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LOGGING PRODUCTION RATES
in young-growth, mixed-conifer stands in north central California

Philip M. McDonald

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To quantify production rates for small trees, this study examined the components of log-making and tractor yarding at the Challenge Experimental Forest, Yuba County, California. Rates were calculated over a range of 12 to 40 inches d.b.h. The rate for incense-cedar was lowest; for ponderosa pine it was intermediate; and for Douglas-fir, white fir, and sugar pine combined, it was highest. Log size strongly influenced production. For log-making, production for 38-inch d.b.h. trees was two and a half times that for 14-inch d.b.h. trees; for yarding, production for a turn of logs averaging 22 inches d.i.b. was two and a half times better than that for one averaging 12 inches d.i.b.

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Retrieval Terms: logging production; logging costs; young-growth stands; California (north central); *Pinus ponderosa; Pseudotsuga menziesii; Abies concolor; Pinus lambertiana; Libocedrus decurrens.*

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The Author

PHILIP M. McDONALD is doing research on silviculture of Sierra Nevada forest types, with headquarters at Redding, Calif. A native of Seattle, Washington, he holds bachelor's (Washington State University, 1960) and master's (Duke University, 1961) degrees in forestry.

Intense competition and narrow profit margins are forcing land managers, foresters, and logging supervisors to become increasingly conscious of logging costs. Tax assessors are similarly concerned with costs as a basis for setting tax rates. At the same time, good silviculture and environmental protection often require that marginal or submarginal trees and logs be removed from the forest. But data on logging cost and production are singularly scant--particularly for young-growth stands. In the Western United States, data on such stands on high-quality sites are especially important. These sites would be the first to be intensively managed because on them the most fiber can be grown in the shortest time. In California, logging production data are needed because many young-growth stands are now of merchantable size. Indeed, as Oswald (1970) points out, "in some areas of the State, harvesting activities on private land are shifting into young-growth stands."

To help fill the need for such information, the Pacific Southwest Forest and Range Experiment Station began a long-term study in 1962 of logging production rates on its Challenge Experimental Forest, Yuba County, California.[1] The most abundant species there is ponderosa pine *(Pinus ponderosa* Laws.*)*. Dominant ponderosa pines average 140 feet tall at 100 years (Arvanitis, *et al.* 1964). Next most abundant is Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco*)*. Found in lesser amounts are white fir *(Abies concolor* [Gord. & Glend.] Lendl.*)*, sugar pine *(Pinus lambertiana* Dougl.*)*, and incense-cedar *(Libocedrus decurrens* Torr.*)*.

This paper reports results from a study of young-growth stands on high-quality sites. Objectives of the study were to quantify various components of log-making and yarding production and to examine the relationships among these components and the effect of species. The results are applicable to about 1.5 million acres of highly productive timberland on the lower west slope of California's north central Sierra Nevada.

BACKGROUND

Stand age was about 95 years at the time of study. Commonly, about 30 overstory trees per acre are greater than 20 inches in breast height diameter (d.b.h.). Beneath these trees are the more shade tolerant Douglas-fir, white fir, incense-cedar and hardwoods. Here 12- to 20-inch d.b.h. trees number about 45 per acre; those 3.5 to 12 inches d.b.h. about 200 per acre. The basal area of all trees 3.5 inches in diameter and larger is about 240 square feet per acre. These basal areas and numbers of stems are typical of young-growth stands on high-quality sites and are part of the logging production picture.

Elsewhere in dense young-growth stands, Csizmazia and McIntosh (1964) found that limbing was the factor affecting log-making production most. For yarding production, choker-setting was most critical. In several studies (Csizmazia and McIntosh 1964; Hasel 1946; King 1963; Worthington 1966), either log-making or yarding production rates or both were inversely related to log size--and significantly so.

Previous work in young-growth, mixed-conifer stands at Challenge has shown that log-making and yarding production rates do not differ appreciably among the seed-tree, single-tree-selection, clearcut, and group-selection cutting methods (McDonald, *et al.* 1969). Production rates were independent of cutting method in general.

In this study, six compartments averaging 38 acres each were partially cut from April to August 1962. Leave trees larger than 20 inches d.b.h. numbered from 2 to 20 and averaged about 7 per acre. Cutting removed 28 to 78 percent of the merchantable volume, meaning that trees down to 12 inches d.b.h. were removed. The minimum log size measured 10 feet long and 10 inches in diameter inside bark (d.i.b.) at the small end. Long logs (32 feet) were desired and cut whenever possible.

In addition to being heavily forested, the study compartments were generally similar, having rolling topography, maximum slopes of 25 percent, and little surface rock. Amount of cull and brush (other than small trees) was minimal. Altogether, this was a "good" logging chance as young-growth chances go *(fig. 1)*.

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[1] U.S. Forest Service research at the Challenge Experimental Forest is conducted in cooperation with the Soper-Wheeler Company, Strawberry Valley, Calif.

Figure 1—The 95-year-old stand b
logging. The large number of trees
their many dead branches is typic
young-growth stands on high-qu
sites in north central California.

LOG-MAKING

The fallers were experienced at their trade and paid at a gyppo rate. They worked as two-man "sets" —set members staying well within earshot of each other, but each man limbed and bucked each tree that he had felled.

During the production study, fallers never knew which of them were to be timed or what day timing would take place. These selections were random. A forestry-trained observer timed functions by stop watch to the nearest 0.1 minute. Different components were (1) preparation time, (2) tree-to-tree travel, (3) felling, (4) limbing, (5) bucking, and (6) lopping branches from tree tops. Timing began when the fallers arrived at the landing each morning and ended when they returned to it in the evening. Altogether, timing was performed on 191 trees of 5 different species and took slightly over 8 full days. Production averaged 22,740 board feet Scribner Scale per man-day. Other recorded data included individual log diameters, lengths, and pertinent remarks.

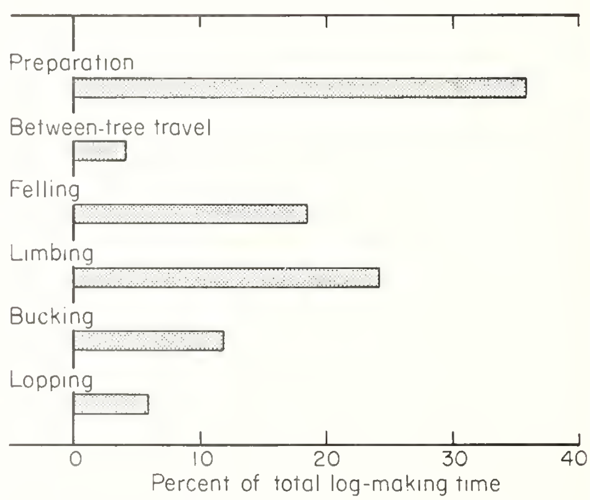

Figure 2—Preparation time is an important component of log-making production.

Preparation

Because of rigorous physical and safety demands, preparation time always is high *(fig. 2)*. Human needs (rest, eat, drink) and mechanical needs (fuel, adjust, and sharpen saw) were the largest categories as the following breakdown shows:

Item:	*Portion of preparation time (percent)*
File and adjust saw	12.1
Fuel saw	11.6
Scout	5.3
Rest	31.0
Drink and lunch	26.6
Fell snags	6.0
Walk to and from landing	7.4
	100.0

Altogether, preparation time amounted to 8 minutes per thousand board feet.

Tree-to-Tree Travel

This component was minimal because the trees to be cut grew relatively close together. Over-all, tree-to-tree travel had a negligible effect on production and amounted to only 0.9 minutes per thousand board feet.

Felling

In felling, size of tree is important. The larger the tree, the greater its height, and the more time and skill necessary to fell it with minimum damage to the residual stand. To avoid damage, some trees were wedged. Occasionally, a small tree or some

