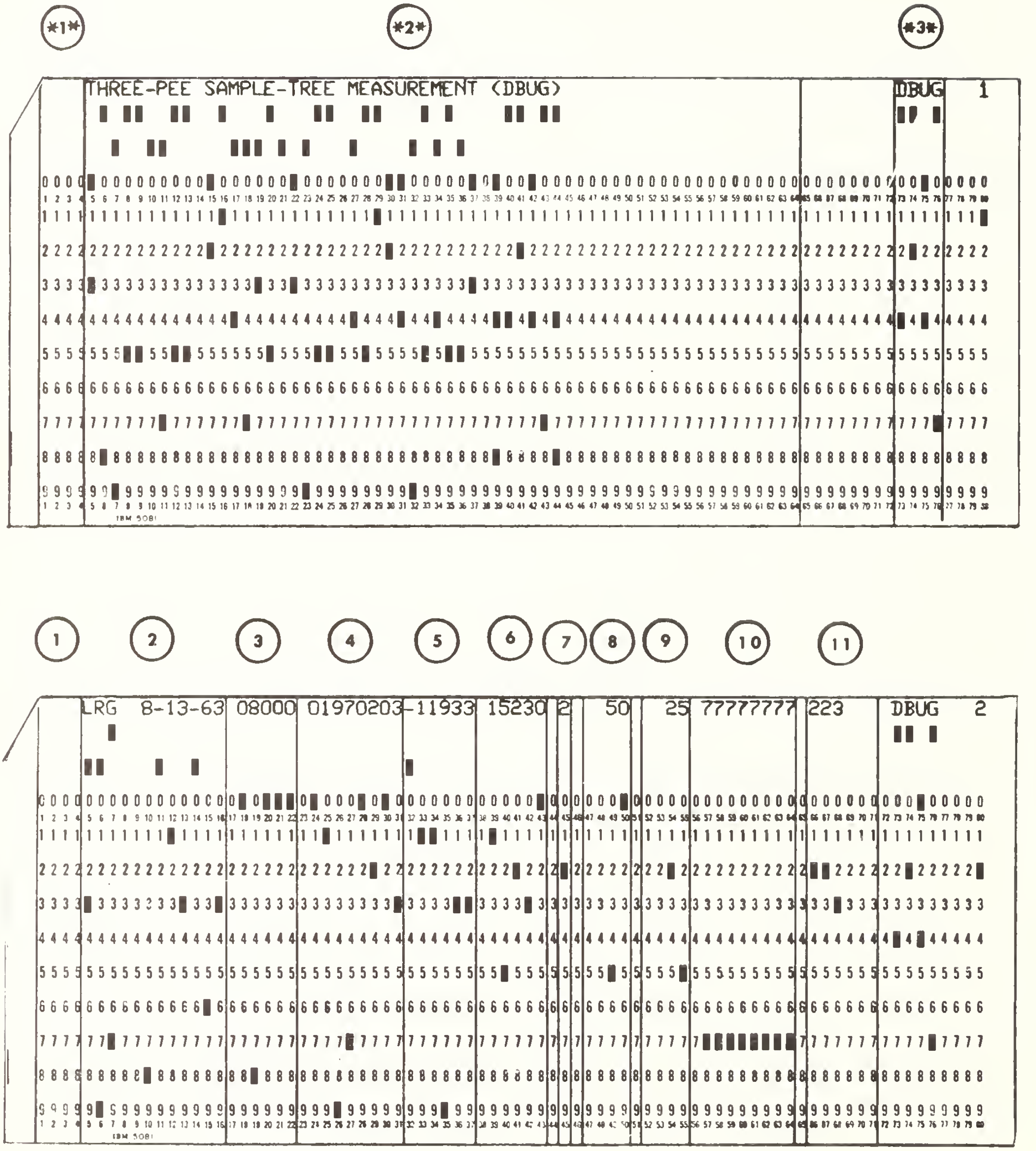
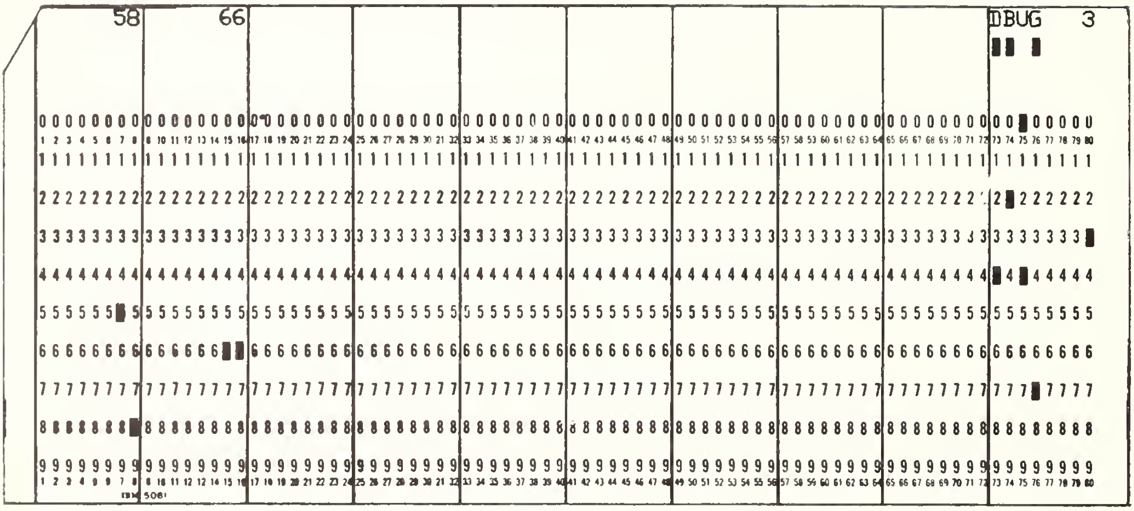


FIGURE 1 (CONTINUED).

```
                         FIRST CONTROL CARD

       *1*=KREENO= ALWAYS BLANK.

       *2*=ALFATH= NAME OF SALE, AREA, OR JOB.

       *3*= COID = BRIEF JCB ICENTIFIER.



                         SECOND CCNTROL CARD

        1 =KREENO= ALWAYS BLANK.

        2 =ADALFA= INITIALS OF USER AND INPUT DATE.

        3 =    B   = SEE TEXT.

        4 =    Q   = SEE TEXT.

        5 =    U   = SEE TEXT.

        6 =    G   = SEE TEXT.

        7 = NSTR = TCTAL NUMBER OF VALUE STRATA USED.

        8 = PRBS = K+Z (SEE TEXT).

        9 =    K   = MAXIMUM POSSIBLE SAMPLE PREDICTION.

       10 =   Q2   = RESERVED FOR POSSIBLE FUTURE USE.

           (LS1)
           (   )
           (LS2)
           (   )
       11 = (LS3)= JOB OPTIONS (SEE TEXT).
           (   )
           (LS4)
           (   )
           (LS5)
           (   )
           (LS6)
```

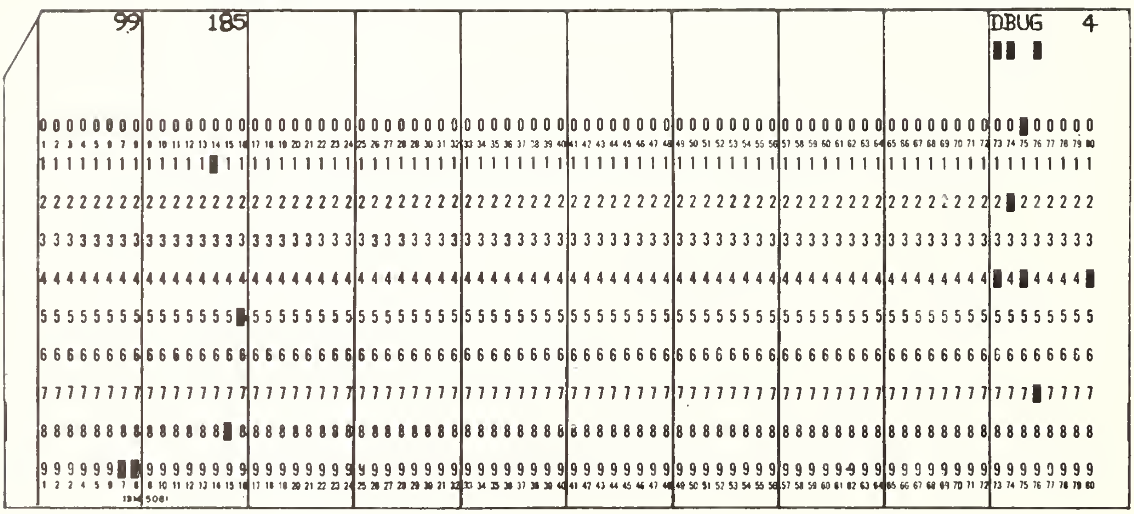
FIGURE 2. THIRD AND FOURTH CONTROL CARDS.

TOTAL POPULATION OF TREES WITHIN EACH VALUE STRATUM.



THIRD CONTROL CARD WILL BE BLANK UNLESS FIRST JOB-OPTION IS '2'.

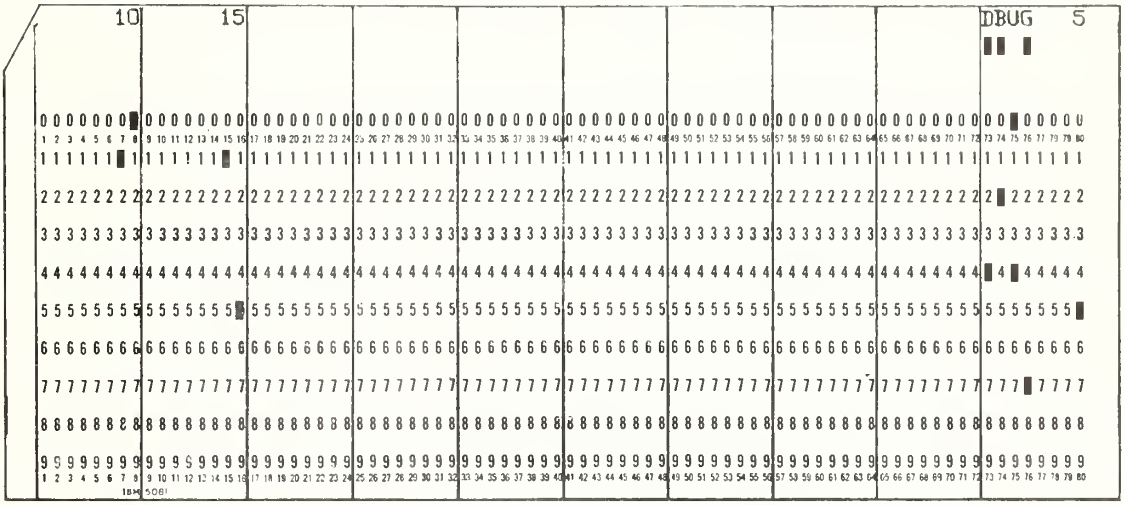
TOTAL PREDICTION FOR TREES WITHIN EACH VALUE STRATUM.



FOURTH CONTROL CARD WILL BE BLANK UNLESS FIRST JOB-OPTION IS '2'.

FIGURE 3. FIFTH CONTROL CARD, WITH FORMATS AND LISTS FOR ALL 5 CONTROL CARDS.

RELATIVE VALUE PER UNIT VOLUME FOR TREES WITHIN EACH VALUE STRATUM.

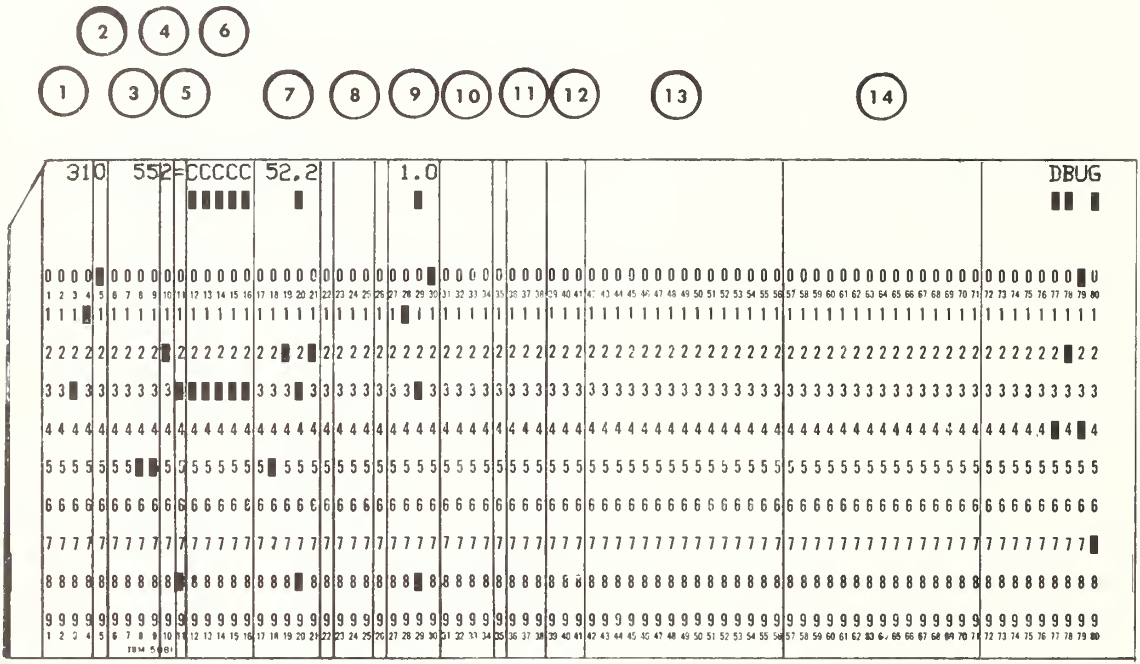


FIFTH CONTROL CARD WILL BE BLANK UNLESS DIFFERENT VALUES PER UNIT-VOLUME ARE USED IN PREDICTING TREE-VALUE IN DIFFERENT STRATA.

FORMATS AND LISTS

```
  1 FORMAT (I4,1CA6,8X,A4)                                                  BCSTX014
    READ  (MRE,1)              KREENO,ALFATH,CCID                           BCSTX025

 20 FORMAT (4X,2A6,F6.3,F9.8,2F6.4,1X,I1,1X,F4.0,1X,I4,F9.8,1X,6I1/9I8      BCSTX015
 21 /9I8/9F8.0)                                                             BCSTX016

920 READ  (MRE,2)              ADALFA,B,Q,U,G,NSTR,PRBS,K,Q2,               BCSTX027
921 LS1,LS2,LS3,LS4,LS5,LS6,(JN(I),I=1,9),(KP(I),I=1,9),(WV(I),I=1,9)       BCSTX028
```

FIGURE 4. TREE INPUT CARD.

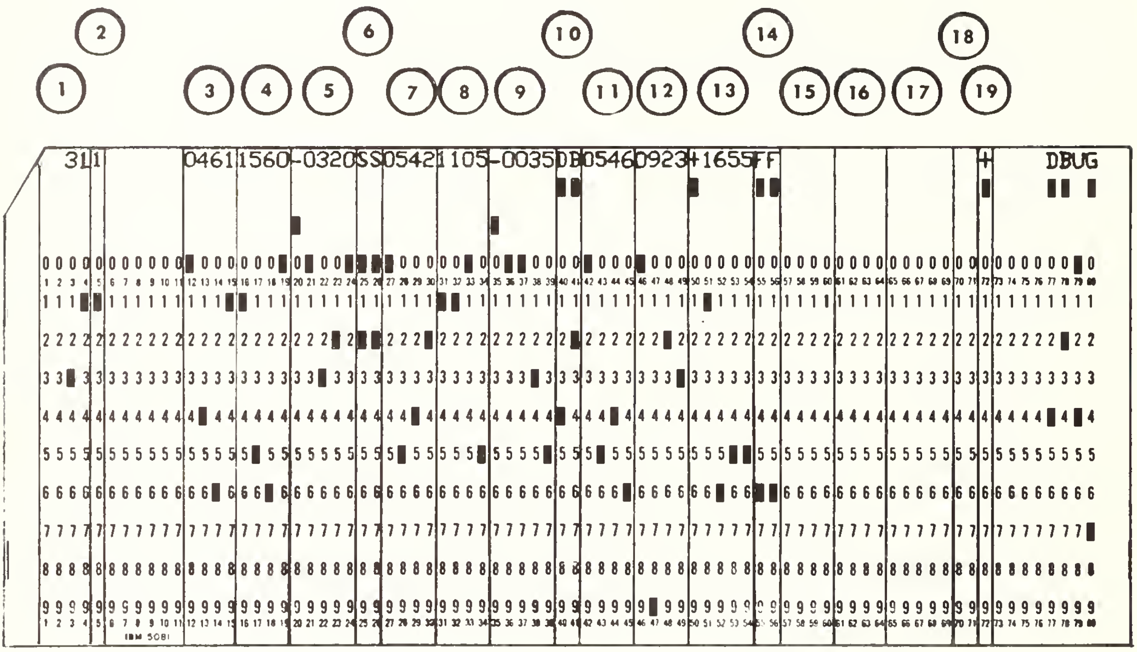



```
X FORMAT(I4,I1,I4,I1,A1,A5,F5.1,1X,3I1,1X,2F4.1,1X,F3.0,F3.2,2F15.0)BCST2

0READ  (JW,X)               KREENO,J,KPI,LST,CERT,BETATH,CBH,METH,MBK,BCST2057
1MUL,BKA,BKB,UMAXL,UDORT,XTRA,XTRB                                     BCST2058
```

FIGURE 4 (CONTINUED).

```
  1 =KREENO= TREE NUMBER.

  2 =   J   = CARD NUMBER WITHIN TREE.

  3 =  KPI  = PREDICTION FOR TREE.

  4 =  LST  = VALUE STRATUM.

  5 = CERT  = SAMPLING CLASS (=,*, ).

  6 =BETATH= OTHER TREE CLASSIFICATIONS.

  7 =  DBH  = BREAST-HIGH DIAMETER IN INCHES.

     (METH)
     (    )
  8 =(MBK )= TREE OPTIONS (SEE TEXT).
     (    )
     (MUL )

  9 =  BKA  = SINGLE-BARK THICKNESS (FIRST).

 10 =  BKB  = SINGLE-BARK THICKNESS (SECOND).

 11 =UMAXL  = SEE TEXT.

 12 =UDORT  = SEE TEXT.

 13 = XTRA  = RESERVED FOR POSSIBLE FUTURE USE.

 14 = XTRB  = RESERVED FOR POSSIBLE FUTURE USE.
```

FIGURE 5. DENDROMETER INPUT CARD.




```
    6 FORMAT (I4,I1,6X,  4(2F4.1,F5.4,A2),A1)                       BCST2015

 2430 READ  (JW,6)         KREENO,J,(TGRADS(I),FGRADS(I),SINELV(I),   BCST2082
 2431 GAMATH(I),I=J1,J4),TERM                                         BCST2083
```

FIGURE 5 (CONTINUED).

```
 1 =KREENO =TREE NUMBER.

 2 =   J   =CARD NUMBER WITHIN TREE.

 3 =TGRADS)
          )
 4 =FGRADS)= LOWEST PAIR OR TRIO OF DENDROMETER READINGS.
          )
 5 =SINELV)

 6 =GAMATH =GRADE AND DEFECT.

 7 =TGRADS)
          )
 8 =FGRADS)=NEXT DENDROMETER READINGS.
          )
 9 =SINELV)

10 =GAMATH =GRADE AND DEFECT.

11 =TGRADS)
          )
12 =FGRADS)=NEXT DENDROMETER READINGS.
          )
13 =SINELV)

14 =GAMATH =GRADE AND DEFECT.

15 =TGRADS)
          )
16 =FGRADS)=NEXT DENDROMETER READINGS.
          )
17 =SINELV)

18 =GAMATH =GRADE AND DEFECT.

19 = TERM  =* IF NEXT CARD STARTS NEW TREE.
           =+ IF NEXT CARD STARTS NEW REFERENCE PLANE FOR SAME TREE.
           =BLANK IF TREE AND REFERENCE PLANE CONTINUE ON NEXT CARD.
```

FIGURE 6. JOB-END AND PROGRAM-END CARDS.