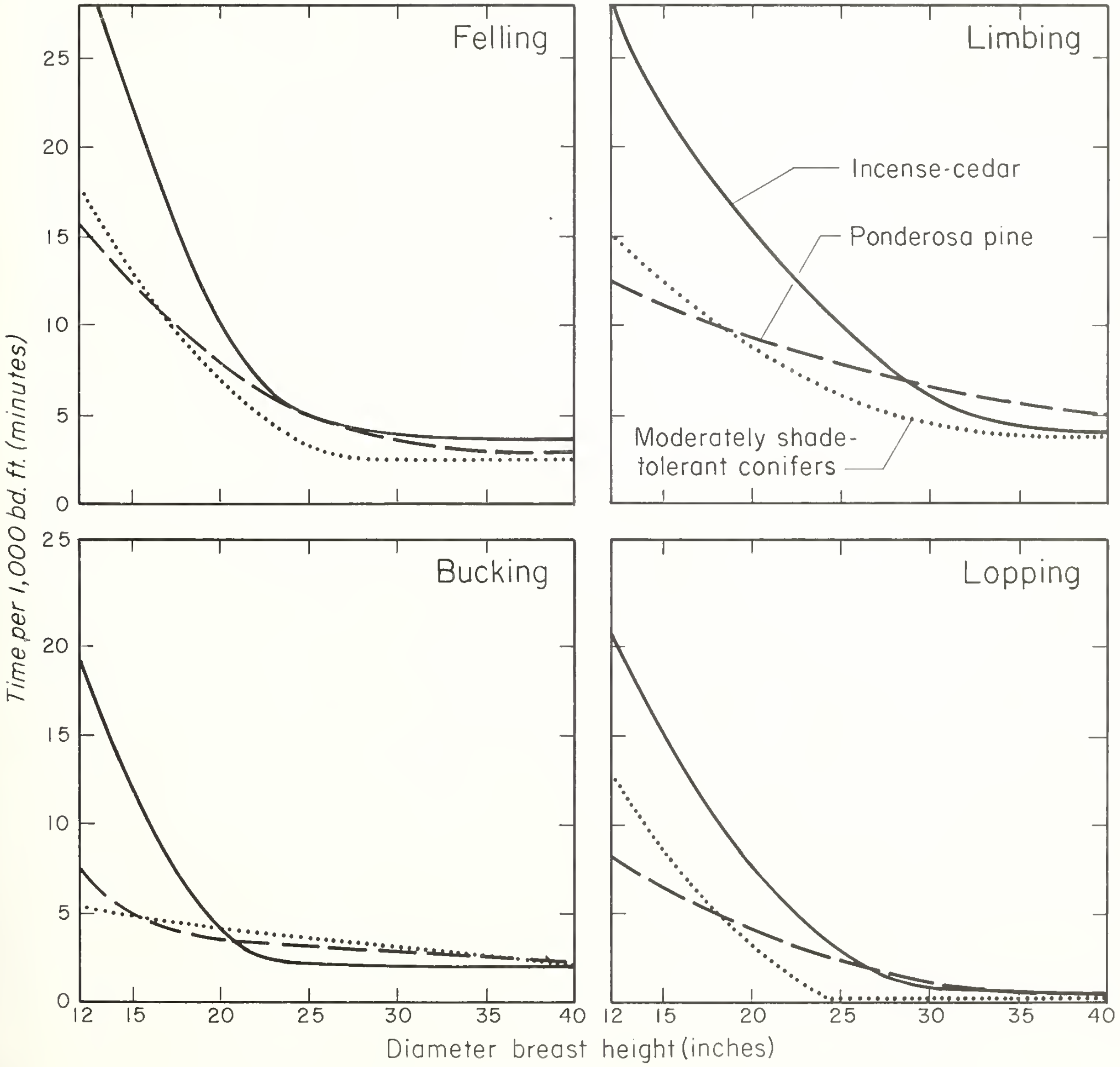

Figure 3—Log-making production rates relative to tree diameters. Species differences are readily seen.

LIMBING

BUCKING

YARDING

SKIDDING

felling, limbing often is the next step in ng a young-growth stand. "Walking the log" mizes the effect of the brushy understory.

ing is usually done at the same time as limbing, he two activities were performed separately in tudy to facilitate timing.

ing begins and ends at the landing. This one is al in size and shape.

it 39 percent of the skidding in this logging ition was adverse but on gentle grades such as The average turn consisted of 4.6 logs.

oking a five-log turn may be slow since the ing apparatus has a greater chance to lodge st or beneath the logs.

HOOKING

brush near the base of a study tree had to be cut before felling could commence. In such cases, brushing time was included in the felling. When brushing or wedging was necessary, felling time often was excessive. Therefore time spent on these activities was considered representative of felling in young-growth stands and was included in felling time in *figure 2*, but ignored in subsequent analyses.

Species differences in felling production rates among trees 12-40 inches d.b.h. were caused primarily by inherent differences in growth form. On high-quality sites Douglas-fir and white fir grow straight and tall with relatively little bole taper. They also have rather thin bark. Young-growth sugar pine has more taper but on such sites grows taller and produces greater volume. This apparently compensated for the taper. Ponderosa pine is generally intermediate in relative taper and height growth. Variation in thickness and fiber content of bark possibly affect production as well. Within the 12- to 24-inch d.b.h. range, the production rate for incense-cedar, which has a noticeably tapering bole, was poorest of all species. In effect, fallers had to saw through greater diameter, including thick, stringy bark, to produce the scaled volume for this species. (The scale is based on small-end diameter.)

Felling production curves for each tree species were drawn by a least-squares curve-fitting procedure. These curves then were compared graphically. Because curves for Douglas-fir, white fir, and sugar pine (the moderately shade-tolerant species) showed only minor differences, they were combined *(fig. 3)*. Throughout the paper some curves have been extrapolated to a common ending point for comparability.

Limbing

In young-growth stands on high sites, 95 years is not enough time to obtain natural pruning, even when stocking is high. Thus, limbing is second to preparation as the most time-consuming component of log-making. Ranking of species by limbing production rates *(fig. 3)* parallels that of felling--incense-cedar was poorest, ponderosa pine intermediate, and the moderately tolerant conifers were best.

The time required to limb a tree is determined mainly by the size and quantity of its limbs. This in turn relates to the tolerance of the species. Highly tolerant incense-cedar generally does not grow into the dominant crown class. Characteristically it has relatively long, spreading, pliable limbs. Few of its branches break when the tree falls. Consequently most branches must be limbed. This trait, plus its tapering bole, greatly affect incense-cedar's limbing production rate.

Ponderosa pine is intolerant. It grows mostly in dominant and codominant crown classes. Few trees survive in the understory. Those that do survive have small crowns and few branches. For these, limbing production rates are high. Larger ponderosa pines, however, carry numerous dead branches and branch stubs along the lower two-thirds of the bole and their living crowns often consist of heavy, pliable branches. Most branches and many of the stubs need to be limbed, and these reduce the limbing production rate.

Branches on the moderately tolerant white fir, Douglas-fir, and sugar pine tend to be relatively small and of limited pliability; they are readily broken when the tree strikes the ground. This characteristic probably contributed most to the similarity of these species' production rate curves, enabling them to be combined. Together, they had the best limbing production rate.

Bucking

In standard practice, bucking and limbing are an integrated operation. The logger fastens his tape to the end of the butt log, limbs up the log to the desired length, and bucks the tree. He proceeds along the tree in this manner, measuring, limbing, and bucking until the minimum top diameter is reached. For this study, however, limbing and bucking were performed and timed separately. No trees with forks, crooks, or cat faces qualified as sample trees.

Bucking production rates were poorest for incense-cedar below 20 inches d.b.h.; ponderosa pine smaller than 16 inches was the next poorest *(fig. 3)*. With these exceptions, species exerted little influence here. Obviously, measuring and walking from log to log is independent of species.

Lopping

The cutting of limbs from tops of felled trees is seldom practiced when harvesting timber. But in dense young-growth stands, the large number of tops, usually with numerous upright branches, commands attention. They are unsightly, a fire hazard, and susceptible to insects, particularly the engraver beetles *(Ips spp.)*. Lopping allows sunlight to reach the boles and render them uninhabitable to undesirable insects. Lopping also places the branches on the ground, speeding their decomposition and returning nutrients to the soil.

Lopping was the last operation performed on each tree. It was done with the chain saw as quickly as conditions would permit.

The lopping production rate was keyed to tree form, taper, and branch habit. It was best for the moderately tolerant conifers *(fig. 3)*. In these species, many limbs broke from the bole and those that remained were easier to reach with the saw. In

Table 1–*Log-making component production rates, by 4-inch diameter classes, all species combined, Challenge Experimental Forest, California*

D.b.h. class (inches)	Volume per tree[1]	Elapsed time for component:				Total time[2]
		Felling	Limbing	Bucking	Lopping	
	Bd. ft.	*Min./M bd. ft.*				
12–16	144	15.4	11.4	4.6	7.8	48.1
17–20	277	7.0	10.0	4.5	3.7	34.1
21–24	506	5.4	8.7	3.7	2.6	29.3
25–28	822	4.4	6.0	3.1	1.7	24.1
29–32	1,334	3.3	6.1	2.5	1.0	21.8
33–36	1,704	3.3	5.3	2.6	.8	20.9
37–40	2,318	3.2	4.0	2.1	.4	18.6

[1]Gross volume, Scribner scale, not adjusted for overrun.
[2]0.9 minutes/M bd. ft. and 8 minutes/M bd. ft. for tree-to-tree travel and preparation respectively, added to each d.b.h. class.

fact, the tops were so shattered on 15 percent of these trees that they required no lopping. Ponderosa pine ranked intermediate in production and incense-cedar poorest.

The production curves relating d.b.h. to time and volume *(fig. 3)* show a common relationship–the smaller the tree, the poorer the production rate. And no matter what the component–felling, limbing, bucking, or lopping–the same relationship holds. This relationship of small trees and poor production rates has been known for years but was not quantified in previous studies. Although statistical comparisons between curves are not possible, differences among species for any diameter between 12 and 40 inches are seen easily for each component.

All Components

A summary of production rates for all components vividly illustrates the effect of tree size *(table 1)*. The comparison of a 14-inch d.b.h. tree to a 38-inch tree shows the larger tree to have nearly five times the felling production rate, three times the limbing rate, twice the bucking rate, and 20 times the lopping rate of the smaller. For all log-making components combined, the production rate of a 38-inch d.b.h. tree bettered the 14-inch tree by two and a half times.

YARDING

"As goes the yarding, so go the profits (or losses)" is an axiom, well known to all who harvest timber. Although log-making is important, relatively little capital goes into that job. But in yarding, expensive equipment and manpower shadow every move in the operation.

Many elements and conditions influence yarding production. Natural elements include weather, soil, ground roughness, slope, and stand density. Spring weather seldom is severe although rainstorms occasionally shut down logging for 2 to 4 days. Deep and internally well drained soil quickly allows logging to resume, however. Ground and stand conditions were described earlier.