JOB-END CARD FOLLOWS LAST DENDROMETER CARD OF LAST TREE IN JOB.

PROGRAM-END CARD FOLLOWS JOB-END CARD OF LAST JOB.

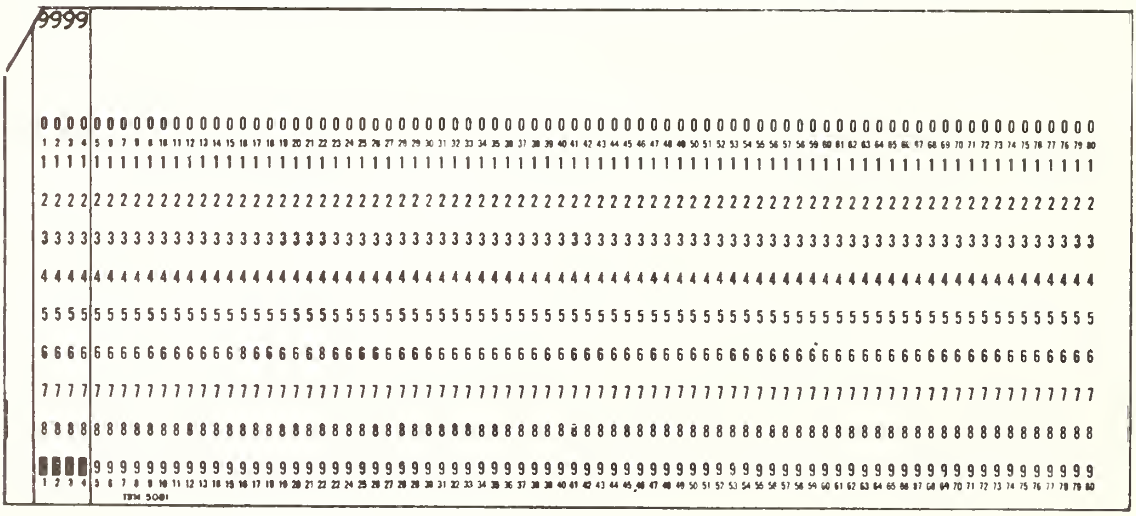


FIGURE 7. SUGGESTED PRINTED CARD-FORMAT TO FACILITATE PUNCHING EITHER TREE OR DENDROMETER INPUT DATA.

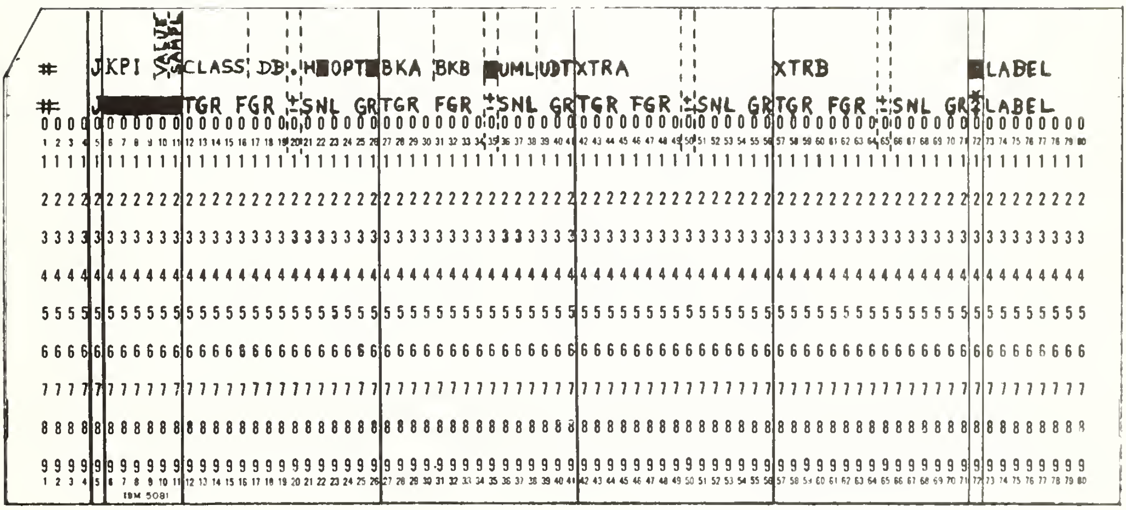
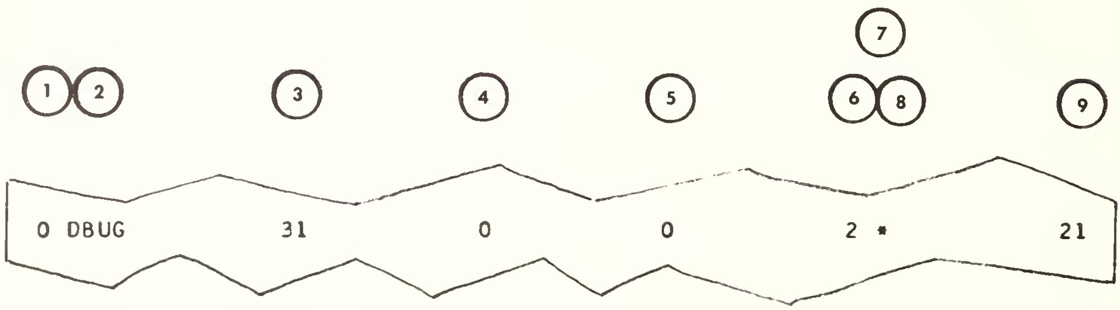


FIGURE 8. INFCRMATION PRINTOUT FOR ERROR ENCOUNTERED BY SUBROUTINE ST1.



1 = NERR = 0 UNLESS ILLEGAL CHARACTER (32) OR BAD TAPE (35).

2 = CDIC = BRIEF JCB IDENTIFIER.

3 =KREENO= TREE NUMBER STORED MOST RECENTLY.

4 = J = CARD NUMBER WITHIN TREE.

5 = KPI = PREDICTION FOR TREE.

6 = LST = VALUE STRATUM.

7 = CERT = SAMPLING CLASS (=,*,).

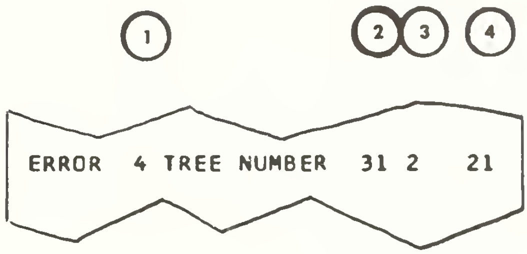
8 = TERM = TERMINAL SYMBOL (,+,*).

9 = LKR = PREVIOUS TREE NUMBER.

FORMAT AND LIST

```
  15 FORMAT (1H ,  I3,XA4,4I12,XA1,A1,I12)                        BCST1032
1000 WRITE (MPR,15)        NERR,CDID,KREENO,J,KPI,LST,CERT,TERM,LKR BCST1153
```

FIGURE 9. ERROR MESSAGE PRINTED FOR ERRORS ENCOUNTERED BY SUBROUTINE ST2.



1 = NERR = ERROR CODE (SEE TEXT).

2 =KREENO= TREE NUMBER.

3 = J = CARD NUMBER WITHIN TREE.

4 = LKR = PREVIOUS TREE NUMBER.

FORMAT AND LIST

```
   8 FORMAT (11H     ERROR ,I3,1X,12HTREE NUMBER ,I4,1X,I1,1X,I4)      BCST2017
1011 WRITE (MPR, 8)          NERR,KREENO,J,LKR                         BCST2237
```

FIGURE 10. PRELIMINARY PRINTOUT (TREE POPULATION).

```
THREE-PEE SAMPLE-TREE MEASUREMENT (DBUG)                                PAGE    1
LRG  8-13-63 8.000.01970202-1.1933 1.5230 2   50.  25 .77777777 223000
       PRELIMINARY REPCRT--COUNTS ANC AGGREGATE PREDICTIONS
=================================================================================

    STRATUM 1                                 TREE COUNTS     PREDICTIONS
---------------------------------------------------------------------------------
        SURE-TO-BE MEASURED  TREES(=1)            0                 0
        THREE-PEE  MEASURED  TREES(*2)            2                 6
        THREE-PEE  PREDICTEC TREES( 3)           56                93
---------------------------------------------------------------------------------
                         ALL TREES(1,2,3)        58                99
---------------------------------------------------------------------------------
               ALL MEASURED  TREES(1,2)           2                 6
               ALL THREE-PEE TREES(2,3)          58                99
                               ESN(*2)           1.980 EXPECTATION

    STRATUM 2                                 TREE COUNTS     PREDICTIONS
---------------------------------------------------------------------------------
        SURE-TO-BE MEASURED  TREES(=1)            4                82
        THREE-PEE  MEASURED  TREES(*2)            2                 6
        THREE-PEE  PREDICTEC TREES( 3)           60                97
---------------------------------------------------------------------------------
                         ALL TREES(1,2,3)        66               185
---------------------------------------------------------------------------------
               ALL MEASURED  TREES(1,2)           6                88
               ALL THREE-PEE TREES(2,3)          62               103
                               ESN(*2)           2.060 EXPECTATION

 TOTALS FOR ALL 2 STRATA                      TREE COUNTS     PREDICTIONS
---------------------------------------------------------------------------------
        SURE-TC-BE MEASURED  TREES(=1)            4                82
        THREE-PEE  MEASURED  TREES(*2)            4                12
        THREE-PEE  PREDICTED TREES( 3)          116               190
---------------------------------------------------------------------------------
                         ALL TREES(1,2,3)       124               284
---------------------------------------------------------------------------------
               ALL MEASURED  TREES(1,2)           8                94
               ALL THREE-PEE TREES(2,3)         120               202
                               ESN(*2)           4.040 EXPECTATION
```

FIGURE 11. DETAILED LOG AND TREE PRINTOUT (OBTAINED BY PUNCHING '3' IN 3RD. JCB-OPTION).

```
THREE-PEE SAMPLE-TREE MEASUREMENT (DBUG)                        PAGE    3
LRG  8-13-63 8.000.01970202-1.1933 1.5230 2   50.  25 .77777777 223000
                 DETAILED LOG AND/OR TREE REPORT
=========================================================================
TREE/  VOLUME   / SURFACE/LENGTH/D.I.B./ LOG/RANGE/
 NO./  CU.FT.  /  SC.FT./ FEET /INCHES/CODE/ FEET/TGRADS FGRADS SINELV
=========================================================================
          64.7     204.6    49.1    14.1  UU     0.     48.0    48.0 0.6758
          18.9      50.8    10.9    17.6  DD   84.6     48.0    86.3 0.6758
          47.8     121.3    24.5    18.1  CC   77.9     46.4    89.0 0.5937
          17.5      39.1     7.0    19.7  CC   66.5     42.7    96.7 0.3275
          33.4      64.2     9.8    23.0  BB   63.4     41.4   105.7 0.2335
          35.1      54.8     6.8    26.8  BB   63.4     41.4   114.3 0.0783
          16.9      21.2     2.1    34.2  DD   61.4     40.5   133.9-0.0305
           0.        0.      0.     41.7  SS   61.0     40.3   156.0-0.0656
-------------------------------------------------------------------------
 21      234.3     556.0   110.3    37.2=D,F=    1.000,   25, 3.9 1*IIIII2
-------------------------------------------------------------------------
          35.7      84.6    15.9    19.4  FZ  171.5     56.8    75.3 0.6080
          54.6     114.8    19.3    21.1  FY  163.4     56.4    77.3 0.5407
          76.7     141.2    20.7    24.4  FX  152.6     55.8    81.4 0.4528
         125.6     202.2    25.9    27.6  FW  141.8     55.1    85.9 0.3410
           0.        C.      0.     31.8  FT  135.2     54.6    91.3 0.1659
          54.6     114.8    19.3    21.1  FC  163.4     56.4    77.3 0.5407
          76.7     141.2    20.7    24.4  FB  152.6     55.8    81.4 0.4528
         125.6     202.2    25.9    27.6  FA  141.8     55.1    85.9 0.3410
           0.        0.      0.     31.8  FS  135.2     54.6    91.3 0.1659
         214.5     246.6    22.8    32.8  FF  135.2     54.6    92.3 0.1655
          28.4      26.7     2.0    48.7  DB  130.2     54.2   110.5-0.0035
           0.        0.      0.     53.1  SS   76.9     46.1   156.0-0.0320
-------------------------------------------------------------------------
 31      792.5    1274.4   172.6    52.2=D,F=    1.0CO,   55, 2.0*1 CCCCC2
-------------------------------------------------------------------------
```

(SEE FIGURE 14 FOR LABELING APPROPRIATE TO LINES WITH TREE NUMBERS AND WHCLE TREE TOTALS).

FIGURE 12. SUMMARY PRINTOUT (TREE POPULATION).

THREE-PEE SAMPLE-TREE MEASUREMENT (DBUG) PAGE 6
LRG 8-13-63 8.000.01970202-1.1933 1.5230 2 50. 25 .77777777 223000
SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES

TOTALS ALL 2 STRATA

SAMPLE VARIABLES	SURE-TO-BE MEASURED AGGREGATIONS	3P-EXPANDED SAMPLE ESTIMATES	TOTAL SAMPLE ESTIMATES PLUS SURE
TREES(FREQUENCY)	4.000	121.200	125.200
PREDICTIONS(KPI)	82.	202.	284.
B.A.(SQ.FT.O.B.)	23.7	115.7	139.5
LENGTH(FT.)	326.7	4529.0	4855.6
SURFACE(SQ.FT.IB.)	1954.0	12966.1	14920.2
VOLUME(CU.FT.I.B.)	1054.9	3138.8	4193.7
REL.VAL.PER BD.FT.	15.00	12.54	13.27
GROSS BD.FT.	8254.4	19642.3	27896.7
ST.ERROR(PCT.)	-----	2.7	1.9
GROSS WTD.BD.FT.	123816.59	246266.05	370082.64
ST.ERROR(PCT.)	-----	2.7	1.8

COMPONENT ITEMS	(1=) NUMBER	(2*) NUMBER	(1,2) NUMBER
MEASURED TREES	4	4	8
MEASURED LOGS	21	16	37

FIGURE 13. SUMMARY PRINTOUT (DATA-PROCESSING STATISTICS AND ERRORS).

```
THREE-PEE SAMPLE-TREE MEASUREMENT (DBUG)                          PAGE     0
LRG  8-13-63 8.000.01970202-1.1933 1.5230 2    50.  25 .77777777 223000
  SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES
===========================================================================

DATA PROCESSING BLOCKED BY    0 INPUT FLAWS.
SAMPLE ESTIMATES INVOLVE    2 SUSPICIOUS ITEMS NUMBERED
          1     1
INPUT READ BEFORE FLAW,IF ANY---
    CARDS WITH TREE PREDICTIONS ONLY         (FIRST)                      116
    CARDS WITH MEASURED TREE INFO            (FIRST)                        8
    -----------------------------------------------------------------------
    CARDS WITH MEASURED TREE INFO            (SECOND)                       8
    CARDS WITH ADDITIONAL DENDROMETER INFO   (SECOND)                      14

PROCESSING DONE BEFORE FLAW,IF ANY---
    NUMBER OF MEASURED TREES PROCESSED                                      8
    NUMBER OF MEASURED LOGS PROCESSED                                      37
    TREE CARDS PUNCHED OR WRITTEN                                           0
    LOG CARDS PUNCHED OR WRITTEN                                            0
    LABEL ON CARD OUTPUT                                                 DBUG

CHECK OF INPUT AGGREGATES WITH EXPANDED 3P SAMPLE
    AGGREGATE NUMBER OF TREES INPUT(1+2+3)                         124
    SAMPLE ESTIMATE(EXPANDED 2)+NO.SURE(1)                         125.200
    -----------------------------------------------------------------------
    AGGREGATE PREDICTIONS(KPI) INPUT(1+2+3)                        284
    SAMPLE ESTIMATE(EXPANDED 2)+KPI SURE(1)                        284.
    ------
```

FIGURE 14. TREE PRINTOUT WITHOUT LOGS (OBTAINED BY PUNCHING '2' IN 3RD. JOB-OPTION).

```
THREE-PEE SAMPLE-TREE MEASUREMENT (CBUG)                             PAGE    2
LRG   8-13-63 8.000.01970202-1.1933 1.5230 2    50.   25 .77777777 222000
                 DETAILED LOG AND/OR TREE REPORT
==============================================================================
TREE/   VOLUME   / SURFACE/LENGTH/D.B.H./
 NO./   CU.FT.   /   SQ.FT./ FEET  /INCHES/
==============================================================================
    1       8.C       34.0    11.7     10.6=D,F=    1.000,    1,-0.   1 F-TND2
    4      74.0      240.0    64.1     20.3=D,F=    9.900,    5, 1.9  1*AAAAA1
    4      73.1      236.3    64.1     20.3=D,F=   10.300,    5, 1.9  1*AAAAA2
    5      16.4       80.9    32.0     11.3=D,F=   49.500,    1, 1.1  1 BBBBB1
    5      16.3       80.6    32.0     11.3=C,F=   51.500,    1, 1.1  1 BBBBB2
    5      20.2       89.7    32.0     11.3=D,F=    1.000,    1,-1.1  1 BBBBB2
   21     234.3      556.0   110.3     37.2=D,F=    1.000,   25, 3.9  1*IIIII2
   31     792.5     1274.4   172.6     52.2=D,F=    1.000,   55, 2.0* 1 CCCCC2
```

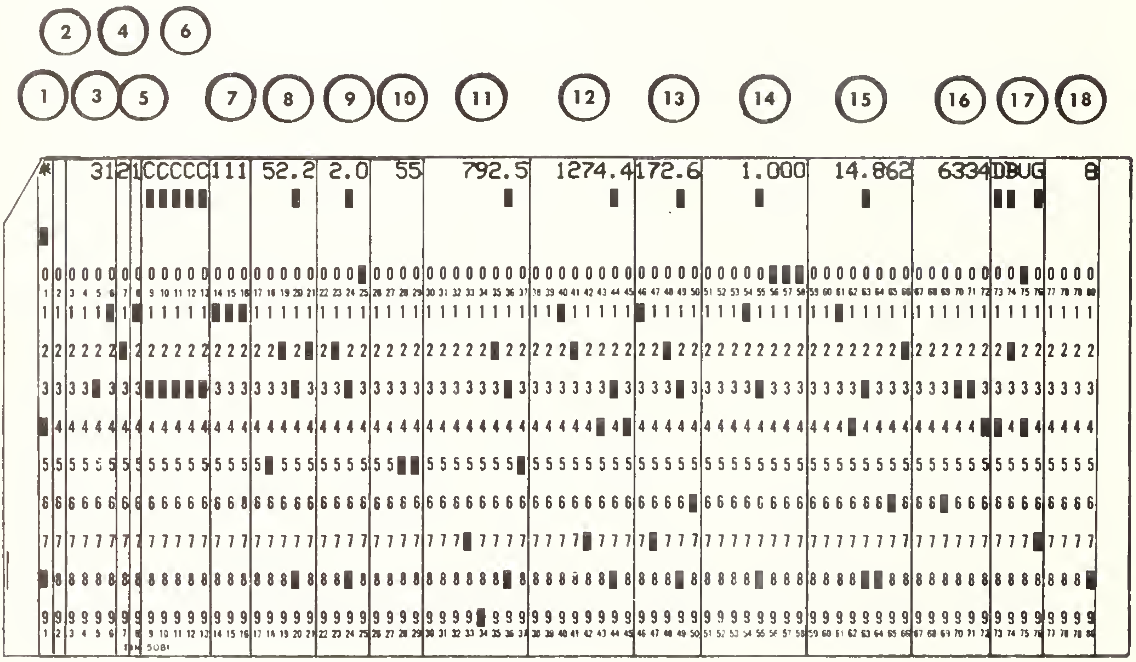
(1) (2) (3) (4) (5) (6) (7) (8) (9) (10) (11) (12) (13)

```
190 FORMAT          (2X,I4,F11.1,F9.1,2F7.1,5H=D,F=F8.3,1H,I4,1H,    BCST2030
191 F4.1,A1,I1,A1,A5,I1)                                             BCST2031

3650 WRITE (MPR,19)          KREENO,SUMV,SUMS,SUMH,DBH,FREQ,KPI,BK,   BCST2170
3651 MX(5),METH,MX(6),BETATH,LST                                     BCST2171
```

FIGURE 14 (CONTINUED).

```
 1 =KREENO= TREE NUMBER.
 2 = SUMV = VOLUME  OF TREE IN CU. FT. AFTER BARK ALLOWANCE.
 3 = SUMS = SURFACE OF TREE IN SQ. FT. AFTER BARK ALLOWANCE.
 4 = SUMH = LINEAL FT. IN TREE (INCLUDING FORKS).
 5 =  DBH = BREAST-HIGH DIAMETER IN INCHES.
 6 = FREQ = POPULATION FREQUENCY REPRESENTED BY SAMPLE TREE.
 7 =  KPI = PREDICTION FOR TREE.
 8 =  BK  = DOUBLE-BARK THICKNESS IN INCHES.
 9 = MX(5)= ASTERISK IMPLIES FORKED TREE.
10 = METH = TYPE OF DENDROMETER (1=SBR, 2=OCL, 3=OFK.)
11 = MX(6)= ASTERISK IMPLIES UNSEEN USABLE MATERIAL.
12 =BETATH= TREE CLASSIFICATIONS.
13 =  LST = VALUE STRATUM.
```

FIGURE 15. TREE OUTPUT CARD (OBTAINED BY PUNCHING '2' IN 4TH. JOB-OPTION).

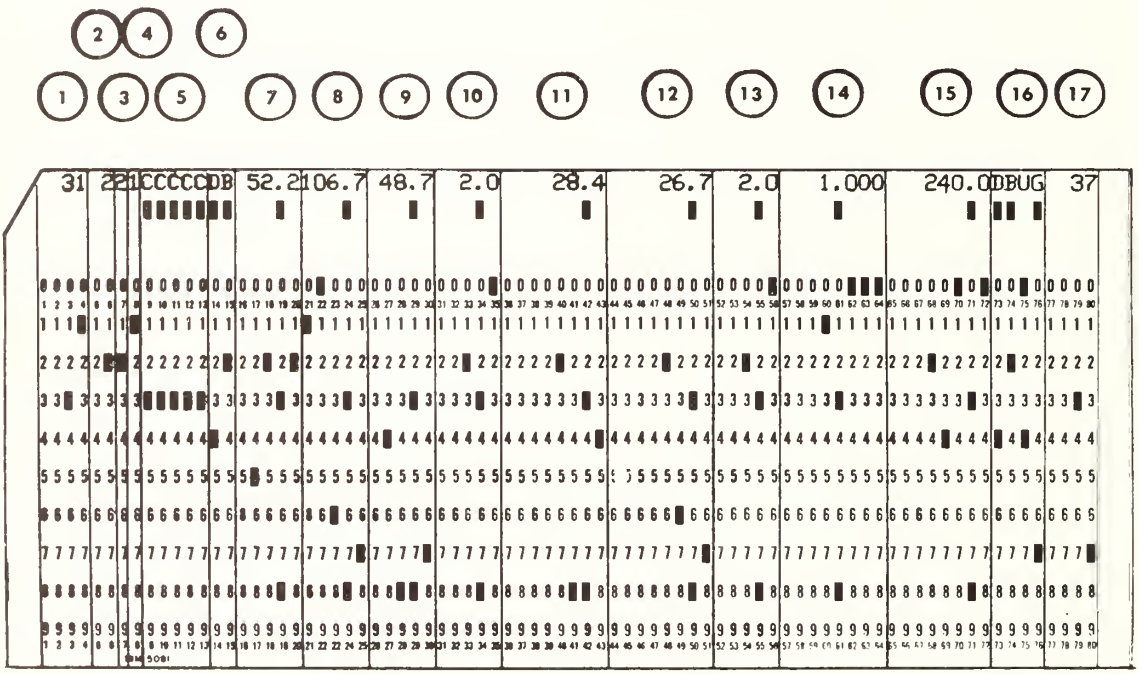



```
21  FORMAT(2A1,I4,2I1,A5,3I1,F5.1,F4.1,I4,2F8.1,F5.1,2F8.3,I6   ,A4,I4)BCST2032

   0WRITE (MPU,21)            MX(5),MX(6),KREENO,LST, CERT,BETATH,METH,BCST2196
   1MBK,MUL,DBH,BK,KPI,SUMV,SUMS,SUMH,FREQ,BA,LOUT,CDID,KRDS2          BCST2197
```

FIGURE 15 (CONTINUED).

```
 1 = MX(5)= ASTERISK IMPLIES FORKED TREE.

 2 = MX(6)= ASTERISK IMPLIES UNSEEN USABLE MATERIAL.

 3 =KREENO= TREE NUMBER.

 4 =  LST = VALUE STRATUM.

 5 = CERT = SAMPLING CLASS (1=CERTAIN, 2=SAMPLE).

 6 =BETATH= OTHER TREE CLASSIFICATIONS.

    (METH)
    (    )
 7 =( MBK)= TREE OPTIONS (SEE TEXT).
    (    )
    ( MUL)

 8 =  DBH = BREAST-HIGH DIAMETER IN INCHES.

 9 =  BK  = DOUBLE-BARK THICKNESS IN INCHES.

10 =  KPI = PREDICTION FOR TREE.

11 = SUMV = VOLUME  OF TREE IN CU. FT. AFTER BARK ALLOWANCE.

12 = SUMS = SURFACE OF TREE IN SQ. FT. AFTER BARK ALLOWANCE.

13 = SUMH = LINEAL FT. IN TREE (INCLUDING FORKS).

14 = FREQ = POPULATION FREQUENCY REPRESENTED BY SAMPLE TREE.

15 =  BA  = BASAL AREA OF TREE IN SQ. FT.

16 = LOUT = VOLUME  OF TREE IN BD. FT.

17 = CDID = BRIEF JOB IDENTIFIER.

18 = KRDS2= CARD OUTPUT SEQUENCE WITHIN JOB.
```

FIGURE 16. LOG OUTPUT CARD (OBTAINED BY PUNCHING '3' IN 4TH. JOB-OPTION).




```
22 FORMAT (I4,I2,2I1,A5,A2,4F5.1,2F8.1,F5.1,F8.3,F8.1,A4,I4)            BCST2033

  0WRITE (MPU,22)          KREENO,I,LST, CERT,BETATH,GAMATH(I),DBH,   BCST2186
  1E(N),DR(I),E(I),CC(I),C(I),H(I),FREQ,PCUT,CDID,KRDS2               BCST2187
```

FIGURE 16 (CONTINUED).

```
 1 =KREENO= TREE NUMBER.
 2 =   I   = DIAMETER SEQUENCE WITHIN TREE.
 3 =  LST  = VALUE STRATUM.
 4 = CERT  = SAMPLING CLASS (1=CERTAIN, 2=SAMPLE).
 5 =BETATH= OTHER TREE CLASSIFICATIONS.
 6 =GAMATH= GRADE AND DEFECT.
 7 =  DBH  = BREAST-HIGH DIAMETER IN INCHES.
 8 = E(N)  = HEIGHT IN FT. ABOVE STUMP OF LAST USABLE MATERIAL IN TREE.
 9 =  DR   = UPPER DIAMETER OF LOG IN INCHES AFTER BARK ALLOWANCE.
10 =   E   = HEIGHT OF UPPER END OF LOG IN FT. ABOVE STUMP.
11 =  CC   = VOLUME  OF LOG  IN CU. FT. AFTER BARK ALLOWANCE.
12 =   C   = SURFACE OF LOG  IN SQ. FT. AFTER BARK ALLOWANCE.
13 =   H   = LENGTH OF LOG IN FT.
14 = FREQ  = POPULATION FREQUENCY REPRESENTED BY SAMPLE LOG.
15 = POUT  = VOLUME  OF LOG  IN BD. FT.
16 = CDID  = BRIEF JOB IDENTIFIER.
17 = KRDS2= CARD OUTPUT SEQUENCE WITHIN JOB.
```

FIGURE 17. LOG AND TREE INFORMATION STORED ON TAPE JX FOR USE BY GRADE-YIELD AND REALIZATION SUBROUTINE ST4 (OBTAINED BY PUNCHING '2' IN 5TH. JOB-OPTION).

```
THREE-PEE SAMPLE-TREE MEASUREMENT (DBUG)                                    PAGE     7
LRG   8-13-63 8.000.01970202-1.1933 1.5230 2    50.   25 .77777777 223020
                 GRADE-YIELD AND REALIZATION REPORT
==========================================================================
```

```
 31  521CCCCCFA  52.200106.698  27.631  50.773    125.641    202.223     25.944
 31  321CCCCCFF  52.200106.698  32.770  24.830    214.543    246.561     22.826
 31  221CCCCCDB  52.200106.698  48.711   2.004     28.371     26.720      2.004
```

(1) (2) (3) (4) (5) (6) (7) (8) (9) (10) (11) (12) (13)

```
 1.0000   15.00   792.488   1274.399   172.618
 1.0000   15.00   792.488   1274.399   172.618
 1.0000   15.00   792.488   1274.399   172.618
```

(14) (15) (16) (17) (18)

```
23   FORMAT (XI4,I2,2I1,A5,A2,4F7.3,3F10.3,F9.4,F7.2,3F10.3)                 BCST2034

    0WRITE (JX ,23)          KREENO,I,LST, CERT,BETATH,GAMATH(I),DBH,     BCST2190
    1E(N),DR(I),E(I),CC(I),C(I),H(I),FREQ,WV(LST),SUMV,SUMS,SUMH             BCST2191
```

FIGURE 17 (CONTINUED).

```
 1 =KREENO= TREE NUMBER.
 2 =   I  = DIAMETER SEQUENCE WITHIN TREE.
 3 =  LST = VALUE STRATUM.
 4 = CERT = SAMPLING CLASS (1=CERTAIN, 2=SAMPLE).
 5 =BETATH= OTHER TREE CLASSIFICATIONS.
 6 =GAMATH= GRADE AND DEFECT.
 7 =  DBH = BREAST-HIGH DIAMETER IN INCHES.
 8 = E(N) = HEIGHT IN FT. ABOVE STUMP OF LAST USABLE MATERIAL IN TREE.
 9 =  DR  = UPPER DIAMETER OF LOG IN INCHES AFTER BARK ALLOWANCE.
10 =   E  = HEIGHT OF UPPER END OF LOG IN FT. ABOVE STUMP.
11 =  CC  = VOLUME  OF LOG  IN CU. FT. AFTER BARK ALLOWANCE.
12 =   C  = SURFACE OF LOG  IN SQ. FT. AFTER BARK ALLOWANCE.
13 =   H  = LENGTH OF LOG IN FT.
14 = FREQ = POPULATION FREQUENCY REPRESENTED BY SAMPLE LOG.
15 =  WV  = STRATUM VALUE PER UNIT VOLUME.
16 = SUMV = VOLUME  OF TREE IN CU. FT. AFTER BARK ALLOWANCE.
17 = SUMS = SURFACE OF TREE IN SQ. FT. AFTER BARK ALLOWANCE.
18 = SUMH = LINEAL FT. IN TREE (INCLUDING FORKS).
```

GPO 968-386

NCTICE
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PAGES 50 THRCUGH 128 (CCMPRISING APPENCICES A, B, C) ARE INCLUDED ONLY IN THE MICRCCARD EDITION CF THIS PAPER OBTAINABLE ON REQUEST FROM THE PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, BOX 245, BERKELEY, CALIFCRNIA 947C1.

Diseases of Monterey pine

in Native Stands of California and in Plantations of Western North America

Harold R. Offord

1964

Pacific Southwest Forest and Range
Experiment Station - Berkeley, California
Forest Service - U. S. Department of Agriculture

U. S. FOREST SERVICE RESEARCH PAPER PSW-14

Page

The Author

Harold R. Offord has been investigating the problems of plant diseases and their control for nearly 40 years. A native of Toronto, Canada, he earned bachelor's and master's degrees at the University of British Columbia, majoring in biochemistry. In 1926 he joined the U.S. Department of Agriculture's Bureau of Plant Industry staff in Berkeley, California, and worked on methods of controlling white pine blister rust and other diseases. He served as pathologist in the Department's Bureau of Entomology and Plant Quarantine from 1935 to 1952, and in the Forest Service's California Region from 1953 to 1955. In 1956 he became chief of the division of forest disease research at the Forest Service Experiment Station in Berkeley. Since mid-1962, he has been in charge of the Station's research on heartrots of conifers, mistletoes, and white-pine blister rust.

Monterey pine (*Pinus radiata* D. Don) is without doubt the best known expatriate of the North American conifers. More than 1½ million acres of plantations in Australia, Chile, New Zealand, South Africa, and Spain attest its economic importance and adaptability (Scott 1960).

Forest biologists have studied Monterey pine intensively as an exotic (Scott 1960; Rawlings 1957), but have given much less attention to native stands of this conifer in California.[1] Botanists have described the species and its distribution (Howell 1941; Jepson 1910; Mason 1934; Shaw 1914). Geneticists have reported on Monterey pine hybrids (Stockwell and Righter 1946), on California plantings of progenies from Australia (Righter and Callaham 1958), and on the ecology and variation of the species (Forde[2]), and entomologists have recorded insects from native stands (Burke 1937; Keen 1952; Struble 1961). Mechanical and other properties of California-grown Monterey pine were described by Cockrell (1959) and Haasis (1932) and the gum turpentines identified by Mirov (1961). Foresters have not entirely overlooked native forest stands (Larsen 1915; Lindsay 1937; U.S. Forest Service 1908; Dunning[3]; McDonald[4]), but their reports are outdated now or are not readily available in libraries. Contributions from forest pathologists and mycologists are widely scattered in lists of host and fungi, or deal with a specific problem or fungus such as "repeating pine rusts" (Meinecke 1929) without recognizing Monterey pine in the title of the publication.

It is surprising that so little has been published about *P. radiata* in California. The pine forests of the Monterey Peninsula were among the first in the state to attract the attention of explorers, botanists, foresters, and recreationists. Cabrillo in 1542 noted the attractive pine forests and called Monterey Bay "the bay of the pines." The first settlers of the area in 1770 cut and used the trees. Artists and recreationists have long glorified the pine and cypress in their sea-coast setting, and in central coastal counties of California, Monterey pine has been widely and successfully planted in home lots, parks, and wildland areas since the turn of the century.

More recently Monterey pine has become a favored Christmas tree (Metcalf 1955), and now has vastly greater potential for afforestation through its frost-resistant hybrid *Pinus* X *attenuradiata* Stockwell and Righter *(P. attenuata* X *radiata)*.

E. P. Meinecke, the pioneer and recognized authority on forest pathology for the western United States, collected and observed diseases in the Monterey area as early as 1909. From about 1881 until the late 1920's other eminent patholo-

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[1]I acknowledge with thanks the help given by Dr. Lee Bonar, professor of botany emeritus, and Dr. Isabelle Tavares, senior herbarium botanist, University of California, Berkeley, in working with host and fungi specimens in the U.C. herbarium. For many years Dr. Bonar has been compiling records of fungi attacking native plants of California and has identified numerous specimens collected by U.S. Forest Service personnel. Thanks are also due Drs. Josiah L. Lowe and R. L. Gilbertson of State University College of Forestry at Syracuse, New York, and Dr. L. K. Weresub, Central Experimental Farms, Ottawa, Canada, for naming some previously unidentified polypores from the pathology herbarium of this Station. Personnel of Del Monte Properties, the California Division of Forestry, and U.S. Forest Service pathologist D. R. Miller and consultant W. W. Wagener expedited disease surveys in Monterey pine areas.

[2]Forde, Margot Bernice. Variation in the natural populations of Monterey pine (*Pinus radiata* D. Don) in California. 1962 (Unpublished doctor's thesis on file at Botany Dept., Univ. Calif., Berkeley.)