Yarding production is also affected by crew organization, the need for minimizing damage to trees and reproduction, and the location of roads and landings.

Two experienced crews contributed to this study. Each consisted of the "cat skinner," a choker-setter, and a landing man who unhooked the logs. The tractors were dozer equipped, and of about 113 drawbar horsepower–a rating probably in excess of that needed in young-growth, mixed-conifer stands. Nevertheless, many forest managers in California harvest both old and young-growth timber, and must gear their size of equipment to the larger-sized timber.

Even though tractor horsepower is more than adequate relative to log size, a limited number of logs are taken out each turn. Four to five logs per turn strikes the best balance–more than that are awkward to hook and unhook; fewer are a waste of tractor capacity. Thus four or five logs per turn was a production goal, although two or three or even six logs per turn were sometimes skidded:

	No. of turns
No. of logs per turn:	
2	2
3	3
4	41
5	59
6	7

Damage to residual trees and advance reproduction was minimized by careful ground skidding, an established policy for the whole logging operation. No logging arches were used.

Terrain and the proximity of roads often interact to govern the number and location of landings. These influence the amount of downhill and uphill (adverse) skidding, which in turn, affects the skidding production rate. Like all logging operations, this one aimed at minimizing adverse skidding, but some was inevitable. Thus, 37 percent of the skids were downhill, 24 percent level, and 39 percent adverse. The adverse skidding was on relatively gentle slopes, however.

Felling and skidding rarely take place simultaneously. Usually the trees are converted into logs well in advance of skidding. Thus in typical young-growth stands, the first-arriving skidding crews often are greeted with a profusion of logs. Most of the main skid trails have been located and the fallers have aligned as many trees to them as possible. Landings are also established before skidding. They are temporary, small, level, and strategically sandwiched into natural flats and openings near the main skid roads.

A trained observer timed each skidding component, paced each skid, measured each log, and recorded all data. Timing was by stopwatch to the nearest 0.1 minute for the following components: (1) preparation time, (2) outbound travel (landing to woods), (3) choker-setting, (4) skidding, and (5) unhooking. Data were collected on a full-day basis but the skidding crews never knew when they would be timed. A complete turn began when the tractor left the landing and ended when it returned, had its last log unhooked, and started back for the next turn. Altogether 112 turns were timed over 8 full days. Production averaged about 20,500 bd. ft. per day Scribner Scale.

Preparation

Preparation time amounted to about 19 percent of total skidding time *(fig. 4)* and occurred on nearly 40 percent of the turns. Human needs (lunch, drink), mechanical needs (tractor and winch line maintenance and repair), and building skid trails contributed most to preparation time as the following breakdown shows:

	Portion of preparation time (percent)
Item:	
Service and fuel tractor	24.8
Repair chokers and winch line	5.8
Overcome impediment to tractor (landing blocked, high centered on stump, etc.)	6.1
Build skid trail	24.8
Lunch and drink	38.5
	100.0

Skid trail building time accrues as the tractor operator extends some of the skid trails while outbound from the landing. Altogether, the skidding preparation rate was slightly over 3 minutes per thousand board feet.

Outbound Travel

The tractor operator usually returns to the woods as fast as conditions permit. Therefore this component of skidding production relates directly to distance. Over-all, the outbound travel production time was just over 16 percent of total skidding time and amounted to 2.6 minutes per thousand board feet.

Choker-Setting

Choker-setting is the most time-consuming of all yarding components *(fig. 4)*, partly owing to characteristics of the operation and to conditions inherent in logging young-growth timber. For example, only one set of chokers is used.

The whole choker-setting job consists of moving from log to log, digging furrows (choker-holes) under logs when they are required for setting the chokers, guiding the tractor to the logs, setting a choker around each log, and hooking the chokers to

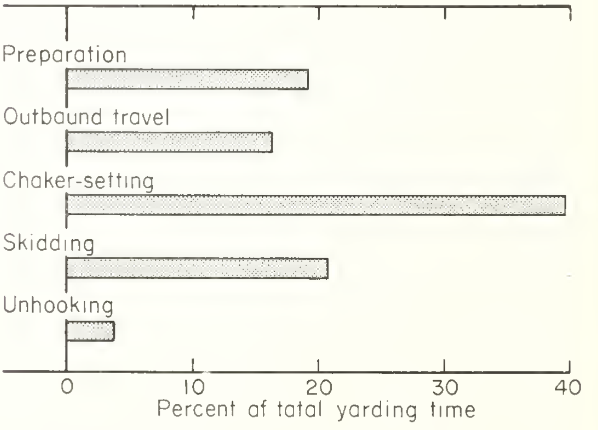

Figure 4—Choker-setting is the most time-consuming component of yarding production.

the winch line. Digging furrows generally takes more time for the larger logs, but this part of the job is usually completed while the tractor is traveling. Consequently, tractor time allocated to choker-setting is about the same for each log regardless of its size, as indicated in the following tabulation (few logs per turn indicate large logs):

No. of logs per turn:	*Average choker-set time per turn (min.)*	*Average time per log (min.)*
3	5.6	1.9
4	8.4	2.1
5	9.7	1.9
6	9.2	1.5

Sometimes logs become jammed against stumps, down trees, or slash, and need nudging with the dozer blade to help set the chokers. In general, the occurrence of these "hangers" is independent of log size.

The experienced choker-setter recognizes that choker-setting time does not depend on log size, and therefore strives to balance each turn to achieve the greatest payload possible with the sizes and lengths of logs on the ground. Thus good choker-setting is not just grabbing the closest bunch of logs. It is getting to and hooking almost the same number of logs each turn and having an equal number of large and small logs and long and short logs in each turn. Since landings are small and have little log storage capacity, the constant and dependable mixture of log lengths and sizes facilitates truck loading and hauling. The choker-setting production rate for a turn of a few logs is better than for a turn of five or six logs *(fig. 5)*. The few-log turn contains more volume and requires less choker-setting time.

Skidding

Skidding distances ranged from 200 feet to 1,250 feet and averaged 745 feet per turn. The volume per turn averaged 1,464 bd. ft. and generally was independent of length of skid *(table 2)*. Furthermore, the number of logs per turn also was independent of the distance skidded:

No. of logs per turn:	*Average distance skidded (feet)*
2	820
3	647
4	785
5	735
6	619

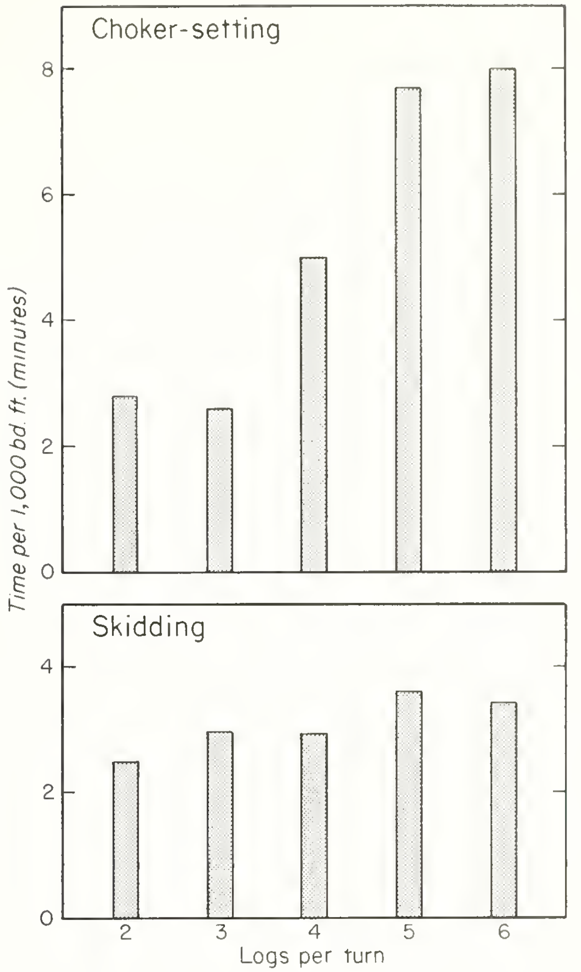

Figure 5—Production rates for choker-setting and skidding in young-growth timber are directly influenced by the number of logs per turn; fewer logs mean a higher volume and a better production rate.

The volume per turn increased greatly, however, as the number of logs per turn decreased. Thus the skidding production rate depended directly on the number of logs per turn and the distance skidded *(figs. 5,6)*.

The skidding production rate curve *(fig. 6)* was based upon all 112 turns. Some turns shuttled along a constant slope and some sprinted and slowed over terrain having several distinctly different grades. Others surmounted adverse grades and some even traversed downhill and adverse pitches. Since many tractor logging operations cover similar terrain, these data have quantitative value.