[3]Dunning, Duncan. A working plan for the Del Monte Forest of the Pacific Improvement Company. 1916 (Unpublished master's thesis on file at School of Forestry, Univ. Calif., Berkeley.)

[4]McDonald, J. B. An ecological study of Monterey pine in Monterey County. 1959. (Unpublished master's thesis on file at School of Forestry, Univ. Calif., Berkeley.)

gists (Bethel, Boyce, Cooke, Gravatt, Harkness, Rhoads, and Wagener) inspected native stands around Monterey Bay and plantations around the San Francisco Bay area. But their findings have never been published.

Researchers in Australia, Chile, New Zealand, South Africa, Spain, and the United Kingdom have provided an extensive and useful literature on the ecology, management, and protection of *P. radiata* as an exotic. Some of the more comprehensive reports on diseases of Monterey pine have come from pathologists working in New Zealand (Cunningham 1948 to 1955; De Gryse 1955; Rawlings 1957; and Hepting[5]). Scott (1960) has summarized world-wide information (including available data on Monterey pine in California) for a bulletin of the Food and Agriculture Organization of the United Nations. In appendix 6 of the Scott report, Rawlings has listed fungi and insects associated with native and exotic *P. radiata*. Of the 99 fungi recorded by Rawlings only 16 are from California, and only one of these California citations bears a dateline as recent as 1938.

In published host-fungi lists many of the fungi reported on *P. radiata* for California go back to collections made by Harkness from 1881 to 1886, which were described in Grevillea and in California Academy of Science bulletins of that time. Saccardo (1882–1931, 13: 849) listed nine fungi on *P. insignis* Dougl. *(P. radiata)* and seven of these appear to be Harkness collections. Seymour (1929) lists 20 fungi for *P. radiata* in North America, but does not provide any source data. Other lists of fungi with *P. radiata* as host appear in publications by the U.S. Department of Agriculture (1960) and those of Spaulding (1956, 1961).

Evidence of increased world-wide interest in Monterey pine is shown not only by the recent publications of Pert (1963), Scott (1960), and Streets (1962), but also by the 1961 recommendation of the Forest Protection Section of the International Union of Forestry Research Organizations that the diseases of native stands of Monterey pine should be inventoried and appraised. To a major extent, this report is the result of that recommendation. Its objectives are to collate previously published records of diseases of Monterey pine in native stands of California and in plantations of western North America, and to augment this record with unpublished information from the forest pathology files of the Pacific Southwest Station. Included are findings from 1961–63 surveys of native stands, and from a study of specimens of fungi in California herbaria.

The Host and Its Environment

The climatic and edaphic environment of native Monterey pine stands in California and of West Coast plantations will be discussed here only to the extent that they bear upon the nature and impact of diseases. More detailed information on the ecology and silvics of native Monterey pine is given by Forde,[2] Lindsay (1937), Scott (1960) and Roy.[6]

Pinus radiata belongs to the hard pine section and to the *Insignes* or closed cone sub-section of the genus *Pinus* (Shaw 1914). The species name is derived from the radiate or rayed markings on the cone scales. Needles occur in groups of three or two per bundle, with three predominating and considered as characteristic. Cones are first produced at 6 to 10 years of age; they persist for many years, shedding viable seed intermittently. The tree normally makes rapid growth in the first 30 to 40 years, slowing down considerably after 50 or 60 years. It is a relatively short-lived conifer.

Native Stands

Native stands of Monterey pine are restricted to three separate pockets in a narrow strip of central coastal California about 6 miles wide and 130 miles long between sea level and 800 to 1,000 feet elevation (fig. 1). Throughout this report these three areas will be referred to as Swanton (the most northerly at 37° N.), Monterey (the central at 36½° N.), and Cambria (the most southerly at 35½° N.).

Estimates of the acreage of native Monterey pine vary, depending on the definition of type, and

[5]Hepting, George H. A report on the condition of the Radiata pine forests of N. Z. Forest Products Limited. 1960. (Unpublished report to New Zealand Forest Products, Ltd., Auckland, N.Z.)

[6]Roy, Douglass F. Silvics of Monterey pine. 1964. (In preparation for publication, Pacific SW. Forest & Range Expt. Sta., U.S. Forest Serv., Berkeley, Calif.)

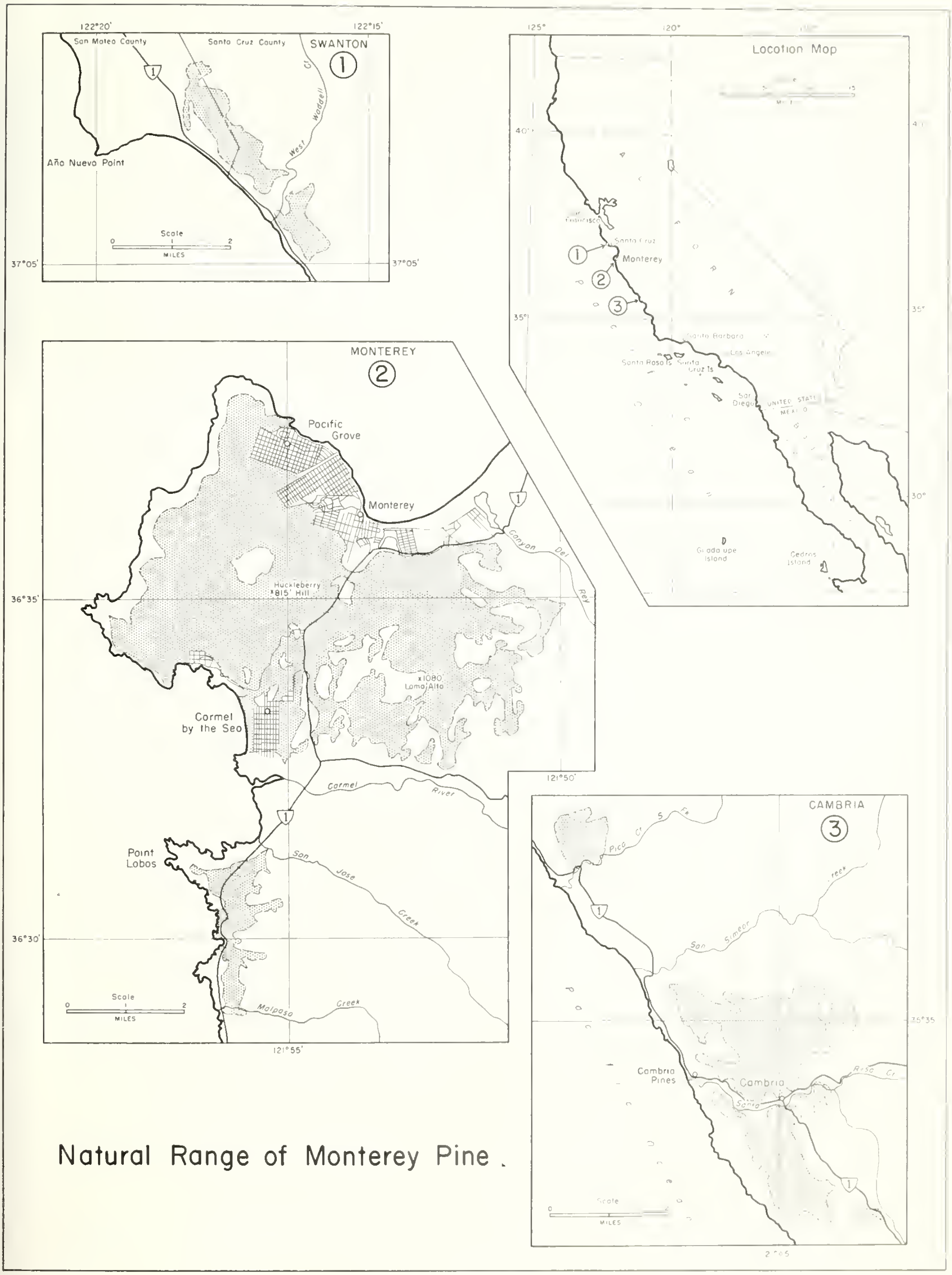


Figure 1.—Native stands of Monterey pine *(Pinus radiata)* in California.

Figure 2.—Natural reproduction of Monterey pine:

(A), on thin clay soil near Pacific Grove.

(B), on sandy soil in Point Lobos State Park near Carmel.

(C), on deep clay loam near Swanton.

A

C

Figure 3.—Forest types in the Cambria area where Monterey pine is the only conifer present in the forest stand. *(A)*, light stocking dominates the upper ridges of Santa Rosa Creek. *(B)*, at the southern limit of Monterey pine merging into grassland. *(C)*, vigorous stand on a 200-foot ridge near the ocean.

B

A

B

C

Figure 4.—Forest types in the Swanton area.

***(A)*, from sea level looking east into the central part of the Swanton stand where Monterey pine (as the elevation increases) is associated with redwood, Douglas-fir, and a mixture of knobcone and ponderosa pine.**

***(B)*, poison oak dominates the brush associates of this nearly pure stand of Monterey pine.**

***(C)*, all-age class stand makes vigorous growth when relieved of the impact of disease.**

Figure 5.—Natural stands of Monterey pine on Monterey peninsula.

***(A)*, densely stocked all-age stand on Huckleberry Hill.**

***(B)*, lightly thinned two age-class forest on the coastal plain.**

***(C)*, windswept stand at ocean edge.**

A

B

C

how lines are drawn around intermingled pine, grazing, and brush land. Some estimates have been as high as 20,000 acres and some as low as 8,000. Vegetation type maps of the Pacific Southwest Station suggest that the total acreage of native Monterey pine in these three localities is closer to 14,000 acres—distributed as follows: 1,000 (Swanton) in San Mateo and Santa Cruz counties, 8,000 to 12,000 (Monterey) in Monterey county, and 3,000 (Cambria) in San Luis Obispo county. The Cambria acreage includes about 400 acres of Monterey pine at Pico Creek some 6 miles north of the main body of pine at Cambria.

The climate in all three localities of the natural stands can be briefly described as Mediterranean and is quite similar in respect to seasonal distribution of 15 to 35 inches rainfall, the prevalence of summer fog, the rarity of frost, the absence of snow or hail, and moderate summer temperatures. About 75 percent of the annual rainfall occurs from December through March.

There is considerable variation in the soils at Swanton, Monterey, and Cambria (Lindsay 1937). Shales and marine sandstones intermixed with calcareous material from underlying rocks predominate at Swanton (Jensen 1939); granite, siliceous shales, and sandstones at Monterey (Carpenter and Cosby 1929); and slates, sandstones, and limestones at Cambria (Carpenter and Storie 1933). Monterey pine does well on soil derived from these rocks if the soil is not too shallow or too poorly drained. Heavy clay soils usually mean poor drainage and restricted aeration and these factors seem to favor the development of root diseases and reduced vigor of the trees.

At Monterey the pine grows best on the Elkhorn calcareous sandy loam 3 to 4 feet deep, a well-drained soil high in organic matter. Oddly enough this same soil in the Cambria area does not support native pine. At Cambria virtually all of the Monterey pine occurs on Arnold sandy loam which is derived from a consolidated sandstone. Most of the Monterey pine at Swanton occurs on Santa Lucia clay loam where growth and vigor of the tree is noticeably better than on the same soils at Monterey.

In general the best growth and the most disease-free conditions in Monterey pine stands will be found in sites where the soils are well drained, deep, and are made up of sandy loam. Although Monterey pine often makes excellent growth on light sandy soils, it seems probable that mycorrhizal formers may be contributing to nutrient assimilation under these conditions. Monterey pine reproduces vigorously (fig. 2) under a wide variety of soil and climatic conditions. Restrictions of environment and disease appear later in their impact on growth and longevity.

Important differences among the three areas in terrain, exposure, and vegetation seem to be reflected in the kind and prevalence of diseases. To a pathologist's eye, the stands at Cambria seem less vigorous than those at Swanton and less vigorous than many of the segments of the forest in the Monterey Peninsula. Perhaps this situation is a reflection of a single-species coniferous stand compared with a mixed-species forest.

California live oak (*Quercus agrifolia* Née) is an associate of Monterey pine in the three locations. In the single-species coniferous stand at Cambria (fig. 3), the coastal form of the western gall rust *(Peridermium harknessii)*[7] and the western dwarfmistletoe *(Arceuthobium campylopodum)* are prevalent and damaging on all age classes of trees. In the mixed coniferous forest at Swanton (fig. 4) where *P. radiata* is associated on lower slopes with redwood *(Sequoia sempervirens* [D. Don] Endl.), on mid-slopes with Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco), and on upper slopes with knobcone pine *(Pinus attenuata* Lemm.), there is a widely distributed but light infection of gall rust and no known dwarfmistletoe. At Monterey both gall rust and dwarfmistletoe cause important losses, but there is considerable variation in the prevalence of all types of diseases in the several sites and plant associations. In table 1 are summarized ratings on the prevalence of diseases in native Monterey stands and data for some of the environmental factors that influence the vigor of the host conifer and its ability to withstand attack of disease organisms.

Botanists have long been interested in the interrelationship of the mainland *P. radiata* and similar closed-cone pines of the islands off the shores of

[7]Authors for scientific names of all pathogens are given later in the lists of fungi and parasitic plants for native stands and plantations and in the Appendix for exotic Monterey pine. Names and authors of fungi have been verified by C. R. Benjamin and John A. Stevenson, mycologists, U.S. Department of Agriculture, using their preferred style of omitting prestarting-point authors. Abbreviations of authors are those given in U.S. Department of Agriculture Handbook 165 (1960).

Table 1. Ratings on prevalence of five types of diseases on Monterey pine at Swanton, Monterey, and Cambria, and some related data on climatic and ecologic factors affecting host vigor

Disease and factor as listed	Swanton	Monterey	Cambria
PREVALENCE[1]			
Gall rust	1	2	3
Root diseases	2	3	1
Heart rots and other decays	1	3	2
Foliage diseases	1	3	2
Dwarfmistletoe	[2]1	2	3
CLIMATIC AND ECOLOGIC DATA			
Rainfall, mean annual (inches)	27.7	16.7	20.4
Av. abs. max. temp. °F. (May-Oct.)	102.7°	90.3°	105.0°
Av. abs. min. temp. °F. (Nov.-Apr.)	24.9°	26.3°	25.5°
Av. length of growing season (frostless days)	270	307	284
Soil variability	Intermediate	Greatest	Least
Diversity of forest stand	Greatest	Intermediate	Least

[1] 1 - disease least prevalent; 2 - intermediate; and 3 - disease most prevalent.

[2] None found.

California and Baja California.[8] Consensus now describes the pine on the Mexican island of Guadalupe as *P. radiata* var. *binata* and those on Cedros (Mexico), Santa Rosa (U.S.A.), and Santa Cruz (U.S.A.) as being most closely related to *Pinus muricata* D. Don. No information is available on pathogens associated with the closed-cone pines on any of these islands. Bannister (1958) reported an unidentified "rust fungus" on one herbarium specimen of pine from Guadalupe Island. A disease survey of these island stands of the closed-cone pines would be of considerable interest to pathologists, especially in respect to tree improvement work.

[8] Bannister (1958), Howell (1941), Jepson (1910), Mason, (1943), and Newcomb (1959).

Plantations

The most extensive and successful plantations of Monterey pine in California are in the counties around San Francisco Bay and in portions of those counties near the ocean where the modified Mediterranean climate prevails (fig. 6). Recent data from Farm Advisors of these central California counties show about 1,200 acres of Monterey pines in larger plantations and numerous small plantings in windbreaks, parks, and home gardens. Trees have been planted as far south as San Diego in California and as far north as British Columbia.

At Placerville, California, in a climatic and soil environment quite different from native stands, planted Monterey pine made excellent growth until it encountered *Fomes annosus* (Bega 1962).

Figure 6.—Successful plantings of Monterey pine in the Berkeley hills, right foreground, and left and center on farther slopes.

Gall rust occurs in a 30-acre plantation of Monterey pine in Jackson State Forest near Fort Bragg, California (Sindel 1963). Some 14,000 seedlings (1-0 age class) were planted there in 1951–52. The number of infested trees and mortality have not yet been determined. Plantings of Monterey pine near Tahkenitch Lake near the coast of southern Oregon[9] and at Coombs, Vancouver Island, B. C.,[10] were successfully established but later became infected with *Peridermium harknessii*. At Tahkenitch 80 percent of the trees were attacked and at Coombs about 5 percent. Molnar (1961) reported a severe outbreak of the sweetfern blister rust *(Cronartium comptoniae)* in several plantations of Monterey pine on Vancouver Island, British Columbia, and warned of the need to guard against the introduction of this rust into other parts of the world.

Some of the oldest and most frequently examined plantations of Monterey pine in California are those in Old Sutro Forest, Golden Gate Park, and the Presidio, in the San Francisco area, and on the University of California campus at Berkeley. The first planting of Monterey pine on the U.C. campus was made about 1870. The Sutro Forest was established about 1880; plantings in Golden Gate Park and the Presidio were started about 1892 and continued on an intermittent schedule for 20 to 30 years. Many of the earliest herbarium collections of gall rust, and of foliage diseases such as the needle rust *(Coleosporium madiae)* (fig. 7), came from plantings in and near San Francisco. From these plantings comes evidence of heavy gall rust infection in young trees that does not continue at this high level as the trees grow older. As trees get taller and older, environmental conditions in the live crown apparently become less favorable for infection. Then, as new infections diminish, there is a commensurate reduction in the amount of local inoculum.

In summary, successful planting of Monterey pine in west coast areas of North America is definitely limited by frost, midsummer heat, disease, and other pests. The most generally suitable sites for planting of Monterey pine in western North America are the coastal counties of central California. To date the western gall rust and the sweetfern blister rust have placed some limitations on the desirability of planting Monterey pine outside of its optimum range in California. Dwarfmistletoe has not yet been a limiting factor in plantations.

Major Diseases

Seventy-two pathogens are listed in a later section as associates of *P. radiata* in native stands of California and in plantations of western North America. The appendix records 86 fungi reported on exotic *P. radiata* but does not duplicate a pathogen if it has already been named for California and West Coast plantations. Mycorrhiza of exotic Monterey pine are not listed in the appendix, but are briefly reviewed later under the heading "Mycorrhiza." Of these 72 native pathogens, 17 are briefly discussed here because of their common occurrence or their potential for damage in natural stands or plantations. Highlights of the behavior of these pathogens are given by categories of so-called major diseases: seed and seedling, foliage, stem, and root diseases, and decays and stains. A more critical appraisal of the damage factor would restrict major diseases in native

[9]Personal correspondence with D. P. Graham, U.S. Forest Service, Portland, Ore. Jan. 3, 1963.