Unhooking

In skidding, the logs continuously squeeze together and drift apart. Sometimes smaller logs are forced beneath the larger. The choker on each log

Table 2–*Effect of distance on skidded volume, Challenge Experimental Forest, California*

Skidding distance (feet)	Turns	Average volume per turn
	No.	*Board feet*
< 500	10	1,043
501- 600	12	1,619
601- 700	25	1,685
701- 800	22	1,358
801- 900	29	1,584
901-1000	7	1,096
1001-1100	4	1,275
> 1100	3	1,130

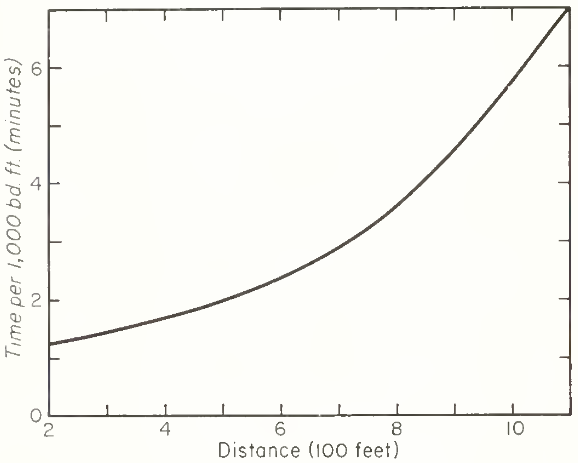

Figure 6—The skidding production rate is related to the distance of logs from the landing.

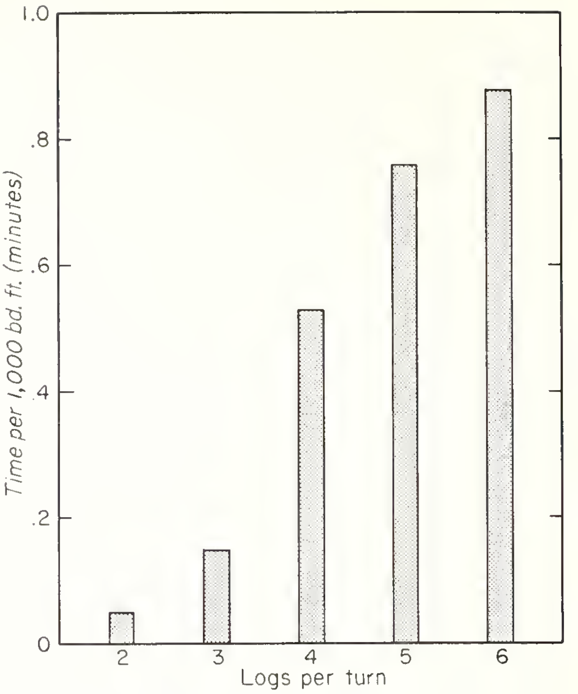

Figure 7—The unhooking production rate is related to the number of logs per turn.

usually is hooked on its upper surface. When the logs reach the landing, however, it is a matter of chance whether the hook is up and easy to unhook, or down and difficult to unhook. The more logs per turn, the greater the chance that one of them will be difficult to unhook. This fact, and the relatively fixed amount of time needed to unhook each log, make the number of logs per turn of primary importance to the unhooking production rate *(fig. 7)*.

Table 3–*Yarding component production rates, by 2-inch log classes, Challenge Experimental Forest, California*

Small-end d.i.b. class (inches)	Number of turns	Volume per turn[1]	Elapsed time for component: Choker-setting	Skidding	Unhooking	Total[2]
		Bd. ft.	*Min./M bd. ft.*			
10-11.9	31	630	15.8	5.5	1.5	28.4
12-13.9	21	1,056	7.7	3.8	.8	17.9
14-15.9	19	1,375	6.7	3.5	.7	16.5
16-17.9	22	1,996	4.6	3.0	.5	13.7
18-19.9	10	2,320	3.9	2.5	.3	12.3
20-21.9	6	2,597	4.5	2.0	.2	12.3
22+	3	3,050	2.5	2.6	.1	10.8

[1]Gross volume, Scribner scale, not adjusted for overrun.

[2]3 minutes/M bd. ft. and 2.6 minutes/M bd. ft. for preparation and outbound respectively, added to each small-end d.i.b. class.

All Components

In general, the larger the number of logs per turn, the greater the bark, the larger the amount of taper, and the less the volume, then the greater the reduction in efficiency.

Thus no matter what component—choker-setting, skidding, or unhooking—the volume in each turn had a pronounced effect on production rates *(table 3).* Comparison of a turn in which logs averaged under 12 inches d.i.b. to one in which logs averaged 22 inches d.i.b. showed that the turn with the larger logs had six times the choker-setting production rate, twice the skidding rate, and 15 times the unhooking rate of the turn of smaller logs. When all yarding rates were combined, the turn with the larger logs bettered the other by two and a half times.

SUMMARY

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In California the amount of land supporting young-growth timber stands is increasing steadily. Some of this timber is being harvested now; more will be soon. Thus, forest managers and loggers are concerned with the effect of small logs on logging cost and production rates and in turn the effect on forest management costs. Each is asking for quantified production-rate values for the major components of logging young-growth timber.

This study provides some answers. Stopwatch times were recorded for every step in the logging process: felling preparation, tree-to-tree travel, felling, limbing, bucking, and lopping; skidding preparation, outbound travel, choker-setting, skidding, and unhooking. These times and corresponding volumes were then transformed into production rates for 12- to 40-inch d.b.h. trees and related to tree species, tolerance, tree diameters, number of logs per turn, and distance.

Log-making production rates depended upon tree size. Production rates were poorer for smaller trees for all steps in the process. When all log-making production components were combined, results for the 38-inch d.b.h. tree were two and a half times better than for the 14-inch d.b.h. tree. As for species, incense-cedar ranked poorest in all components, followed by ponderosa pine, while the moderately tolerant conifers (Douglas-fir, white fir, and sugar pine) had the best production rate. Tolerance influenced the size, number, and tendency of branches to break when fallen—greatly affecting limbing and lopping production rates.

Size of tree and resultant size of logs also affected skidding production rates associated with the 113 drawbar horsepower tractors used in this study. For a turn of skidded logs that averaged 22 inches d.i.b. the production rate was two and a half times better than for a turn that averaged under 12 inches d.i.b. Choker-setting and unhooking production rates were influenced most by the number of logs per turn, and the skidding production rate was governed by the number of logs per turn and the distance skidded.

An inescapable conclusion from this study is that even in young-growth timber, relatively large differences in tree size occur. In turn, these differences play a major role in determining logging production rates as well as costs and returns for forest management. Recognition of this fact should aid loggers, forest owners, timber appraisers, and tax assessors in their work.

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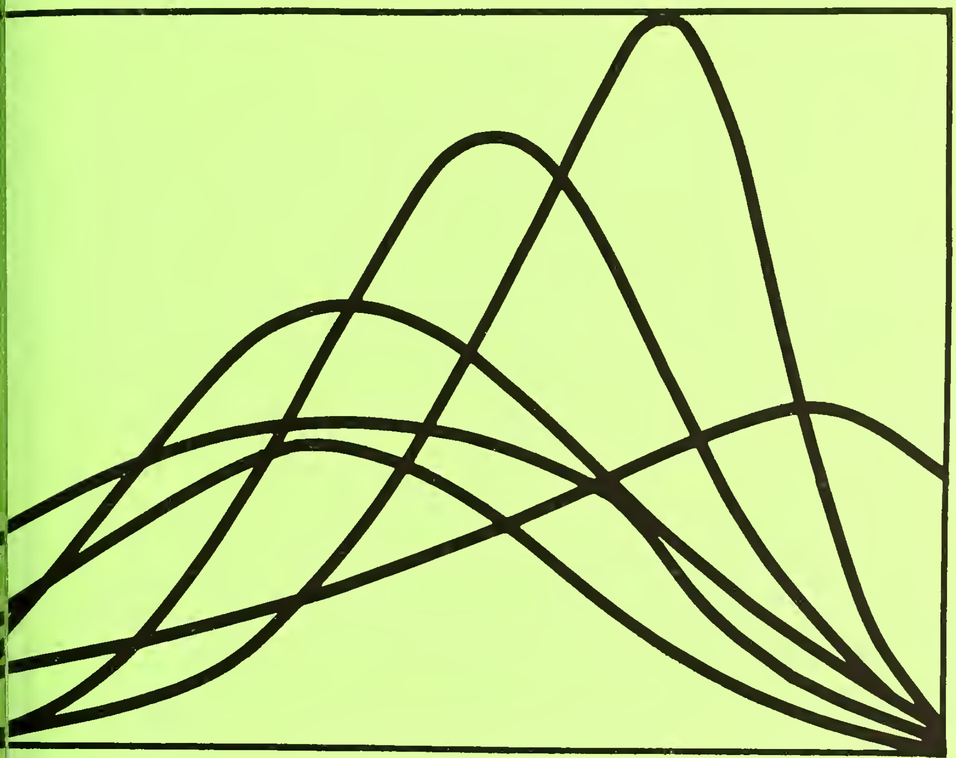
PACIFIC SOUTHWEST Forest and Range Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701



Optimum Target Sizes for a SEQUENTIAL SAWING PROCESS

H. Dean Claxton

USDA FOREST SERVICE RESEARCH PAPER PSW-87 /1972

Claxton, H. Dean

1972. **Optimum target sizes for a sequential sawing process.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif., 10 p., illus. (USDA Forest Serv. Res. Paper PSW-87)

A method for solving a class of problems in random sequential processes is presented. Sawing cedar pencil blocks is used to illustrate the method. Equations are developed for the function representing loss from improper sizing of blocks. A weighted over-all distribution for sawing and drying operations is developed and graphed. Loss minimizing changes in the control variables of saw settings are calculated from the developed equations.

Oxford: 852.2–015.6: 832.15

Retrieval Terms: sawing; operations research; sequential processes; saw setting; mathematical analysis; quality control.