[10]Personal correspondence with A. C. Molnar, Canadian Forest Entomology and Pathology Laboratory, Victoria, B.C. Feb. 19, 1963.

stands and West Coast plantations to those caused by: *Arceuthobium campylopodum, Armillaria mellea, Cronartium comptoniae, Fomes annosus, Fomes pini, Peridermium harknessii (Peridermium cerebroides* nomen nudum), and *Polyporus schweinitzii.*

Seed and Seedling Diseases

No disease problems of any significance have affected the production and germination of Monterey pine seed and the natural or nursery establishment of seedlings under California conditions.

At Swanton, Monterey, and Cambria *P. radiata* flowers in early spring, and produces some fertile cones at 6 to 8 years of age. From the age of 15 to 20 years while trees are in good vigor they produce seed in abundance. Cones shed seed annually and remain on trees for many years. Mirov (1946) states that the seed of Monterey pine has excellent keeping quality in cold storage and Schubert (1952) reports that cold-stored seed retained a viability of 71 to 87 percent after 16 to 17 years. The quality of seed, however, may be impaired by improper treatment during collection, extraction, storage, and other pre-planting procedures.

Figure 7.—*Coleosporium madiae*, needle rust showing, left, the ruptured aecial pustules on Monterey pine needles, and right, the uredial stage on the leaves of tarweed. Alternate host, in this case, is *Madia sativa.*

No special disease research has been directed to seed of Monterey pine in California, but the role of fungi on coniferous seed in West Coast areas is suggested by reports from Schubert (1960) for sugar pine and Shea (1960) for Douglas-fir. Not all of the fungi listed by Schubert and Shea were believed to be pathogenic on the embryo or to carry over into the post-emergence period of development. Among the suspect genera of fungi isolated were: *Aspergillus, Gliocladium, Monilia, Mucor, Penicillium, Pullularia, Rhizopus,* and unidentified bacteria.

In California most of the Monterey pine nursery stock is grown in the State Division of Forestry Ben Lomond nursery near Santa Cruz. Production of *P. radiata* there is scheduled for about one-half million seedlings per year. In 1962 a modest start was made in production of Monterey pine nursery stock at the Forest Service nursery at Arcata, California. A few commercial nurseries in other parts of the State grow a small amount of stock for home garden supply.

The performance of Monterey pine seedlings in California nurseries has generally been excellent. In fact, nurserymen have to guard against excessive growth for field planting stock. At the Ben Lomond nursery seedlings may grow to an average size of 16 inches from the normal seeding time, in April, until the preferred lifting date, the following January or February.

P. radiata is not immune to damping-off and to some of the later developing root diseases, but little trouble has been experienced to date in well-designed nursery procedures. Although *Pythium, Rhizoctonia, Fusarium,* and *Macrophomina* have been isolated from soils at Ben Lomond nursery, no major losses have occurred in beds of Monterey pine. *Pythium* in particular, as well as *Rhizoctonia,* appears to have an impact on root regeneration of Monterey pine seedlings and this problem is being studied by forest scientists from the University of California and the Forest Service.

The stocking and persistence of Monterey pine reproduction in both natural stands (fig. 2) and plantations (fig. 6) attest the vigor of this species even though gall rust and dwarfmistletoe often take a substantial toll of young age-class trees.

Foliage Diseases

Judging from collections and reports of the past 50 years, the most prevalent or potentially damaging foliage diseases are: *Coleosporium madiae, Hypodermella limitata, Hypoderma pedatum, Lophodermium pinastri,* and *Naemacyclus niveus.* Of these fungi *N. niveus* is probably the most widespread and damaging in the three areas of native pine. *Diplodia pinea,* a much-studied foliage and twig blight of exotic Monterey pine, occurs but rarely on native pine and has not been a serious pathogen under California conditions. The absence of hailstorms in coastal areas of California may be one of the important environmental factors that has curtailed the buildup of *D. pinea,* a wound parasite, in native stands. In exotic stands, *D. pinea* is often troublesome in localities persistently subjected to hailstorms.

The damage caused by foliage diseases varies considerably from year to year depending on climatic conditions. For a heteroecious rust such as *Coleosporium madiae* (fig. 7) close association of host plants as well as locally favorable climatic conditions are essential to rust intensification. Since the host *Madia* spp. are intolerant plants, they are suppressed with increased age and density of plantations or natural regeneration. *C. madiae* is most apt to occur in young open stands of pine during years when spring rains are above normal.

It is worth noting that *Elytroderma deformans* (Weir) Darker, a prevalent and damaging foliage and twig blight of hard pines in California, is not known to occur on Monterey pines.

Personal communications from pathologists I. A. S. Gibson, L. S. Gill, and J. O. Whiteside, and a report by Gibson (1963) call attention to the occurrence of a damaging needle blight *(Dothistroma pini)* in Monterey pine plantations of East Africa. This pathogen has not been found in western North America, or not reported under that name. A further report on the situation in East Africa by I. A. S. Gibson, P. S. Christensen, and F. M. Munga is in preparation.

Stem Diseases

Gall Rust

The western gall rust in its coastal form of *Peridermium cerebroides* occurs at damaging levels in Cambria, Monterey, and Swanton stands of Monterey pine and in plantations throughout central coastal California (fig. 8). *Peridermium cerebroides,* a nomen nudum as described by Meinecke (1929), has not yet been described validly as a species. The *Peridermium harknessii* form of the gall rust is found in some plantations in California, and in Oregon, Washington, and British Columbia wherever natural inoculum of this form of the rust is locally prevalent. Introduced into exotic plantations in regions where native gall rust does not occur, this fungus might seriously impair the productivity of Monterey pine as a forest species. Experience in North America shows clearly that the gall rusts may be vigorous and damaging diseases under a wide range of climatic conditions.

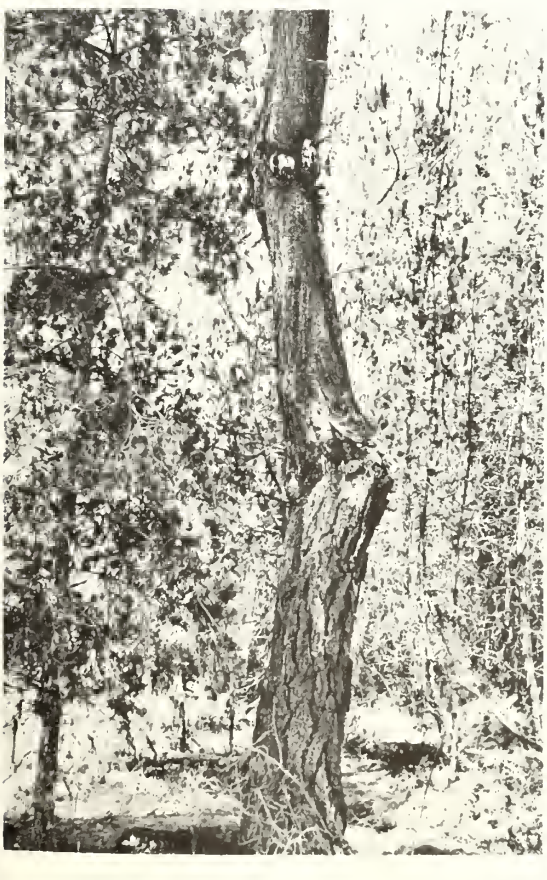
Both forms of the western gall rust have been transmitted to Monterey pine seedlings by artificial inoculation (Meinecke 1916, 1920, 1929). Successful inoculations were made by the spore shower method on intact stems and foliage, thus showing that artificial wounding of tissue is not necessary. Galls produced by inoculation retained characteristics typical of *Peridermium cerebroides* or *Peridermium harknessii.* Swelling and typical infection spots occurred in 5 to 20 months and sporulation in about 20 to 35 months.

From a series of inoculations of hard pines with aecia of gall rusts obtained from several sources, Boyce (1957) obtained infection of Scotch pine *(Pinus sylvestris* L.), with aecia from Monterey pine. Boyce's tests did not include inoculation of Monterey pine seedlings with gall rust aecia from other hard pines. Nevertheless, he did confirm in the case of the Scotch pine, Meinecke's (1920) descriptions of the distinctive appearance of the *P. cerebroides* galls on Monterey pine.

Both *Peridermium harknessii* and *P. cerebroides* stimulate the formation of witches'-brooms and both retard the growth of the infected stem; where infection of the main stem occurs they can cause death of a small tree. Mycelium is invariably confined to the gall and its immediate surroundings. The galls of *P. cerebroides* tend to become spherical and seldom show exfoliation of bark during or after sporulation (fig. 9A). By contrast the bark that overlays *P. harknessii* galls tends to break and scale off, showing underlying smooth, naked wood (figs. 9B and 9C) well in advance of branch killing. The exfoliation of bark results in the formation of a collar of dead bark on *P. harknessii* galls that stands out most clearly at the proximal end of the swelling (fig. 9B). This collar seldom if ever is seen on the *P. cerebroides* galls on Monterey pine or on other coastal hard pines *(Pinus muricata* and *Pinus attenuata)* attacked by

A

B



C

Figure 8.—Bole defects to mature *(A)* and *(B)* and pole and sapling *(C)* Monterey pine by gall rust *(Peridermium cerebroides)*. Trees shown in *(A)* and *(B)* were also attacked by dwarfmistletoe.

A

Figure 9.—Galls formed by *Peridermium cerebroides* and *P. harknessii.* *(A)* On Monterey pine *P. cerebroides* forms a globose gall that retains bark scales and does not form the bark collar shown in *(B)*. *P. harknessii* on *Pinus sabiniana (B)* causes early exfoliation of bark, induces the formation of a bark collar, and progresses towards the bare wood galls as shown in *(C)* well in advance of branch suppression. Note also in *(B)* and in *(C)* on left, the mass of confluent aecia.

C

A B

Figure 10.—Bole defects caused by long-established dwarfmistletoe infections. *(A)* Swelling and cavity. *(B)* Long fusiform swelling.

A

B

Figure 11.—Western dwarfmistletoe *(Arceuthobium campylopodum* f. *typicum)* on Monterey pine. *(A)* Seed-bearing (female) plant on a small branch. *(B)* Pollen-bearing (male) plant on the trunk of a pole-size tree.

this form of the rust. Meinecke (1920) states that aecia of *P. harknessii* are larger and more definitely confluent than those of *P. cerebroides*, but these characteristics by themselves do not always help the field man to identify the fungus.

As with other Peridermia of conifers the pycnia of *Peridermium cerebroides* are rarely seen in the field. Although Meinecke (1929) never observed pycnia on natural or artificially induced infections of *P. cerebroides*, he believed that the production of pycnia is merely repressed and that internal pycnia should be found. Gill (1932) reported seeing pycnia on native *P. attenuata* in the Santa Cruz Mountains of California in February and on a collection made in January from planted *P. radiata* near Palo Alto, California, after infected tissue had been sectioned in the laboratory. Production of aecia extends over several months in coastal regions of California, the period depending on the ecologic niche in which the host is growing. Usually peak production of aecia takes place in February and March.

Sweetfern Blister Rust

Sweetfern blister rust *(Cronartium comptoniae)*, a well-known and widely distributed rust of hard pines (Anderson 1963; Boyce 1961), does not occur in native stands of Monterey pine. Experience in plantations of British Columbia (Molnar 1961), however, clearly shows that this rust is a dangerous disease of Monterey pine. Sweetgale *(Myrica gale* L.), known in British Columbia, Washington, and Oregon, is a confirmed alternate host. *Myrica californica* Cham., widely distributed in coastal areas of California, Oregon, and Washington, and *Myrica hartwegii* Wats. from the Central Sierra Nevada of California are unproven but suspect hosts. In the West, known susceptible native pines are lodgepole, ponderosa, bishop, Jeffrey, and Monterey. Thus, both hosts and the rust are widely distributed in West Coast areas.

Molnar (1961) recorded damage to 9,000 Monterey pine in 12 British Columbia plantations. He found 2, 5, 1, and 3 plantations falling respectively into five designated classes of 0, 1-10, 11-50, 51-75, and 76-100 percent of pine infected. Molnar (1961) concluded that Monterey pine is a high risk species for planting in the coastal regions of British Columbia.

Dwarfmistletoe

Arceuthobium campylopodum f. *typicum*, the western dwarfmistletoe, is a parasitic seed-bearing plant that attacks and damages the hard pines. This parasite, native to Monterey pine stands in California, finds a highly susceptible host in *P. radiata* (fig. 10). In the Cambria and Monterey areas dwarfmistletoe and the gall rust are the most prevalent and destructive pathogens of Monterey pine.

There are no special features of the western dwarfmistletoe on Monterey pine to distinguish it from the dwarfmistletoe found on other hard pines (fig. 11). Gill (1935, pp. 185, 190, and 221) in his publication on dwarfmistletoes in the United States states that "On *Pinus radiata* the (dwarfmistletoe) shoots are characteristically a distinctive olive green shade"—and "The large

Figure 12.—Gall rust *(Peridermium cerebroides)* and western dwarfmistletoe *(Arceuthobium campylopodum)* often combine their attacks on Monterey pine. Mature seeds of dwarfmistletoe were ripe and being discharged in November at Cambria when this picture was taken.

dense clusters of shoots characteristic of old infections—seem especially to attract spittle insects (Cercopidae) which mine out the stems causing the death of branches or entire shoots." Kuijt (1960) includes Monterey pine as host for the western dwarfmistletoe in California but does not go into detail on this host-parasite combination. A comprehensive review of the literature of the mistletoes has been made by Gill and Hawksworth (1961).

Observations on the host strongly suggest that trees weakened by dwarfmistletoe are often attacked by insects.

Dwarfmistletoe is most prevalent on trees of young pole class or larger though occasionally it will occur on reproduction under 10 feet in height. All sizes of trees are damaged, deformed, or, in multiple heavy infections, killed by this parasite. The pathogen often causes fusiform swellings on twigs and branches. Older infections on the main stem may cause little or no swelling; here the dwarfmistletoe breaks out between cracks in the bark. Witches'-brooms caused by dwarfmistletoe are common.

Decayed and sunken faces of older branches or the trunk of Monterey pine may be associated with gall rust, dwarfmistletoe, or mechanical or animal damage. In many locations within the Cambria and Monterey pine areas dwarfmistletoe and gall rust may occur in multiple infections on the same tree (figs. 8 and 12). Both pathogens apparently find an ideal environment for spread and intensification in coastal areas of central California.

Linder (1938) reported the occurrence of *Metasphaeria wheeleri* Linder sp. nov. a natural parasite on scales and stems of *Arceuthobium campylopodum* on Monterey pine, Point Lobos State Park, California.

Control of dwarfmistletoe in Monterey pine is through removal of infected branches or trees in accordance with silvicultural objectives as outlined by Kimmey (1957) and by Kimmey and Mielke (1959). There are no special elements in the control of dwarfmistletoe on Monterey pine that require different methods from those recommended for other hard pines.

Cankers

There are no parasitic canker fungi of any significance occurring in native stands of California or in West Coast plantations. Mention should be made, however, of the susceptibility of Monterey pine to pitch canker *Fusarium lateritium pini* as reported by Hepting (1961). This fungus is primarily a wound parasite. It is pathogenic and destructive to Monterey pine seedlings and should be regarded as potentially dangerous to Monterey pine both native and exotic. Nothing comparable to the smothering fungus, the so-called "Glenburvie fungus" from New Zealand or its reported equivalent of *Peniphora sacrata* (Gilmour 1959), has been found in California.

Root Diseases

The most prevalent and damaging or potentially damaging root diseases associated with Monterey pine in native stands or West Coast plantations are: *Armillaria mellea, Fomes annosus,* and *Polyporus schweinitzii.*

Of these, *Fomes annosus* is unquestionably the most important. It was reported about 1909 in some of the earliest surveys by Meinecke and others in the Monterey peninsula. Experience at the Eddy Arboretum of the Institute of Forest Genetics at Placerville (Bega 1962) attests to the high susceptibility of Monterey pine to *F. annosus* in plantations. Most of the tree killing by *F. annosus* in the Monterey area seems to be associated with shallow, poorly drained, heavy soils where the trees have not been making average growth.

E. P. Meinecke, in an unpublished report in the forest pathology files of the Pacific Southwest Station, provides a detailed description of the annosus rot in wood and bark, and of the sporophores and mycelium of the fungus. In herbarium records supporting these descriptions, he noted that "40 to 70 percent of trees over 40 years of age in the grounds of the Del Monte Hotel property a little above sea level" were affected.

The prevalence of oaks in natural stands of Monterey pine at Cambria and Monterey suggests that *Armillaria mellea* should be of fairly common occurrence. It is. Losses from *A. mellea,* however, are not alarming and generally appear to be contained by natural biologic agents.

Although *Phytophthora cinnamomi* has been found only once on nursery stock from southern California (Zentmyer and Munnecke 1952), experience in New Zealand (Newhook 1959, 1960) provides ample evidence of the aggressiveness of *Phytophthora* spp. to Monterey pine. Great care should be exercised to prevent *Phytophthora* spp. from being introduced into forest nurseries or native stands of Monterey pine. Sutherland et al.

Figure 13.—*Fomes pini* conks on Monterey pine in Huckleberry Hill, Monterey area. For Monterey pine these are unusually large and conspicuous conks of this heart rot fungus.

(1959) observed increased susceptibility to *Phytophthora* spp. and a slower recovery rate of affected Monterey pine growing in poorly drained soils.

Polyporus schweinitzii is widely distributed in the three areas of native Monterey pine, where it often is associated with the mortality of fast growing and apparently vigorous pole-sized or young mature trees. It seems likely that in addition to its well-known role in causing decay of root and butt, *P. schweinitzii* can actually be a root pathogen as described by Boyce (1961). Not infrequently *P. schweinitzii* conks occur on the main stem about 15 to 25 feet from the base of a standing tree. At Swanton and Monterey, *P. schweinitzii* conks were found in association with insects on recently killed trees that had been making excellent growth in deep, seemingly fertile soils.

Decays and Stains

Native and exotic Monterey pines are attacked by a broad spectrum of organisms causing decay of heartwood and sapwood, staining of sapwood, and deterioration of wood. Of the rot fungi causing significant losses of Monterey pine timber in California, *Fomes pini* (fig. 13), *Polyporus schweinitzii, Armillaria mellea,* and *Polyporus tomentosus* are especially noteworthy. *F. pini* and *P. schweinitzii* both occur at Cambria, Monterey, and Swanton, but occurrence is spotty within these areas. Heart rot losses in Monterey pine are generally low, probably on the order of 2 or 3 percent of the total volume of merchantable timber. *Polyporus anceps* has been found on native Monterey pine but it is not common. The most prevalent saprophyte found on dead trees or down logs and slash is *Polyporus abietinus*. Under favorable conditions blue stain and other sapstain fungi will develop in windblown or felled trees in the woods and in log decks.