CONTENTS

The Author

H. DEAN CLAXTON is in charge of the Station's research on timber conversion systems, with headquarters in Berkeley. He earned a bachelor's degree in forestry at Oklahoma State University (1955), a master of forestry degree at Duke University (1958), and a doctorate in agricultural economics at the University of California, Berkeley (1968). He joined the Forest Service and the Station staff in 1961.

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Workers in operations research and systems analysis encounter problems based on sequential processes having random components. Raw material conversion based on a series of cutting operations is one example of this class of problems. At each stage in the series, operating characteristics of the saws, together with their random factors, affect succeeding stages. Determining the best size settings for each type of saw in the series is a complex decision process that requires consideration of saw characteristics and the loss caused by having the wrong size piece at the end of the process.

This paper describes a method of solving this problem. The technique is applicable to a wide range of sequential cutting operations. The cutting of cedar pencil blocks is used as an illustration.

Cedar pencil blocks are about 3 by 3 by 7-1/4 inches. They are sawn and air dried before being sent to further cutting processes. This process uses a circular headsaw, a horizontal bandsaw, resaw, and a double arbor edger. Logs are cut into pieces of wood that are essentially square in cross section. The number of blocks contained in each piece varies according to the length of the logs. These log length pieces are then air-dried and cut into 7-1/4-inch blocks. The resulting blocks form several size groups according to the characteristics and size settings of saws that cut them. Each block is subsequently cut (in a radial plane) into 12 pencil slats if it is the proper size. If the block is too small, slats are lost; if it is too large, wood is wasted.

If the final size is = X°, the block will produce exactly 12 pencil slats. If the final size is not X°, a loss will occur. The final size of a block depends on the value of the saw settings. The problem can be stated by specifying a loss function $L(X)$, with the effect of saw settings as control variables Γ. The aim is then to find the values of Γ that will produce the least expected loss.

This formulation of the loss function ignores two steps in the actual process. One is the cutting of the 7-1/4-inch length, which does not affect the number slats per block and is therefore excluded from consideration. The second step ignored, the cutting which determines the radial dimension of the blocks, is actually a part of the sawing sequence, but it does not affect the number of slats obtainable. Although the blocks are essentially square in cross section (radial and tangential dimension) only the tangential dimension affects the number of slats obtained. The size requirements for the radial dimension of blocks will be satisfied throughout the range of setting that will be considered. Consequently the cuts which determine the radial dimension of blocks can be ignored.

DECISION PROBLEM

The decision is to choose saw settings that will minimize losses. Losses can be described as a function of block sizes resulting from the control variables of saw setting. Since random factors involved in the process of sawing and drying affect the final block sizes, the loss function can be specified as a random variable with a given probability distribution. To determine such a probability distribution, variability in both sawing and drying must be considered, as it is the final block size that determines how many slats will be obtained.

Loss Function

A loss function can be written, $L(X)$. If blocks are too small and one or more slats are irrecoverably lost, an appropriate loss function could be drawn as shown:

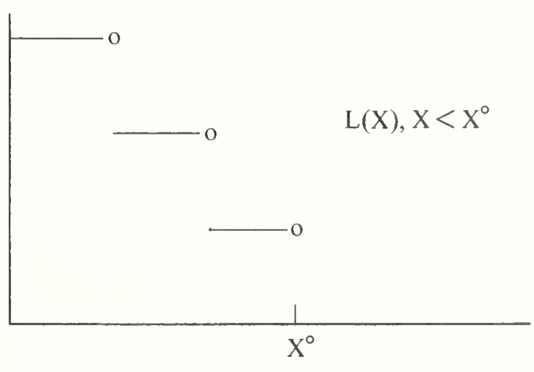


Figure 1—The 95-year-old stand be[illegible] logging. The large number of trees v[illegible] their many dead branches is typica[illegible] young-growth stands on high-qua[illegible] sites in north central California.

LOG-MAKING

The fallers were experienced at their trade and paid at a gyppo rate. They worked as two-man "sets" —set members staying well within earshot of each other, but each man limbed and bucked each tree that he had felled.

During the production study, fallers never knew which of them were to be timed or what day timing would take place. These selections were random. A forestry-trained observer timed functions by stop watch to the nearest 0.1 minute. Different components were (1) preparation time, (2) tree-to-tree travel, (3) felling, (4) limbing, (5) bucking, and (6) lopping branches from tree tops. Timing began when the fallers arrived at the landing each morning and ended when they returned to it in the evening. Altogether, timing was performed on 191 trees of 5 different species and took slightly over 8 full days. Production averaged 22,740 board feet Scribner Scale per man-day. Other recorded data included individual log diameters, lengths, and pertinent remarks.

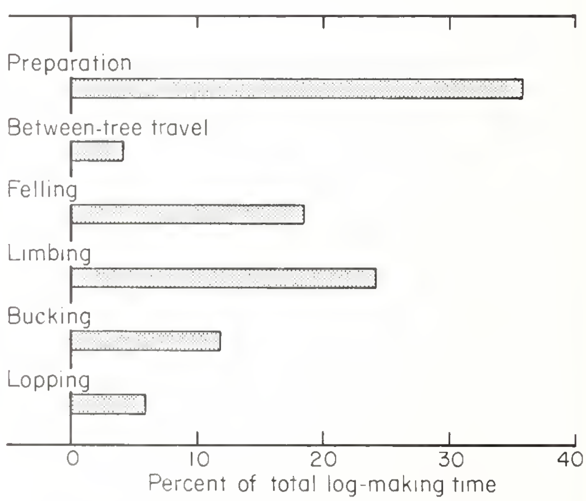


Figure 2—Preparation time is an important component of log-making production.

Preparation

Because of rigorous physical and safety demands, preparation time always is high *(fig. 2)*. Human needs (rest, eat, drink) and mechanical needs (fuel, adjust, and sharpen saw) were the largest categories as the following breakdown shows:

Item:	Portion of preparation time (percent)
File and adjust saw	12.1
Fuel saw	11.6
Scout	5.3
Rest	31.0
Drink and lunch	26.6
Fell snags	6.0
Walk to and from landing	7.4
	100.0

Altogether, preparation time amounted to 8 minutes per thousand board feet.

Tree-to-Tree Travel

This component was minimal because the trees to be cut grew relatively close together. Over-all, tree-to-tree travel had a negligible effect on production and amounted to only 0.9 minutes per thousand board feet.

Felling

In felling, size of tree is important. The larger the tree, the greater its height, and the more time and skill necessary to fell it with minimum damage to the residual stand. To avoid damage, some trees were wedged. Occasionally, a small tree or some

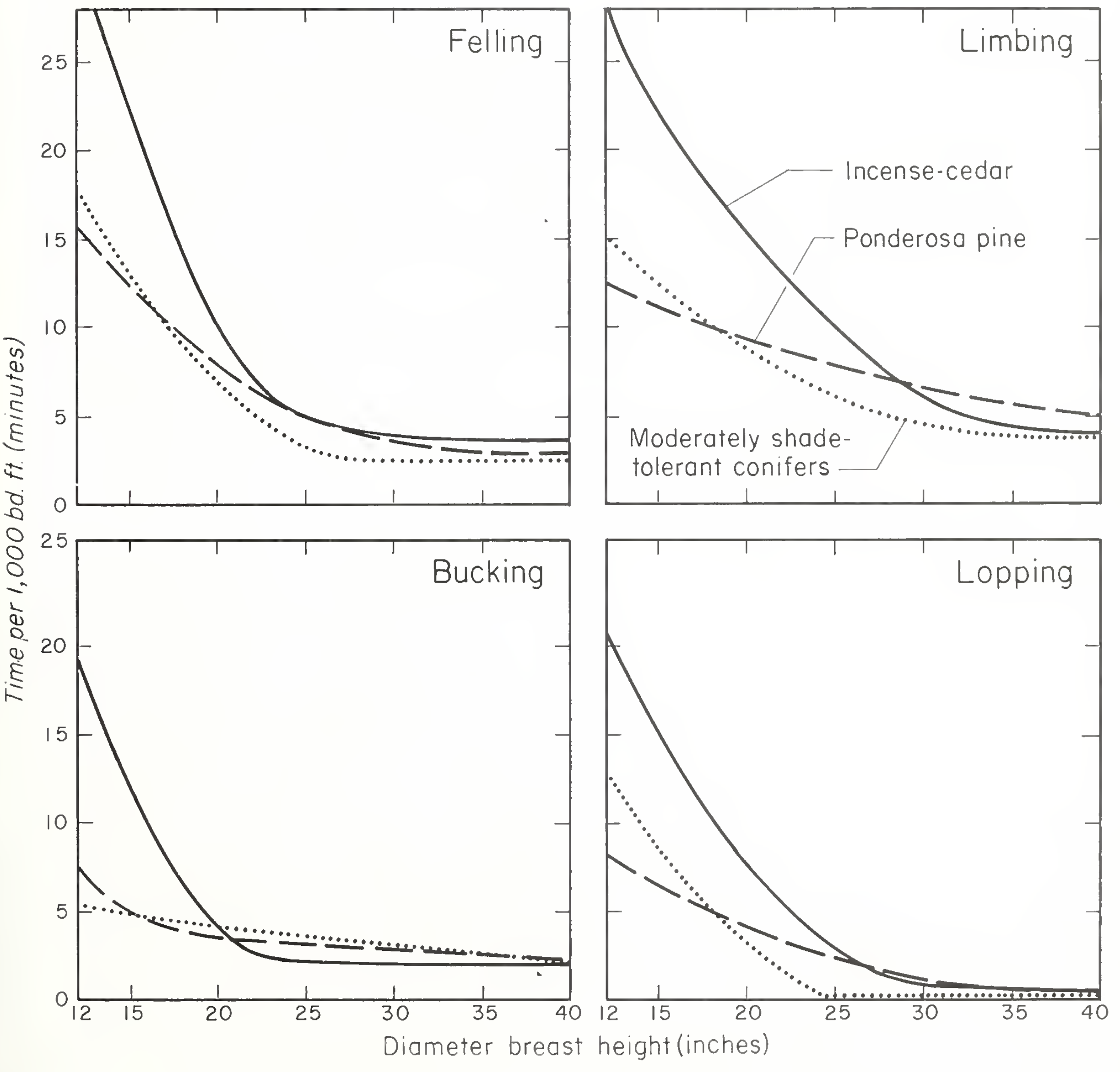


Figure 3—Log-making production rates relative to tree diameters. Species differences are readily seen.