Other Diseases, Disorders, and Protection Problems

Mycorrhiza

No published information is available on mycorrhizal symbionts of Monterey pine in native stands of California. Several of the well-known mycorrhizal formers are native to California and others listed for Monterey pine from other parts of the world will doubtless be found here. Sporophores of *Boletus* sp. and *Amanita* sp. were often seen in Monterey pine stands of the Cambria, Monterey, and Swanton areas, during recent surveys by Forest Service personnel.

Trappe (1961) observed sporophores of *Inocybe lacera* associated with Monterey pine seedlings grown in jars of soil inoculated with freshly gathered mycorrhiza of Douglas-fir and ponderosa pine. MacDougal and Dufrenoy (1944a, 1944b) made histological studies of the ectendotrophic symbionts of *P. radiata,* and reported that the association did not seem to be connected with any morphological alterations. They described the anatomy of the pine symbiont and also the biochemistry of phenolic compounds in the root pericycle and endodermis. Wallis (1959) studied the effects of chlordane, allyl alcohol, dieldrin, and other biocides on mycorrhizal fungi associated with *P. radiata,* which seemed generally to be little affected by these chemicals in dosages used.

Zak and Bryan (1963) have properly emphasized the difficulties of extrapolating from data on mycorrhizal synthesis to conditions as they exist in the forest. Several workers have reported the role of mycorrhiza in the culture of *P. radiata* as an exotic.[11] In a recent review Trappe (1962) listed the following fungus associates of the ectotrophic mycorrhiza for *P. radiata*:

- *Amanita muscaria* (L. ex Fr.) Pers. ex Hooker
- *Cenococcum graniforme* (Sow.) Ferd. & Winge
- *Gomphidius rutilus* (Schaeff. ex Fr.) Lund & Nannf.
- *G. vinicolor* Peck
- *Inocybe lacera* (Fr.) Kumm.
- *Laccaria laccata* (Scop. ex Fr.) Berk. & Br.
- *Lactarius deliciosus* (L. ex Fr.) S. F. Gray
- *Rhizopogon luteolus* Fr. & Nordh.
- *R. roseolus* (Corda) Hollos
- *R. rubescens* Tul.
- *Scleroderma aurantium* (Vaill.) Pers.
- *S. bovista* Fr.
- *Suillus granulatus* (L. ex Fr.) O. Kuntze
- *S. luteus* (L. ex Fr.) S. F. Gray
- *S. piperatus* (Bull. ex Fr.) O. Kuntze
- *S. subaureus* (Peck) Snell

Martinez[12] has reported *Amanita muscaria, Cantharellus cibarkus* Fr., and *Marasmius oreades* Fr. as mycorrhizal symbionts of Monterey pine in Spain. Of all these only *C. graniforme, I. lacera, R. rubescens,* and *S. luteus* have been established for Monterey pine by pure culture technique (Rawlings 1951, Trappe 1961).

Physiogenic Disorders

In recent years planted Monterey pine in the San Francisco Bay counties has shown an increasing amount of needle cast and chlorosis of foliage. No fungus or insect of a primary nature is involved in this damage. It is suggested that physiogenic needle cast from drought, nutrient deficiencies, and occasional spells of low temperature plus some added impact from air pollutants are responsible. Monterey pine may be one of the more sensitive of the pines to air pollutants.

Large brooms (fig. 14) that resemble those associated with dwarfmistletoe infections have been observed occasionally on scattered Monterey pine in the Cambria, Monterey, and Swanton areas. Close examination of these brooms discloses no evidence of the causal agent. They are presumed to be the result of some physiogenic disorder.

In field trials at Tahkenitch Tree Farm in southern Oregon (Austin and Strand 1960) *P. radiata* and *Pinus* X *attenuradiata* hybrid showed increased response in height growth to phosphorus fertilizers. Increased phosphorus uptake has been credited to mycorrhizal symbionts (Morrison 1957). Neither the native stands of California nor West Coast plantations have produced unusual symptoms such as needle fusion, rosette disease or the obvious symptoms of zinc, potassium, phosphorus,

Figure 14.—Physiogenic brooming in Monterey pine. Note large brooms in upper crown of tree at left side of mill. The mill shown is in Carmel Valley and is one of two small mills in California cutting Monterey pine lumber for local sale.

[11]Azevedo 1959; Clements 1938; Cromer 1935; Morrison 1957; Rawlings 1951, 1960.

[12]Martinez, José Benito. Third annual report of progress of research sponsored by P. L. 480. 1963 (Unpublished report to Inst. Forest. de Invest. y Exper., Madrid.)

and boron deficiencies such as have been reported in exotic stands from Australia and other countries.[13]

Insect, Animal, and Fire Damage

Keen (1952) lists 50 species or genera of insects occurring on Monterey pine in California. Of these, three species of ips and the red turpentine beetle *(Dendroctonus valens* Lec.) are marked as tree killers. Burke (1937) reports 26 insects as important enemies of native Monterey pine. Struble (1961) in discussing the Monterey pine ips *(Ips radiatae* Hopk.) states that maturing trees may be attacked when weakened by competition from drought, mistletoe infection, or fungus infection by *Peridermium*. Similarly the red turpentine beetle seems to be unusually aggressive in plantings located in hot, dry sites that might be considered as marginal for growth of Monterey pine. Pathologists have remarked on the prevalence of the spittle bug *Aphrophora permutata* Uhl. in trees and stands where *Peridermium cerebroides* or *P. harknessii* infections are common.

The sequoia pitch moth *Vespamima sequoiae* (Hy. Edw.) causes the formation of large amounts of a greyish resin on the bark. Old dwarfmistletoe bole infections also contribute to copious resin flow that often combines with that produced by the pitch moth. Associated with this external body of resin there may be a wedge-shaped intrusion of pitch in the sapwood that closely resembles the pitching caused by pitch canker *Fusarium lateritium pini* on Virginia pine *(Pinus virginiana* Mill.). Attempts to isolate this fungus from these pitch wedges of Monterey pine wood have failed.

[13]Hall and Purnell 1961; Herman 1938; Kessell 1943; Ludbrook 1942; Purnell 1958; Smith 1943; Stoate and Bednall 1957; Vail et al. 1961; and Will 1961.

Beetles, of course, are involved in the introduction of blue-stain fungi *(Ceratocystis* spp.) into the sapwood of Monterey pine, and a sooty mold *(Epicoccum* sp.) is often seen in association with scale insects.

In California the low level of incidence of *Diplodia pinea* on Monterey pine may be attributed to the nature of injuries caused by some of the aphids, mites, and scale insects as well as to the absence of hailstorms. Native stands of Monterey pine have not been subject to outbreaks of wood wasps and associated fungi similar to the *Sirex noctilio* Fabr. outbreaks reported from New Zealand (Rawlings 1955).

Native stands of Monterey pine at Cambria and Monterey were subjected to considerable grazing and burning until the late 1920's when land managers became active in protecting the timbered areas. Monterey pine produces seed in such abundance, and it regenerates so aggressively that depredations by cone and seed insects, ants, rodents, and deer are not often serious problems to the forest manager. Schaefer (1962) describes *Conophthorus radiatae* Hopkins as a major pest of Monterey pine cones in central California. This cone beetle is reported to have killed 90 percent of the cones in some stands of the Monterey area but is not known to occur in the Cambria and Swanton areas. There seems to be no special disease problems correlated with animal damage, though damage by deer and rodents has been observed in plantations (Sindel 1963).

A relatively thin-barked pine, *P. radiata* has been rated in Australia (Pryor 1940) as more susceptible to fire damage than *Pinus ponderosa* Laws. or *Pinus jeffreyi* Grev. & Balf. In native stands, fire-wounds are frequently associated with the presence of heart or butt rots and almost always with many saprophytic fungi. Extensive patches of even-age Monterey pine that have come in after fire tend to be free of dwarfmistletoe, but may be heavily infected with gall rust.

Pathogens Associated with Pinus Radiata in Native Stands of California and Plantations of Western North America

In the list that follows the pathogens are identified by the name used in the supporting publication or as indexed in the California herbarium of record. The symbols for the four herbaria consulted are: PSW for the Pacific Southwest Forest and Range Experiment Station, Berkeley; UC for the University of California (Botany Department), Berkeley; CAS for the California Academy of Science, San Francisco; and PC for Pomona College, Claremont. The collector is named but not the one who identified the fungus. The symbols (X), (XX), and (XXX) that appear next to the name of the pathogen mean saprophyte, wound parasite, or obligate parasite in the sense of Spaulding (1961). As used here, these symbols refer to the behavior of the fungus on Monterey pine in western North America (when known) and do not necessarily categorize the fungus on other hosts.

Well-known fungi are not described unless the characteristics are noteworthy for Monterey pine. No attempt has been made to provide a list of synonyms.

Herbarium records, usually those for the earliest collections, are provided to support previously published listings of fungi marked U.S.A., California, as in Scott (1960) or where origin of collection has been unreported as in Seymour (1929).

Dwarfmistletoes

***Arceuthobium campylopodum* Engelm. forma *typicum* (Engelm.) Gill (XXX) (Loranthaceae)**

Seed bearing plant parasitic on conifers. PSW 97954 (W. H. Long) from an arboretum near Palo Alto, San Mateo County, California, September 1911. Other collections from native stands in PSW herbarium. Occurs throughout native stands of Monterey pine at Cambria and Monterey but not yet reported from the Swanton area. Not known to occur on Monterey pine outside of central California, U.S.A.

Fungi

***Armillaria mellea* (Fr.) Quél. (XX) (Basidiomycetes, Agaricales)**

Root rot. PSW 85069 (E. P. Meinecke) Golden Gate Park, San Francisco, May 1923. This collection from a planted tree 22 inches d.b.h. having roots and base of trunk affected, poor foliage throughout and tree declining, mycelium almost girdling the base up to 2 to 3 feet high in places. Recent Forest Service surveys in native stands of Monterey pine confirmed the presence of this fungus and its killing of pines in Monterey, Santa Cruz, and San Mateo counties. A host list for this fungus (Raabe 1962) shows a collection from a planted Monterey pine in California. Parasitic on roots of weakened trees causing decay of roots and death of trees. Characteristics of fungus and decay in Monterey pine similar to those described by Boyce (1961) for other pines. Listed by Scott (1960) for Chile, Kenya, and New Zealand, by Green (1957) for Great Britain, and by Martinez[14] for Spain.

***Botrytis cinerea* Fr. (XX) (Fungi Imperfecti, Moniliales)**

Mold blight. Collected (G. R. Hoerner) March 1934, from the Peavy Arboretum, Corvallis, Oregon, on seedlings of Monterey pine (Hoerner 1938). Listed by Shaw (1958) for Oregon. World-wide distribution as a blight of coniferous and broad-leaved trees. Described by Gibson (1962) as a nursery disease in Kenya causing dieback. Listed by Scott (1960) for New Zealand.

***Cenangium abietis* (Fr.) Rehm (XX) (Ascomycetes, Pezizales)**

Twig blight. PSW 97700 (E. P. Meinecke) February 1926, Del Monte, Monterey County, California, on foliage and twigs of reproduction 5 to 10 feet tall. UC 469644 (H. E. Parks) Berkeley Hills, Alameda County, California, February 1923, on dead bark of planted Monterey pine. Apothecia small, black, cup-shaped. Listed by

[14]See footnote 12.

Seymour (1929) as similar to *Cenangium ferruginosum* Fr. and now generally called by this name rather than *C. abietis*. Usually associated with and follows injury by gall midge or scale insects. Boyce (1961), referring to *C. ferruginosum*, calls it "pruning disease" which causes intensive flagging injury of ponderosa pine in the Southwest, most prominent in spring and early summer.

Coleosporium madiae **(Syd.) Arth. (XXX)**
(Basidiomycetes, Uredinales)

Needle rust. PSW 83479, 83480 (E. P. Meinecke) April 1915, near Monterey, California, and indexed as *Peridermium californicum*. Twelve later collections were made, February through early May 1917–1922 (E. P. Meinecke, W. W. Wagener, and E. Bethel) at Monterey and Carmel, along Skyline Boulevard in San Mateo County, and from Golden Gate Park, San Francisco. These collections, indexed as *Coleosporium madiae*, provide both aecial and telial stages of the fungus. The connection of the alternate stages was demonstrated by E. P. Meinecke in 1917 using aeciospores (PSW 85840, 85997) from *P. radiata* on *Madia dissitiflora* Nutt. T. & G. (Rhoades et al. 1918). Jeffrey and Coulter pines have also been reported as aecial hosts in California.

Coleosporium madiae on tarweed hosts has been collected in various parts of the coastal mountains and Sierra Nevada of California. An early report is that of Cooke (1879) who reported the fungus on living foliage of *Madia nuttallii* Gray in the Sierra Nevada; a later collection, UC 538806, on this same host was made near the coast in Humboldt County. Other California collections of the rust-infected *Madia* spp. were on *M. capitata* Nutt., UC 568080, Marin County, September 1922; on *M. congesta* T & G., UC 959786, Presidio, San Francisco, August 1913; on *M. dissitiflora*, UC M64532, Berkeley, Alameda County, July 1923; on *M. elegans* Don, UC 976868, Marin County, June 1926.

Arthur (1962) describes pycnia, aecia, uredia, and telia on host foliage. Aecia may occur on any face of the needle and all belong to the form genus *Peridermium*. Peridium flattened, laterally tongued-shaped; aecia white, large, appear in early spring (February to May) in native stands and central California plantations. Aecia are globoid to broadly ellipsoid. On tarweed leaves uredia are hypophyllous, round, golden-yellow; telia hypophyllous, orange-yellow when fresh; teliospores cylindric or oblong-lanceolate.

Coniothyrium acuum **(Cke & Ell.) Harkn. (XX)**
(Fungi Imperfecti, Sphaeropsidales)

Needle rot. Collected (Harkness #1591) May 1884, on needles of planted pine at Woodland, California (Harkness 1885). Listed by Seymour (1929) as equivalent to *Phoma acuum* Cke. & Ell. and by Scott (1960) for U.S.A.

Corticium punctulatum **Cke. (X)**
(Basidiomycetes, Agaricales)

Wod rot. PSW 85763 (E. P. Meinecke) April 1911, near Del Monte, Monterey County, California. On bark of dead tree. Listed by Scott (1960) for New Zealand.

Cronartium comptoniae **Arth. (XXX)**
(Basidiomycetes, Uredinales)

Stem rust. Molnar (1961) confirmed the identity of the rust on planted Monterey pine from Vancouver Island by aeciospore inoculations on *Myrica* sp. and *Castilleja* sp. to distinguish *C. comptoniae* from *Peridermium stalactiforme* Arth. & Kern. The pathogen and its symptoms are described by Boyce (1961) and Anderson (1963). To date infection of Monterey pine with this rust is known only from British Columbia.

Dasyscypha bicolor **(Fr.) Fckl. (XX)**
(Ascomycetes, Pezizales)

Canker. UC 585683 (Lee Bonar) October 1937, Oakland, California. Forms a canker-like lesion on dead bark. Spaulding (1961) reports *Dasyscypha calyciformis*, a probable synonym for *D. bicolor*, as a wound parasite occasionally causing damage to Monterey pine in New Zealand.

Dermatea pini **Phill. & Harkn. (XX)**
(Ascomycetes, Pezizales)

Twig blight. CAS 2042 (Harkness #2505) type specimen, February 1881, San Francisco, California, on twigs of planted pine. Reported by Phillips and Harkness (1884) and listed by Seymour (1929) and Scott (1960) as equivalent to *Cenangium pini* (Phill. & Harkn.) Newcomb. U.S.A. only.

Diplodia pinea **(Desm.) Kickx (XX)**
(Fungi Imperfecti, Sphaeropsidales)

Twig blight. UC 257173 (Lee Bonar) in San Rafael, Marin County, California on cone scales of planted *P. radiata*. UC 209258 (D. R. Miller) in Deer Flat County Park, Monterey County, California, November 1962 on dead needles and some live twigs. In Deer Flat County Park this fungus seems to have contributed to damage of foliage and twigs, but host trees here are in poor vigor and other stem and foliage disease are also present.

Hedgcock (1932) noted *Sphaeropsis ellisii* Sacc. *(D. pinea)* on greenhouse seedlings of *P. radiata* in Washington, D. C. Surprisingly, only two collections of *Diplodia pinea* as noted above have been made from Monterey pine in California.

The nomenclature and morphological and cultural characteristics of *Diplodia pinea* as well as the behavior of this fungus as a saprophyte and parasite are described in detail by Birch (1936) and Waterman (1943). Crandall (1938) reported that *Sphaeropsis ellisii* in nurseries of the United States caused root rot and death of 3- to 5-year-old red pines and of 5- to 6-year-old eastern white pine. Spaulding (1961) refers to *D. pinea* as causing a canker or twig blight. Slagg and Wright (1943) reported that *D. pinea* caused extensive damage to seedlings of *Pinus nigra* Arnold, *P. edulis* Engelm., *P. ponderosa,* and *Pseudotsuga menziesii* in a Kansas nursery, and that the fungus was found on needles, needle bases, bark, and cone scales of damaged branches of mature trees of *P. nigra, P. ponderosa, P. pungens* Lamb., *P. rigida* Mill., and *P. sylvestris* L.

Diplodia pinea on exotic Monterey pine has been the subject of much research and attention by pathologists and foresters.[15] *D. pinea* may be parasitic after injury by wind, hail, insects, birds, or frost and physiogenic disorders.[16] The fungus has been charged (Birch 1936) with damage to unthrifty trees resulting in: Secondary infection of stag-headed trees, red-top, stem infection, bud-wilt of seedlings, and sap stain. It is widespread and common in New Zealand as a saprophyte on foliage, dead bark, wood, and cones. Recently, many pathologists take the position that damage, potential or actual, from *D. pinea* has been greatly overrated.

Diplodia pinea is widely distributed in exotic plantations of Monterey pine in Argentine, Australia, Chile, New Zealand, South Africa, and Spain.

Eriosphaeria vermicularia **(Fr.) Sacc. (XX)**
(Ascomycetes, Sphaeriales)

Collected (Harkness #1350) circa 1881 on planted pine near San Francisco and Martinez, California. Reported by Harkness (1885) as a stain fungus but collection not available for study. Lister by Seymour (1929) and Scott (1960) for U.S.A.

Fomes annosus **(Fr.) Cke. (XX)**
(Basidiomycetes, Agaricales)

Root rot. Sporophores PSW 10000 (E. P. Meinecke) and rot specimens of bark and wood PSW 85156 (E. P. Meinecke) both collected in December 1909 from Del Monte Properties in Monterey area, Monterey County, California. Other collections in PSW herbarium. *Fomes annosus* often kills Monterey pine rapidly as reported for many other pine species (Bega 1962), first destroying the function of cambial tissue. Pines attacked by this fungus show typical root disease symptoms of reduced growth and thin, chlorotic foliage. Usually the attack of the fungus is associated with copious resin infiltration of wood around the base of the tree at ground level. Most of the roots may be sound at the time of fading and death of the tree. In later stages the fungus causes the typical soft white stringy rot in roots and butt (Boyce 1961). Lowe (1957) and others have described the fungus. Not yet reported on Monterey pine outside of California.