Sawing Distribution

The distribution, f^1 (Y), of block sizes depends on the five saw settings identified earlier. The distribution is also affected by the combination of saws used to produce a group of blocks and the number of blocks in each group. The sawing distribution can be specified as follows:

$f^1(Y,\Gamma) = W_1 \cdot f_1^1(Y,\Gamma_1)$	Headsaw
$+ W_2 \cdot f_2^1(Y,\Gamma_2)$	Resaw
$+ W_3 \cdot f_3^1(Y,\Gamma_3)$	Double arbor edger
$+ W_4 \cdot f_4^1(Y,\Gamma_2)$	Headsaw-resaw; bottom cuts from 6- or 9-inch boards
$+ W_5 \cdot f_5^1(Y,\Gamma_4,\Gamma_2)$	Headsaw-resaw; top cuts from 6-inch boards
$+ W_6 \cdot f_6^1(Y,\Gamma_5,\Gamma_2)$	Headsaw-resaw; top cuts from 9-inch boards
$+ W_7 \cdot f_7^1(Y)$	Headsaw-double arbor edger

in which

W_i is the weight or proportion of blocks sawn by method i

f_i^1 for i = 1, 2, 3 are distributions determined by one saw alone

f_i^1 for i = 4, 5, 6, 7 are distributions created by a combination of saws.

Now we define

$$F_i^1(Y) = \int_{-\infty}^{Y} f_i^1(Z,\Gamma)\, dZ$$

and specify

$$F_i^1(Y) = [1+e^{-\beta_{1i}(Y-\beta_{2i})}]^{-\beta_{3i}}$$

The mode of the density function derived from this cumulative distribution function is

$$M_i = \beta_{2i} + \frac{\log \beta_{3i}}{\beta_{1i}}$$

Then let

$$L_i = \frac{\log \beta_{3i}}{\beta_{1i}}$$

and

$$\beta_{2i} = M_i - L_i \qquad i = 1,2,3$$

We further assume the mode to be the sum of the relevant saw setting and some constant. For values of i from 1 to 3 we will denote k=i and

$$\beta_{2i} = (\Gamma_k + c_i) - L_i$$

For values of i from 4 to 7 a slight modification of this formulation is required. There are only three saws, and the last four of the distributions are the results of combinations of the saws. We will consider each of the combinations separately.

Headsaw-Resaw Combination; Bottom Cuts From 6- or 9-inch boards: $f_4^1(Y,\Gamma_2)$

The initial cut made by the headsaw determines the straightness of one side of a square several blocks long. The other side of all the blocks in this square is cut by the resaw. Thus, the size of such blocks is determined by both the headsaw and the resaw in the following manner: For blocks with one side cut by the headsaw and one side by the resaw, when cut from the bottom of a 6- or 9-inch board, the wet size Y is determined by the setting of the resaw and the irregularity of the headsaw cut. The actual thickness setting of the headsaw has nothing to do with the thickness of the bottom piece cut from 6- and 9-inch boards.

As the variations of the saw are assumed fixed, or not subject to control, the difference between the density function of these blocks and those with both sides cut by the resaw is specified by a different function with the same control parameter as the resaw function. The cumulative distribution function is as follows:

$$F_4^1(Y) = \int_{-\infty}^{Y} f_4^1(Z,\Gamma_2)\, dZ$$

then we specify

$$F_4^1(Y) = [1+e^{\beta_{14}(Y-\beta_{24})}]^{-\beta_{34}}$$

in which

$$\beta_{24} = M_4 - L_4$$

But above we have

$$\beta_{22} = M_2 - L_2$$

We shall assume the difference between M^4 and M^2 to be caused by an effect from the irregular headsaw cut. Then we can write

$$\beta_{24} = M_2 + (M_4 - M_2) - L_4$$

and

$$\beta_{24} = (\Gamma_2 + c_2) + (M_4 - M_2) - L_4$$

Headsaw-Resaw Combination; Top Cuts From 6-Inch Boards: $f_5^1(Y,\Gamma_2,\Gamma_4)$

When the blocks are produced from the top cut, the size setting of the headsaw as well as its variability has a direct bearing on sizes of the blocks. We can designate Y_1 as the size of the boards cut by the headsaw (nominally 6 inches) and Y_2 as the size of blocks produced by the resaw. The bottom blocks from the 6-inch board are sawn by the resaw, leaving the size of the top blocks as the difference between the 6-inch headsaw setting and the resaw setting. As before specify

$$F_5^1(Y,\Gamma_4,\Gamma_2) = \int_{-\infty}^{Y} f_5^1(Z,\Gamma_4,\Gamma_2)\, dZ$$

$$F_5^1(Y,\Gamma_4,\Gamma_2) = [1+e^{-\beta_{15}(Y-\beta_{25})}]^{-\beta_{35}}$$

$$\beta_{25} = M_5 - L_5$$

$$\beta_{25} = [(\Gamma_4 + c_4) - (\Gamma_2 + c_2)] - L_5$$

Headsaw-Resaw Combination; Top Cuts From 9-Inch Boards: $f_6^1(Y,\Gamma_5,\Gamma_2)$

These blocks are produced in much the same manner as the blocks with distribution f_5^1. The exception is that the top cut from the wider board is a residual from two resaw cuts instead of one. Specification is as follows:

$$F_6^1(Y,\Gamma_5,\Gamma_2) = \int_{-\infty}^{Y} f_6^1(Z,\Gamma_5,\Gamma_2)\, dZ$$

$$F_6^1(Y,\Gamma_5,\Gamma_2) = [1+e^{-\beta_{16}(Y-\beta_{26})}]^{-\beta_{36}}$$

$$\beta_{26} = M_6 - L_6$$

$$\beta_{26} = [(\Gamma_5 + c_5) - 2(\Gamma_2 + c_2)] - L_6$$

Headsaw-Double Arbor Edger Combination: $f_7^1(Y)$

Some blocks have one side cut by the headsaw and the other side by the double arbor edger. The probability density function of these blocks can be expected to vary widely from either the headsaw or the double arbor edger blocks. The headsaw cut edge is influenced by the variability of the headsaw, but not its size settings. Similarly the double arbor edger side is influenced by the variation of the saw but the size setting is not relevant. As the size of these pieces is primarily influenced by the way a board is positioned for feeding to the double arbor edger, the wet size can be regarded simply as a random variable with distribution $f_7^1(Y)$. Specification of the function is as before:

$$F_7^1(Y) = \int_{-\infty}^{Y} f_7^1(Z)\, dZ$$

$$F_7^1(Y) = [1+e^{-\beta_{17}(Y-\beta_{27})}]^{-\beta_{37}}$$

PARAMETERS OF CUMULATIVE DISTRIBUTION FUNCTIONS

Parameters of the cumulative distribution functions

$$F_1^1, \ldots, F_7^1 \text{ and } F^2(P)$$

can be estimated using the technique of nonlinear least squares.

Block Size Distribution

Estimates of the probability of occurrence of blocks at or below specified wet sizes for each of the sawing methods defined were made as follows:

A sample of blocks from each sawing method was drawn and its critical dimension measured at three places on each block. An average of these three measurements was taken to be the block size. Histograms were constructed by defining intervals of 0.001 inch and counting all blocks whose dimension was smaller than the maximum limit of each interval. Then the number of such blocks in each interval was divided by the total number of blocks of that sawing method to provide observations suitable for fitting the specified functions.

The estimated coefficients and accuracy measures are shown in *table 1*, and the data points and resulting curves in *figure 1*.

From the definition of $F^1(Y,\beta)$ we obtain the probability density function as $f^1(Y,\beta) = \frac{dF^1(Y,\beta)}{dY}$

and

$$\frac{dF^1}{dY} = -\beta_3 [1+e^{-\beta_1(Y-\beta_2)}]^{-\beta_3-1} \cdot [-\beta_1 e^{-\beta_1(Y-\beta_2)}]$$

Table 1–*Estimated coefficients for block size distribution*

Item	β_1	β_2	β_3	Mean squared deviation
F_1^1	27.0284	3.02729	2.99416	0.01606
F_2^1	46.1520	3.09395	1.00253	.01707
F_3^1	478.9543	3.13276	.34495	.02092
F_4^1	86.6924	3.13536	.33552	.01304
F_5^1	39.5252	3.08650	.33309	.01078
F_6^1	25.3623	3.07697	1.04801	.01589
F_7^1	75.4782	3.17829	.13328	.02962

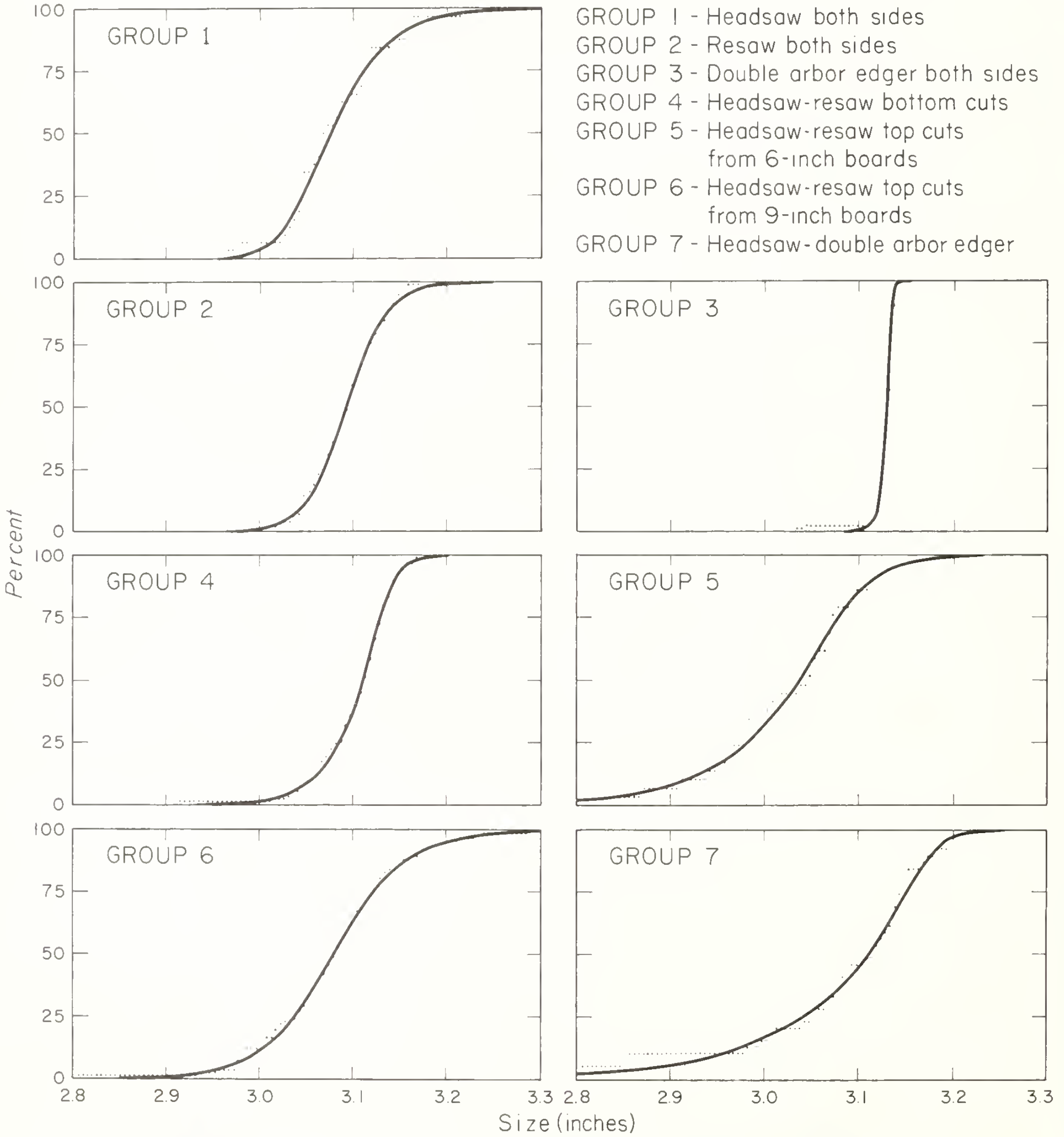


Figure 1—Block size distribution is determined by saw characteristics and settings. The curves show the distribution for three saws and four combinations of saws.

The resulting probability density functions using the estimated values for β are as shown in *figure 2*.

To combine these results into a single distribution, estimates of the proportion of total block production from each sawing method are required as weights. As the sample taken to determine frequency of size occurrence in each group did not contain the information necessary to determine proportion of blocks in each sawing group, another sample was taken. The fraction of blocks in each group is:

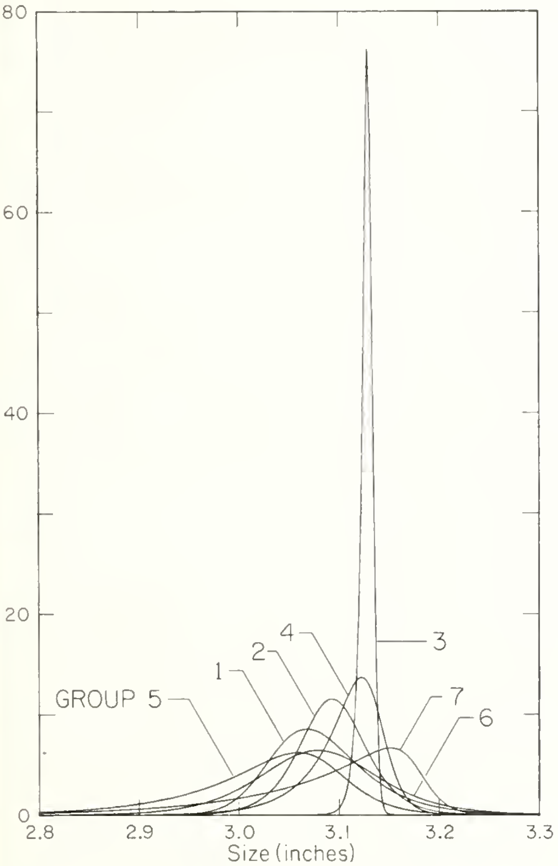


Figure 2—The probability density curves for the sawing operation shown here are for the various saws and combinations. Group 1-Headsaw both sides; 2-Resaw both sides; 3-Double arbor edger both sides; 4-Headsaw-resaw bottom cuts; 5-Headsaw-resaw top cuts from 6-inch boards; 6-Headsaw-resaw top cuts from 9-inch boards; 7-Headsaw-double arbor edger.

$W_1 = .01558$ $W_5 = .00554$
$W_2 = .09254$ $W_6 = .04274$
$W_3 = .58856$ $W_7 = .13071$
$W_4 = .12432$

Combining the previous results with these weights produces the over-all sawing density function.

Drying Distribution

The drying distribution was obtained in much the same manner as the sawing distribution. A sample of blocks was drawn and measured while wet and later remeasured when dry. The ratio of dry size to wet size is the variable for which a probability density function is to be constructed. Like the sawing function, the drying function is a sum of individual drying functions. Here the individual functions are the result of different wood types drying at different rates. The wood types were (1) kiln-dried sapwood, (2) air-dried sapwood, and (3) kiln-dried light heartwood.

A separate cumulative distribution function for each type of wood was estimated using the same algebraic form and the procedures described. For computational convenience the coefficients for these curves were computed using the variable 100 · (1-P) rather than P. The coefficients are given in *table 2* and the graphs of the functions in *figure 3.*

Table 2–*Estimated coefficients for drying distribution*

Item	α_1	α_2	α_3	Mean squared deviation
F_1^2 (P)	1.92096	3.58300	0.69993	0.03136
F_2^2 (P)	2.28439	1.51630	1.72986	.00822
F_3^2 (P)	1.93950	-1.45374	125.94974	.01124

The proportion of blocks occurring in each wood type was obtained from a separate sample and used as weights along with the above given coefficients to produce a weighted drying distribution function. This was then combined with the weighted sawing distribution to obtain the over-all sawing and drying density function given in *figure 4*.

The final form of the expression is then

$$0 = \frac{\partial E}{\partial \Gamma} = \int_x L(X) \int_v \left[\frac{\partial}{\partial \Gamma} \sum_{i=1}^{M} W_i f_i^1 (X \cdot V^{-1}, \Gamma) \right] \cdot$$

$$\sum_{j=1}^{N} U_j f_j^2 (V) V^{-1} \, dV dX \quad M = 6, \; N = 3$$

where $\frac{\partial E}{\partial \Gamma}$ is the vector of partial derivatives $\frac{\partial E}{\partial \Gamma_k}$.
Note that M is equal to 6 because the 7th distribution is independent of Γ, and that the partial with respect to Γ can be brought through the two integrals, their limits and L(X) both being independent of Γ.

Rather than solving for Γ we will solve for another vector of variables, Z. This procedure is somewhat more convenient, and by the composite function rule of differentiation is equivalent to solving with respect to Γ given the linear relationship between Z and Γ.