Fomes pini **(Fr.) Karst. (XX)**
(Basidiomycetes, Agaricales)

White pocket heartrot. PSW 85224 (E. P. Meinecke) April 1911, at Monterey, California; later collections PSW 85228, 85230, 85247, and 85248 (Meinecke and Boyce) from Monterey area of native pines. Observations in 1962 showed that *F. pini* sporophores were common in native stands of pine at Cambria, Monterey, and Swanton on live and dead trees. Causes typical white pocket decay of heartwood with some invasion of sapwood. The perennial conks and pattern of decay in the heartwood for Monterey pine are typical of hard pines. The dark colored conks when sunken somewhat in the bark at branch stubs, are hard to see on the dark bark of Monterey pine. General characteristics of this well-known fungus are described by Boyce (1961) and Lowe (1957).

Fomes pinicola **(Fr.) Cke. (X)**
(Basidiomycetes, Agaricales)

Brown crumbly rot. PSW 98036 (H. R. Offord), March 1963 from Green Oaks Creek, San Mateo County, California, near northern limit of the Swanton-Año Nuevo stand of pine. Occurred at the base of a 2½ foot stump, a recently cut tree. Rare on Monterey pine in native stands though often found on associated Douglas-fir. Not previously listed for Monterey pine.

[15] Bancroft 1911; Birch 1936; Capretti 1956; DeGryse 1955; Eldridge 1957; Ferreirinha 1953; Gibson 1958; Laughton 1937; Purnell 1956, 1957.

[16] Legat 1930; Ludbrook & White 1940; Poynton 1957; Rawlings 1955; Saravi 1950; Young 1936.

Fomes roseus **(Fr.) Karst. (X)**
(Basidiomycetes, Agaricales)

Brown cubical rot. PSW 98035 (G. B. Rawlings and W. W. Wagener) October 1956. On down log in exposed location in fog belt near Swanton, Santa Cruz County, California.

Guepiniopsis tortus **(Fr.) Pat. (X)**
(Basidiomycetes, Tremellales)

Jelly fungus. UC 641049 collected March 1940, Oakland, Alameda County, California, on debris underneath planted pine.

Hydnum stevensonii **Berk. & Br. (X)**
(Basidiomycetes, Agaricales)

White stringy rot. PSW 85742 (E. P. Meinecke) April 1911, Pacific Grove, Monterey County, California, on dead fallen branch. Yellow conk in small recessed branch stub.

Hypoderma pedatum **Darker (XX)**
(Ascomycetes, Phacidiales)

Needle cast. PSW 83843 (J. S. Boyce) January 1920, San Francisco, California. Seven other early collections from Monterey and from Golden Gate Park area, San Francisco in PSW herbarium. Collected (D. R. Miller) November 1962, at Cambria, Monterey, and Swanton. Described by Darker (1932) as a new species from a collection made in Golden Gate Park, San Francisco, California, August 1929; specimen in Arnold Arboretume (Pathological Herbarium 655). Darker (1932) states, "The diseased needles occurred in tufted branches on the dead ends of twigs, but there was no evidence to indicate that *Hypoderma pedatum* was the primary cause of the trouble. *H. pedatum* can be easily diagnosed in the field by the small brownish hysterothecia scattered along the stomatal lines." Listed by Scott (1960) for U.S.A.

Hypodermella limitata **Darker (XX)**
(Ascomycetes, Phacidiales)

Needle cast. PSW 83889 (E. P. Meinecke) April 1915, Monterey County, California. From J. S. Boyce collection #293 of May 1919, Darker (1932) described this fungus as a new species; type locality Golden Gate Park San Francisco. Part of same collection in UC herbarium at Berkeley.

Darker (1932) states that, "*H. limitata* infects only short portions of the needle. Usually restricted to sections a few mm. long located in the center of green needles. In the case of *H. limitata* only four spores mature. Hysterothecia shining black, amphigenous on sordid areas on green or languishing needles." Listed by Scott (1960) for U.S.A.

Hypodermella montivaga **(Petr.) Dearn. (XX)**
(Ascomycetes, Phacidiales)

Needle cast. PSW 83001 (W. W. Wagener) April 1926, Fort Scott, San Francisco on foliage of planted trees. Darker (1932) says this fungus is similar to *Hypodermella sulcigena,* a destructive parasite in Europe. Described by Dearness (1924) from type collection on *Pinus contorta* Dougl. from Idaho.

Hysterangium gardneri **E. Fischer (X)**
(Basidiomycetes, Lycoperdales)

Terrestrial fleshy fungus. UC 126142 collected November 1904, under planted Monterey pine on University of California Campus, Berkeley. Listed by Seymour (1929) and Scott (1960) as *Hysterangium fuscum* Harkn. for U.S.A.

Lophium mytilinum **Fr. (XX)**
(Ascomycetes, Hysteriales)

Canker. Collected (Harkness #2682) from planted trees in San Francisco, California, June ca. 1881 and reported by Harkness (1885). In Germany Engler and Prantl (1897) describe this fungus as developing on blackened surfaces of bark and wood of conifers. Reported on Monterey pine only for U.S.A.

Lophodermium nitens **Darker (XXX)**
(Ascomycetes, Hysteriales)

Needle cast. PSW 83052 (W. W. Wagener) near Monterey, California, March 1930, on foliage and acting as a weak parasite. Appears as shiny black subcuticular bodies on outer face of needles. Boyce (1961) reports *L. nitens* on five-needle pines as a saprophyte.

Lophodermium pinastri **(Fr.) Chev. (XXX)**
(Ascomycetes, Hysteriales)

Needle cast. PSW 83852 (J. S. Boyce #340) at Golden Gate Park, San Francisco, California, May 1919, on planted pine. Other collections from same area in PSW herbarium. Marked heavy infection and very common on all needles except current year. Collected (Darker #658) Golden Gate Park San Francisco, California and in Pathological Herbarium of Arnold Arboretum. Described by Darker (1932).

Tehon (1935) lists *P. radiata* as host for *Lophodermium pinicolum* Tehon n. nom. for *L. pinastri,* basing his description on a collection by J. S. Boyce made March 1919, at Cisco, California. Mild winters and wet summers may create epidemic outbreaks on Monterey pine (Rawlings 1955). Under favorable conditions this fungus may cause serious injury, especially in nurseries, but usually is a mild parasite. Listed by Scott (1960) for New Zealand, South Africa, and Spain.

Macrophoma pinea **(Desm.) Petr. & Syd. (XX)**
(Fungi Imperfecti, Sphaeropsidales)

Needle blight. Collected on seedlings, state of Washington, as reported by Hedgcock (1932). Listed by Shaw (1958). U.S.A. only.

Merulius confluens **Schw. (X)**
(Basidiomycetes, Agaricales)

Trunk rot. UC 568821 collected February 1937, on burned dead log, Oakland Hills, Alameda County, California.

Mycosphaerella acicola **(Cke. & Harkn.) Lindau (XX)**
(Ascomycetes, Sphaeriales)

Needle blight. CAS 1849 (H. W. Harkness #2303) type specimen collected April 1881, San Francisco, California on pine needles and called (Cooke and Harkness 1884b) *Sphaerella acicola* Cke. & Harkn. Indexed in UC herbarius as *M. acicola* but no specimen filed. Listed by Seymour (1929) and Scott (1960) for U.S.A. as *S. acicola*.

Naemacyclus niveus **(Fr.) Sacc. (XXX)**
(Ascomycetes, Phacidiales)

Needle cast. PSW 97988 and UC 756713 (Vera M. Miller) November 1942, and UC 652850 (E. B. Copeland) November 1940, all from the University of California Campus, Berkeley, parasitic on foliage of planted pine. Listed by Darker (1932) as in California on Monterey pine. Collected (D. R. Miller) Deer Flat Park, Monterey County, March 1962, and noted again at Monterey, Cambria, and Swanton, in November 1962.

Darker (1932) states that ascocarps are scattered, somewhat rectangular in appearance when partially open, at first waxy, dark brown, later becoming concolorous with leaf surface, opening along stomatal lines, the two halves of the covering layer becoming widely opened through the tearing of the epidermis. Listed by Scott (1960) for New Zealand and Spain, by Gibson (1962) for Kenya.

Peniophora burtii **Rom. (X)**
(Basidiomycetes, Agaricales)

Sapwood rot. UC 641021 (Vera M. Miller) March 1940, on down twig of Monterey pine, near Pacific Grove, Monterey County, California.

Peniophora cinerea **(Fr.) Cke. (X)**
(Basidiomycetes, Agaricales)

Sapwood rot. UC 620883 (Lee Bonar) November 1935, on dead bark and wood of planted Monterey pine near San Rafael, Marin County, California.

Peniophora gigantea **(Fr.) Mass. (X)**
(Basidiomycetes Agaricales)

Sapwood rot. UC 532368 (Lee Bonar) March 1935, in Oakland Hills, Alameda County, California, on dead bark from a planted tree.

Boyce (1961) says that *P. gigantea* causes a superficial sap rot of both conifer and hardwood slash and wood products in storage. It often appears as a fluffy white mycelial growth on a wood surface. Reported as a major cause of decay of deadwood by the New Zealand Forest Service (1961).

Peridermium cerebroides **Meinecke nomen nudum (XXX)**
(Basidiomycetes, Uredinales)

Coastal gall rust. PSW 83526 (E. P. Meinecke) April 1912, from vicinity of Monterey, California. Thirty-one collections of gall rust on Monterey pine in California were deposited in the PSW herbarium from 1912 to 1944. Depending on the date of collection these specimens were marked *Peridermium harknessii*, *Peridermium cerebrum*, or *P. cerebroides*. They come from Monterey, Santa Clara, San Mateo, San Francisco, Marin, and Alameda Counties. *P. cerebroides*, the coastal form of the western gall rust *Peridermium harknessii* J. P. Moore, is prevalent and damaging in native stands of Monterey pine at Swanton, Monterey, and Cambria. It is common also in plantations of central coastal California. In or adjoining these same areas bishop pine *(Pinus muricata)* and knobcone pine *(Pinus attenuata)* may be infectd by one or both forms of this rust.

Peridermium harknessii **J. P. Moore (XXX)**
(Basidiomycetes, Uredinales)

Western gall rust. This widely distributed gall rust occurs in plantations of Monterey pine in California, Oregon, Washington, and British Columbia. Cummins in the Supplement of the 1962 revision of Arthur (1962, p. 4a) leaves both *Peridermium cerebroides* and *P. harknessii* with *Cronartium coleosporioides*.

Pestalotia funerea **Desm. (XX)**
(Fungi Imperfecti, Melanconiales)

Needle and twig blight. PSW 97860 (E. P. Meinecke) March 1920, from the Presidio, San Francisco, California. UC 209261 (D. R. Miller) November 1962, Deer Flat County Park, Monterey County, California, on senescent needles of living trees.

Hedgcock (1932) reported this fungus on Monterey pine in Washington, D. C., probably the same occurrence as noted by Scott (1960) for U.S.A. Grove (1937) says that this species can be a true parasite and cause disease and that *Pestalotia funerea* forma *conigena* (Lév.) has been found on cones of Monterey pine planted in Cornwall. Noted by Birch (1937) for New Zealand, and by J. B. Martinez[17] for Spain.

***Pezicula livida* (Berk. & Br.) Rehm (XX)**
(Ascomycetes, Helotiales)

Canker. Collected (D. R. Miller) at Deer Flat County Park, Monterey, Monterey County, California, March 1962, from dead or damaged twigs of pines generally of poor vigor. Twigs show many small, round or elongated swellings that often open into a slit in the bark. Lee Bonar commented on the difficulties in identifying this fungus: He said (personal communication) that swellings are acervulus in nature, forming cushion-shaped to conical stroma with a layer of conidiospores and conidia on the outer surface, and that this fungus is probably the conidial stage of the Pezicula named.

Spaulding (1961) states that *Pezicula livida* occurs in North America and Europe on pine, fir, and spruce weakened by drought or frost.

***Phytophthora cinnamomi* Rands (XXX)**
(Phycomycetes, Peronosporales)

Root rot. Zentmyer and Munnecke (1952) report Monterey pine killed by this fungus in a southern California nursery where it acted as a typical root parasite.

This highly destructive pathogen is world wide in distribution Spaulding (1961). It has not yet been found, however, in native stands of Monterey pine. Listed by Scott (1960) for exotic plantations in Argentina, and by Newhook (1957, 1960) and Hepting & Newhook (1962) in New Zealand and of major importance in littleleaf of *Pinus echinata* in the United States (Campbell & Copeland 1954).

***Pithya cupressi* (Fr.) Rehm (X)**
(Ascomycetes, Pezizales)

Needle spot. UC 553899 from planted trees, Oakland Hills, Alameda County, California, January 1936. The preferred name of this fungus is *Pithya cupressina* (Fr.) Fckl.

***Pleurotus ostreatus* (Fr.) Kummer (X)**
(Basidiomycetes Agaricales)

Trunk rot. UC 532355 (Lee Bonar) March 1935, at Redwood Peak, Oakland, Alameda County, California on dead bark of Monterey pine stump. Described by Boyce (1961) and Spaulding (1961) on hardwoods where it is usually saprophytic but occasionally a wound parasite.

***Polyporus abietinus* Fr. (X)**
(Basidiomycetes Agaricales)

Trunk rot. PSW 85397 (E. P. Meinecke) April 1911, near Monterey, Monterey County, California. Recent collections (D. R. Miller) from native stands were made at Monterey, Cambria, and Swanton, November 1962. Other specimens are available from Sutro Forest and Fort Scott, San Francisco, California (PSW 85388, 85389, 85391, 85395, and 85411), all on dead trees or branches and on down logs. Abundant on trees killed by fire. All early collections in PSW Herbarium were named *Polystictus abietinus*. Found on conifers in all parts of the United States and Canada. Noted by Martinez[18] from Spain as *Polystictus abietinus* Sacc. & Cub.

***Polyporus anceps* Pk. (XX)**
(Basidiomycetes Agaricales)

White pocket rot. PSW 98041 (D. R. Miller) November 1962, Del Monte Properties, Monterey County, California; on basal trunk of dead standing tree. Not previously reported on Monterey pine.

***Polyporus caesius* Fr. (X)**
(Basidiomycetes Agaricales)

PSW 98037 (D. R. Miller) November 1962, Deer Flat County Park, Monterey, Monterey County, California, from debris on ground under mixed age stand of pine. Listed by Scott (1960) for New Zealand as a saprophyte on dead trees.

***Polyporus carbonarius* Murr. (X)**
(Basidiomycetes Agaricales)

Sapwood rot. Rhoads (1921) reported on a stump and a fallen log in a plantation at San Francisco, California. Listed by Scott (1960) for U.S.A.

***Polyporus dichrous* Fr. (X)**
(Basidiomycetes Agaricales)

Trunk rot. PSW 85447 (E. P. Meinecke and A. S. Rhoads) April 1912, near Pebble Beach, Monterey County, California, from down tree decaying on one side. Reported by Rhoads (1921). Close to the sporophore the rot produced by this fungus is of the brown carbonizing type with associated decay having a white appearance. Listed by Scott (1960) for U.S.A.

[17] See footnote 12.

[18] See footnote 12.

***Polyporus fragilis* Fr. (X)**

(Basidiomycetes Agaricales)

Brown carbonizing rot. UC 521276 (Wm. Lucke) March 1934, Oakland Hills, Alameda County, California, on rotting bark of a stump of planted tree. Conks small to medium-size, occur in large numbers often overlapping. The pore surface of fresh conks changes color readily when touched

***Polyporus gilvus* (Schw.) Fr. (X)**

(Basidiomycetes, Agaricales)

Trunk rot. UC 539465 (Lee Bonar) November 1935, on dead planted pine, San Rafael, Marin County, California. Decay mostly confined to sapwood. The annual sporophore is small and often occurs in large numbers. Occurs chiefly on deciduous trees.

***Polyporus mollis* Fr. (XX)**

(Basidiomycetes, Agaricales)

Brown carbonizing rot. UC 525451 (H. E. Parks) 1922 in Berkeley Hills, Alameda County, California, on planted trees. Resembles *Polyporus fragilis*.

***Polyporus perennis* Fr. (X)**

(Basidiomycetes, Agaricales)

Slash rot. PSW 85505 (A. S. Rhoads) April 1919, at Fort Scott, San Francisco, California on debris under planted trees.

***Polyporus schweinitzii* Fr. (XXX)**

(Basidiomycetes, Agaricales)

Root and butt rot. PSW 85550 and 85555 (E. P. Meinecke) April 1911, at Del Monte, Monterey County, California, on living and dead trees. Noted during surveys of November 1962, in Cambria, Monterey, and Swanton areas. Listed by Scott (1960) for U.S.A. as *Coltricia schweinitzii* (Fr.) G. H. Cunn.

In Monterey pine the fungus causes the typical, brown carbonizing, cubical butt rot and root decay. Incipient decay shows as light-yellow to red-brown discoloration as wood becomes soft. Cubes of decayed wood crumble into a fine powder. Annual conks appear during wet season; sporophores as described for other conifers by Boyce (1961).

***Polyporus smallei* (Murr.) Sacc. & Trott. (X)**

(Basidiomycetes, Agaricales)

Slash and sapwood rot. PSW 85563 (E. P. Meinecke) February 1926, from Del Monte Forest, Monterey County, California. On dead limb of pine 7 inches diameter lying on ground.

***Polyporus tomentosus* Fr. var. *circinatus* (Fr.) Sartory & Maire (XXX)**

(Basidiomycetes, Agaricales)

Root and butt rot. PSW 85449 and PSW 85453 (E. P. Meinecke) April 1911, at Del Monte, Monterey County, California and (E. P. Meinecke and F. Gravatt) March 1916, in same area. Both collections from a living tree near base of the trunk. This fungus causes white pocket rot of stumps, basal trunk, or roots. Decay looks much like that caused by *Fomes pini*.

***Polyporus versicolor* Fr. (X)**

(Basidiomycetes, Agaricales)

White trunk rot. PSW 85403 and 85605 (A. S. Rhoads) April 1919, Sutro Forest and Fort Scott, San Francisco, California, on planted trees killed by fire. Common and world-wide on deciduous trees and only occasional on conifers. Rhoads (1921) reported this collection as *Polystictus versicolor* (L.) Fries. Listed by Scott (1960) as *Coriolus versicolor* (L. ex Fr.) Quél. in New Zealand, and by Martinez[19] for Spain.

***Polyporus volvatus* Pk. (X)**

(Basidiomycetes, Agaricales)

White trunk rot. PSW 85627 (E. P. Meinecke) Monterey, California April 1915. Common on dead trees recently killed by fire or insects in Monterey, Swanton, and Cambria native stands. Scott (1960) lists *P. volvatus* for U.S.A.

***Poria cinerascens* Bres. (X)**

(Basidiomycetes, Agaricales)

Trunk rot. PSW 98040 (D. R. Miller) November 1962, Miller Ranch Road, Swanton, Santa Cruz County, California, on down log.

***Poria mollusca* (Fr.) Bres. (X)**

(Basidiomycetes, Agaricales)

Trunk or slash rot. PSW 85672 (A. S. Rhoads) January 1919, and PSW 85671 (E. P. Meinecke) May 1924, from Sutro Forest and Fort Scott, San Francisco, California, on fallen branches.

***Poria sericeomollis* (Rom.) Baxter (X)**

(Basidiomycetes, Agaricales)

Brown cubical rot. UC 605295 (Lee Bonar) November 1938, Oakland Hills, Alameda County, California, on decayed planted pine. Listed by Scott (1960) for New Zealand.

***Poria spissa* (Schw.) Cke. (X)**

(Basidiomycetes, Agaricales)

Brown rot. UC 477470 (N. L. Gardner) March 1916, near Ingleside, San Mateo County, California. Common on angiosperms in eastern North

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[19]See footnote 12.

America. This collection is probably the basis for the listing of Seymour (1929) and Scott (1960) for U.S.A.

Poria vulgaris **(Fr.) Cke. (X)**
(Basidiomycetes, Agaricales)

Trunk rot. UC 554992 (H. E. Parks) February 1924, on burned Monterey pine long along Tunnel Road, Berkeley, Alameda County, California.

Poria xantha **(Fr.) Cke. (X)**
(Basidiomycetes, Agaricales)

Trunk rot. PSW 98038 (D. R. Miller) November 1962, Del Monte Properties, Monterey County, California, on dead standing snag.

Rhizina undulata **Fr. (XX)**
(Ascomycetes, Pezizales)

Root rot. UC 292000 (Lee Bonar) July 1923, Berkeley Hills, Alameda County, California, under planted pines in wet soil. Annual fructifications developing on ground are irregular in shape and have an undulating brown upper surface. Spaulding (1961) says the pathogen is associated with root rot of conifers shortly after fire. Forms effused brown-black fungus bodies with root-like tendrils reaching into soil and starting from coniferous roots damaged by fire. Often cited in literature as *Rhizina inflata* (Schaeff.) Sacc. Weir (1915) cites evidence of parasitism on conifers.

Schizophyllum commune **Fr. (X)**
(Basidiomycetes, Agaricales)

Sapwood rot. PC 239462 (E. B. Copeland #3745) October 1903, Palo Alto, California, on planted tree. Rare on conifers and not previously listed for Monterey pine in North America. Listed by Scott (1960) for New Zealand.

Scoleconectria scolecospora **(Bref.) Seaver (XX)**
(Ascomycetes, Hypocreales)

Canker. PC 236523 (C. F. Baker #68) October 1901, Palo Alto, San Mateo County, California, on dead twigs. This fungus is generally called *Ophionectria scolecospora* Bref.

Overholts (1924) reports finding this fungus in Pennsylvania on *Pinus ponderosa, P. strobus* L., and *P. sylvestris* L.; found also on a dead sapling of *Abies balsamea* (L.) Mill. Often ocurs in association with white pine blister rust. Seaver (1909) describes the *Scoleconectria.*

Sparassis radicata **Weir (XX)**
(Basidiomycetes, Agaricales)

Root rot. UC 372395 (E. E. Morse) February 1927, Berkeley Hills, Alameda County, California, from roots of a live tree, which died the following year. Fruiting body similar to that described by Weir (1917) for his collections from the roots of living conifers in North Idaho.

Boyce (1961) describes the Sparassis root rot as causing a yellow brown carbonizing decay of old conifers in the West, confined to roots. The annual large, white fleshy fruiting bodies with thin flat branches arise from perennial stalks that are connected with underlying diseased roots.

Stereum hirsutum **Fr. (X)**
(Basidiomycetes, Agaricales)

White rot. Collected (A. S. Rhoads) on fallen branches of planted pine, San Francisco, California. PSW 85803 (W. W. Wagener) July 1931 (Stereum) probably same species, on lower dead limbs of planted trees in Hillsborough, San Mateo County, California. Rhoads (1921) reported that a conifer is an unusual host. Listed by Scott (1960) for U.S.A. and by Seymour (1929).

Stereum purpureum **(Fr.) Fr. (X)**
(Basidiomycetes, Agaricales)

White mottled rot. UC 294732 (H. E. Parks) February 1924, Tunnel Road, Berkeley, Alameda County, California, from burned pine trees.

According to H. E. Parks, trees were killed by fire in September 1923, and badly infected the following spring. Conks were covering large areas of the burned trees and were mostly resupinate, but some showed a bracket form. Fruiting surface brownish and folded, upper surface light gray or dirty white and densely tomentose, obscurely zonate.

Stereum sanguinolentum **Fr. (X)**
(Basidiomycetes, Agaricales)

Trunk rot. PSW 85761 (E. P. Meinecke) April 1911, Del Monte Properties, Monterey County, California, on bark of dead branch. UC 568923, February 1937, Sequoia Park, Oakland, Alameda County, California, on stump of dead tree.

Boyce (1961) states that *S. sanguinolentum* causes mottled bark disease and has been associated with the death of planted conifers in Idaho. Widespread as saprophyte on coniferous slash and causes heart rot of living trees of eastern white pine, balsam fir, and spruce. World wide in distribution according to Spaulding (1961), but not previously listed for Monterey pine in North America. Listed by Scott (1960) in Australia and New Zealand.

Tremella pinicola **Britz. (X)**
(Basidiomycetes, Tremellales)

UC 585779 (T. T. McCabe) March 1938, in Oakland Hills, Alameda County, California.

Tubercularia insignis **Cke. & Harkn. (X)**
(Fungi Imperfecti, Moniliales)

Twig blight. CAS 1720 (H. W. Harkness #2170) type specimen, February 1881, San Francisco, California, (Cooke & Harkness 1884c) on bark of twigs. Listed by Seymour (1929), and by Scott (1960) in California.

Venturia barbula **(Berk. & Br.) Cke. var. *foliicola* Ell. (XX)**
(Ascomycetes, Sphaeriales)

Needle scab. UC 209259 (D. R. Miller) November 1962, Deer Flat County Park, Monterey County, California, on faded, grayish needles, mostly on older needles.

Zygodesmus fuscus **Cda. (XX)**
(Fungi Imperfecti, Moniliales)

Collected (Harkness #2489) May 1884, at Mt. Diablo, California, on planted tree. Reported by Harkness (1885) and listed in Seymour (1929). Corda's type specimen of *Z. fuscus* was checked by Rogers (1948) and said to be *Tomentella biennis* (Fr.) A. M. Rogers. Specimen from Monterey pine not available for study.

Zygodesmus marginatus **Cke. & Harkn. (XX)**
(Fungi Imperfecti, Moniliales)

CAS 1899 (H. W. Harkness #2360) type specimen, April 1881, in San Francisco, California, on decaying bark of planted pine. Threads thicker than diameter of spores, or of equal thickness (Cooke and Harkness 1884a).

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APPENDIX

Fungi Associated with Pinus Radiata Outside of Western North America

This list of fungi is based on publications available to the author through 1963. A report in press (1964) entitled "The Pathology of Forest Trees and Shrubs in New Zealand," by J. W. Gilmour, New Zealand Forest Service, lists three fungi not listed here that are associated with Monterey pine in New Zealand: *Cylindrocladium scoparium* Morg., *Dematophora necatrix* Hartig, and *Phytophthora megasperma* Drechs. These fungi cause root disease.

Anthostomella piedmontana Ferr. & Sacc.
Pathogenicity not reported. Scott (1960). Australia.

Ceratostomella coerulea Münch (X)
(=*Ceratocystis pilifera* (Fr.) C. Moreau)
Blue stain. Cummins (1933), Scott (1960). Australia.

Ceratostomella pilifera (Fr.) Wint. (XX)
(=*Ceratocystis pilifera* (Fr.) C. Moreau). Blue stain. Cummins (1933), Laughton (1937), Scott (1960). Australia, South Africa.

Coriolus sanguineus (Fr.) G. H. Cunn. (X)
(=*Polyporus sanguineus* Fr.)
Brown rot. Cunningham (1948b), Birch (1937), Scott (1960). New Zealand.

Coriolus zonatus (Fr.) Quél. (X)
(=*Polyporus zonatus* Fr.). White rot. Scott (1960). New Zealand.

Corticium punculatum Cke. (XX)
On bark and fallen branches. Cunningham (1953), Scott (1960). New Zealand.

Corticium utriculicum G. H. Cunn. (XX)
On bark and decaying branches. Cunningham (1953), Scott (1960). New Zealand.

Daedalea trabea (Pers.) Fr. (X)
(=*Lenzites trabea* (Fr.) Fr.) Brown rot. Cunningham (1948c), Scott (1960). New Zealand.

Dacryomyces palmatus Bres. (X)
Trunk and branch decay. Martinez (1942), Scott (1960). Spain.

Dasyscypha calyciformis ((Fr.) Rehm (XX)
Canker. De Gryse (1955), Spaulding (1961). New Zealand.

Diplodia acicola Sacc. (XX)
Needle disease. Martinez (1942), Scott (1960). Spain.

Diplodia natalensis P. Evans (XX)
(=*Diplodia theobromae* (Pat.) Nowell). Needle blight. Young (1936). Australia.

Dothistroma pini Hulb. (XX)
Needle blight and die-back. Gibson (1963) Kenya, So. Rhodesia, Tanganyika, Uganda. Previously reported as *Actinothyrium marginatum* Kunze by Gibson (1962).

Fomes applanatus (S. F. Gray) Gill. (X)
White rot. Scott (1960). New Zealand.

Fomes mastoporus (Lév.) Cke. (X)
White rot. Scott (1960). New Zealand.

Fomes scruposus (Fr.) G. H. Cunn. (X)
White rot. Scott (1960). New Zealand.

Fusarium lateritium Nées var. *pini* Hepting (XX)
Pitch canker. Hepting (1961). Eastern U.S.A.

Fusarium oxysporum Schlecht. (XXX)
Damping-off. Frezzi (1947), Spaulding (1961). Argentina. Martinez (See footnote 12). Spain.

Hydnum coralloides Fr. (X)
Rot in dead trees. Scott (1960). New Zealand.

Hypoderma brachysporum Rostr. (XX)
Needle cast. Green (1957). Great Britain. Martinez (See footnote 12). Spain.

Hypoderma desmazieri Duby (XX)
Needle cast. Peace (1962). Great Britain. Darker (1932) includes *H. brachysporum* and *H. strobicola* Tub. under this single species name.

Hymenochaete mougeotii (Fr.) Cke. (X)
Trunk rot, fire-killed trees. Scott (1960). New Zealand.

Hypodermium sulcigenum Fr.
(=*Hypodermella sulcigena* (Lk. ex Fr.) Tub.) Pathognicity not reported. Scott (1960). Australia.

Inonotus tabacinus (Mont.) Karst.
(=*Polyporus tabacinus* Mont.). Pathogenicity not reported. Scott (1960). New Zealand.

Irpex brevis Berk. (X)
White rot. Cunningham (1949), Scott (1960). New Zealand.

Irpex fuscoviolaceus Fr. (X)
Yellow rot with white pockets. Martinez (1942), Scott (1960). Spain.

Lecanosticta acicola Wolf & Barbour (XX)
Needle blight. Martinez (See footnote 12). Spain.

Lenzites beckleri Berk. (X)
Stump rot. Scott (1960). New Zealand.

Lenzites palisoti Fr. (X)
(=*Daedalea elegans* Fr.) Stump rot. Doidge (1950), Scott (1960). South Africa.

Leptoporus trabeus (Rostk. (XX)
(=*Lenzites trabea* (Fr.) Fr.). Trunk rot. Martinez (See footnote 12). Spain.

Lopharia cinerascens (Schw.) G. H. Cunn.
Pathogenicity not reported. Scott (1960). New Zealand.

Lopharia vinosa (Berk.) G. H. Cunn.
Pathogenicity not reported. Scott (1960). New Zealand.

Macrophomina phaseoli (Maubl.) Ashby (X)
Root rot. Spaulding (1956). South Africa.

Merulius himantioides Bourd. & Galz. (X)
Wood decay. Martinez (See footnote 12). Spain.

Merulius lacrymans (Wulf.) Fr. (X)
Lumber decay. Scott (1960). New Zealand.

Nectria pinea Dingley (X)
Trunk rot. Dingley (1951), Scott (1960). New Zealand.

Odontia bicolor (Fr.) Bres. (X)
Stringy white rot. Scott (1960). New Zealand.

Pellicularia filamentosa (Pat.) Rogers (XXX)
Damping off. Thulin et al. (1958). New Zealand.

Pellicularia vaga (Berk. & Curt.) Rogers (X)
Trunk rot. Cunningham (1953), Scott 1960). New Zealand.

Peniophora cremea (Bres.) Sacc. & Syd.
Pathogenicity not reported. Cunningham (1955), Scott (1960). New Zealand.

Peniophora sacrata G. H. Cunn. (XX)
Root and stem canker. Gilmour (1959). New Zealand.

Pestalotia hartigii Tub. (X)
Stem canker. Spaulding (1956). South Africa.

Pestalotia macrochaeta (Speg.) Guba
Pathogenicity not reported. Doidge (1950), Scott (1960). South Africa.

Phacidiopycnis pseudotsugae (M. Wils.) Hahn (XX)
Canker. Spaulding (1961). New Zealand.

Phoma acicola (Lév.) Sacc. (XX)
Needle blight. Martinez (See footnote 12), Scott (1960). Australia.

Phoma pinastrella Sacc.
Pathogenicity not reported. Doidge (1950), Scott (1960). South Africa.

Phoma strobiligena Desm. var. *microspora* Sacc.
Pathogenicity not reported. Scott (1960). Australia.

Phomopsis pseudotsugae Wilson (XX)
Canker. Great Britain Forestry Commission (1961). Great Britain.

Phomopsis strobi Syd. (XX)
Twig canker. Birch (1935), Scott (1960), Stoate and Bednall (1953). Australia, New Zealand.

Phytophthora cactorum (Leb. & Cohn) Schroet. (XXX)
Seedling blight. Newhook (1959). New Zealand.

Phytophthora citricola Saw.
Pathogenicity not shown. Newhook (1959). New Zealand.

Phytophthora cryptogea Pethyb. & Laff.
Pathogenicity not shown. Newhook (1959). New Zealand.

Phytophthora citrophthora (R. E. & E. H. Sm.) Leonian (X)
Root rot. Spaulding (1956). Argentina.

Phytophthora parasitica Dast. (XXX)
Canker and blight. Scott (1960). Australia.

Phytophthora syringae Kleb. (XXX)
Dieback. Newhook (1959). New Zealand.

Polyporus albidus Fr. (X)
Brown cubical rot. Scott (1960). New Zealand.

Polyporus amorphus Fr. (X)
Trunk rot. Cunningham (1948a), Scott (1960). New Zealand.

Polyporus lacteus Fr. (X)
(=*Polyporus tulipiferae* (Schw.) Overh.). Trunk rot. Cunningham (1948a), Scott (1960). New Zealand.

Polyporus rosulatus G. H .Cunn. (X)
Brown cubical rot. Cunningham (1948a), Scott (1960). New Zealand.

Polyporus setiger Cke. (X)
Trunk rot. Scott (1960). New Zealand.

Polyporus tephroleucus Fr. (X)
Trunk rot. Cunningham (1948a), Scott (1960). New Zealand.

Polyporus thelephoroides Fr. (X)
Trunk rot. Cunningham (1948a), Scott (1960). New Zealand.

Polyporus vernicifluus Berk. (X)
Trunk rot. Scott (1960). New Zealand.

Poria ferruginosa (Fr.) Karst. (XX)
White spongy rot. Spaulding (1961). Australia.

Poria lenis (Karst.) Sacc.
Pathogenicity not reported. Scott (1960). New Zealand.

Poria mucida (Fr.) Cke.
Pathogenicity not reported. Scott (1960). New Zealand.

Poria vaillantii (Fr.) Cke. (X)
Tumber decay. Birch (1937). New Zealand.

Poria versipora (Pers.) Rom. (X)
White rot. Scott (1960). New Zealand.

Pullularia pullulans (deBy.) Berk. (XX)
Needle blight. Cummins (1933), Scott (1960). Australia, New Zealand. Called *Hormonema dematoides* Lob. & Melin by Cummins (1933).

Pythium ultimum Trow (XX)
Root rot. Doidge (1950), Thulin et al. (1958), Scott (1960). South Africa, New Zealand.

Rhizoctonia lamellifera Small (XXX)
Root rot. Laughton (1937), Spaulding (1961). South Africa.

Rhizoctonia silvestris Melin (XXX)
Root disease. Levisohn (1954), Scott (1960). Great Britain.

Rhizoctonia solani Kuehn (XXX)
Damping-off. Thulin et al. (1958), Scott (1960). New Zealand.

Scirrhia acicola (Dearn.) Siggers (XX)
Leaf spot. Spaulding (1961). Spain. Siggers (1939) shows that this fungus is the perfect stage of *Septoria acicola* Sacc.

Scleroderris abietina (Lager.) Gremmen (XX)
Pine dieback. Spaulding (1961). Spain.

Septoria acicola Sacc. (XX)
Needle cast. Martinez (1942), Scott (1960). Spain.

Solenia candida Fr. (X)
Wood rot. Scott (1960). New Zealand.

Stereum schomburgkii Berk. (X)
Trunk rot. Scott (1960). New Zealand.

Thelephora fimbriata Schw. (X)
Smothering fungus. Doidge (1950), Scott (1960). Australia, Chile, New Zealand, S. Africa.

Thelephora terrestris Fr. (X)
Smothering fungus. Birch (1937). New Zealand.

Trametes protea (Berk.) G. H. Cunn. (X)
Brown rot. Cunningham (1948c), Scott (1960). New Zealand.

Trametes trogii Berk. (XX)
Trunk rot. Spaulding (1956). Argentina.

Trichoscyphella calycina (Fr.) Nannf. (X)
Canker. Scott (1960). New Zealand.

Vermicularia tiliae Lk.
Listed by Seymour (1929) for U.S.A. (California) but not confirmed for *P. radiata* by any records available.

Xylogramma hysterinum (Fr.) Rehm
Pathogenicity not reported. Scott (1960). Australia.

Xanthochrous abietis Bourd. & Galz. (XX)
(=*Trametes abietis* Karst.) Butt rot. Martinez (See footnote 12). Spain.

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