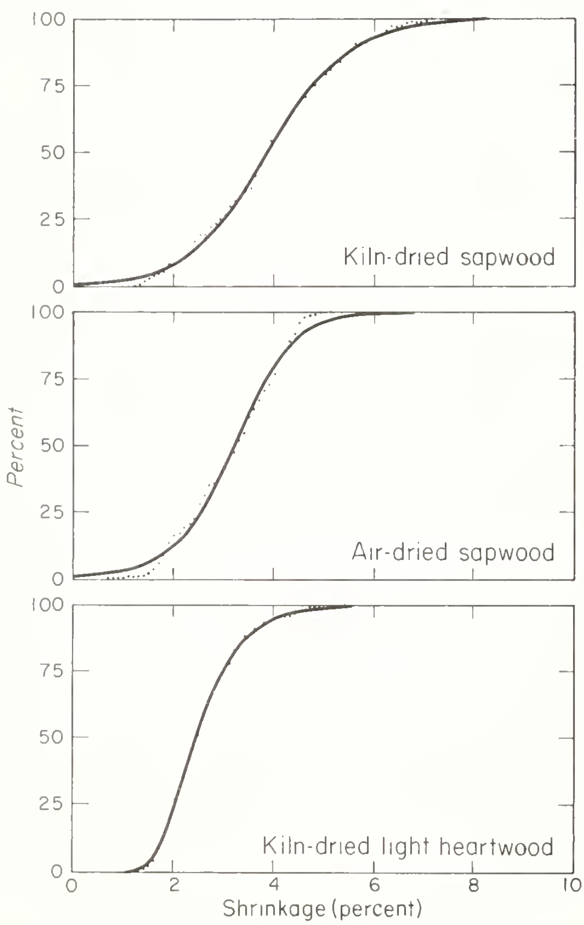


Figure 3—Distribution of shrinkage in the drying operation was determined for three types of wood.

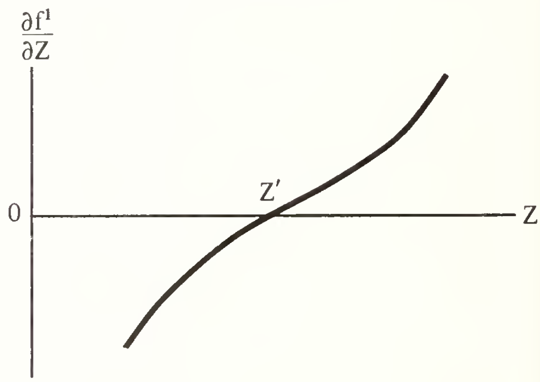
Then the partial for the ith sawing distribution has the form

$$\frac{\partial f_i^1}{\partial Z_i} = W_i \beta_{1i}^2 \beta_{3i} \, e^{-\beta_{1i}(X/V - Z_i)} \, .$$

$$[1 + e^{-\beta_{1i}(X/V - Z_i)}]^{-\beta_{3i} - 2} \cdot [\beta_{3i} \, e^{-\beta_{1i}(X/V - Z_i)} - 1]$$

Solving Equations by Approximation

We expect each partial derivative of the expected loss functions with respect to Z_i to have zero value and to be continuous in the range of interest. The partial will then have the shape shown below:



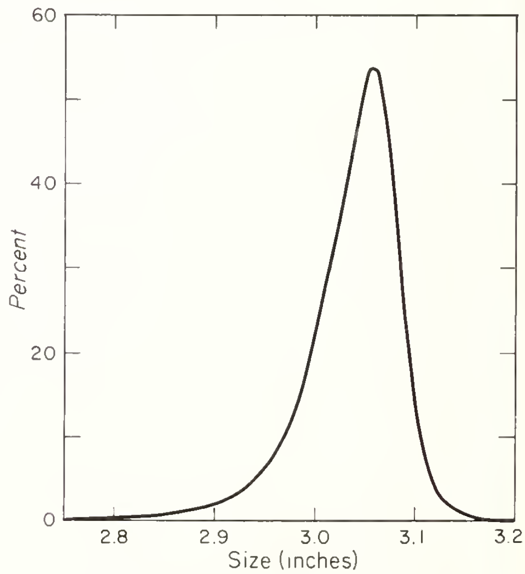


Figure 4—The weighted distribution functions for the drying and sawing operations were combined to produce this over-all curve.

We are given a tolerance e; a lower limit on the accuracy with which we are to find the zero point Z_i'. (In this case we used e = 0.001.) In other words we wish to find Z_i' such that

$$|Z_i - Z_i'| < \frac{e}{2}, \qquad e > 0$$

To obtain an approximation of Z_i', we used the Newton iteration procedure.

Calculating Setting Changes

The solution, Z', can be translated into a set of optimum values, one for each saw setting.

For Γ_1 and Γ_3 (Headsaw and Double Arbor Edger)

Each Z_i, is a parameter of one density function. For each minimization, we obtain a minimizing Z_i, Z_i':

$$Z_i' = (\Gamma_k' + c_k) - L_k \qquad k=i = 1,3$$

But we know

$$\beta_{2k} = (\Gamma_k + c_k) - L_k \qquad k = 1,3.$$

So that the difference in setting is given by

$$\Gamma_k' - \Gamma_k = Z_i' - \beta_{2k} \qquad k=i = 1,3.$$

For Γ_2 (Resaw)

Both f_2^1 and f_4^1 are functions of Γ_2 and no other Γ_k. (Recall the earlier "sawing distribution" discussion of the headsaw-resaw combination, bottom cuts.) We take

$$Z_2 = (\Gamma_2 + c_2) - L_2$$

and express Z_4 in terms of Z_2

$$Z_4 = Z_2 + (\beta_{24} - \beta_{22}).$$

We then take the partial with respect to Z_2, then obtain a minimizing

$$Z_2' = (\Gamma_2' + c_2) - L_2.$$

As

$$\beta_{22} = (\Gamma_2 + c_2) - L_2$$

then

$$\Gamma_2' - \Gamma_2 = Z_2' - \beta_{22}.$$

For f_5^1 (Headsaw-Resaw; Top Cuts From 6-Inch Boards) and f_6^1 (Headsaw-Resaw; Top Cuts From 9-Inch Boards)

Both f_5^1 and f_6^1 are functions of two saw settings, (Γ_4 and Γ_5). Both are also functions of the resaw setting Γ_2, for which we have already obtained a change in setting.

We can then calculate the changes in Γ_4 and Γ_5 given $\Gamma_2' - \Gamma_2$ and values for Z_5 and Z_6. We have for Γ_4 a minimizing Z_5, as

$$Z_5' = [(\Gamma_4' + c_4) - (\Gamma_2' + c_2)] - L_5$$

and

$$\beta_{25} = [(\Gamma_4 + c_4) - (\Gamma_2 + c_2)] - L_5 .$$

Then

$$\Gamma_4' - \Gamma_4 = (Z_5' - \beta_{25}) + (\Gamma_2' - \Gamma_2)$$

or

$$\Gamma_4' - \Gamma_4 = (Z_5' - \beta_{25}) + (Z_2' - \beta_{22})$$

We have also a minimizing Z_6' as

$$Z_6' = [(\Gamma_5' + c_5) - 2(\Gamma_2' + c_2)] - L_6$$

and

$$\beta_{26} = [(\Gamma_5 + c_5) - 2(\Gamma_2 + c_2)] - L_6 .$$

Then, as above,

$$\Gamma_5' - \Gamma_5 = (Z_6' - \beta_{26}) + 2(Z_2' - \beta_{22}).$$

Numerical Results

This gives us the complete vector $(\Gamma' - \Gamma)$ as follows:

$$(\Gamma_1' - \Gamma_1) = (Z_1' - \beta_{21})$$

Headsaw change for 3-inch setting

$$(\Gamma_2' - \Gamma_2) = (Z_2' - \beta_{22})$$

Resaw setting change

$$(\Gamma_3' - \Gamma_3) = (Z_3' - \beta_{23})$$

Double arbor edger setting change

$$(\Gamma_4' - \Gamma_4) = (Z_5' - \beta_{25}) + (Z_2' - \beta_{22})$$

Headsaw change for 6-inch setting

$$(\Gamma_5' - \Gamma_5) = (Z_6' - \beta_{26}) + 2(Z_2' - \beta_{22})$$

Headsaw change for 9-inch setting.

Minimizing values (Z'_i) are tabulated here.

Z'_1 = 3.092 inches

Z'_2 = 3.121 inches

Z'_3 = 3.126 inches

Z'_5 = 3.299 inches

Z'_6 = 3.377 inches

Minimizing changes in the saw settings calculated using the coefficient estimates given in *table 1* are as follows:

Headsaw, 3-inch cut	3.092 - 3.027	= .065
Resaw	3.121 - 3.094	= .027
Double arbor edger	3.126 - 3.133	= -.007
Headsaw, 6-inch cut	(3.145 - 3.087) + 0.027	= .085
Headsaw, 9-inch cut	(3.129 - 3.077) + .054	= .106

CONCLUSIONS

The method of analysis presented here should be of value to operations researchers and systems analysts engaged in optimizing (or improving) results from random sequential processes. The method was illustrated by solving to determine optimum settings for saws in a sequential process. Of course, the loss functions and data for the illustration are not widely applicable. The method is. Appropriate data and loss functions would be required before a different application could be made.

Problems based on sequential processes of this nature have proven difficult to solve. We hope the method presented here will lead to solutions of a number of similar problems.

SUMMARY

Claxton, H. Dean
1972. **Optimum target sizes for a sequential sawing process.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif., 10 p., illus. (USDA Forest Serv. Res. Paper PSW-87)

Oxford: 852.2–015.6: 832.15.
Retrieval Terms: sawing; operations research; sequential processes; saw setting; mathematical analysis; quality control.

A method of solving problems based on sequential processes is presented and illustrated using the sawing of cedar pencil blocks as an example. Losses resulting from cutting of blocks to improper sizes are described as a function of block sizes resulting from the control variables of saw settings, from drying processes, and from random factors.

From the saw setting variables $\Gamma_1 \ldots \Gamma_5$ an expected loss function is developed. A joint probability density function for sawing and drying is developed from separate functions for sawing and drying. The distribution of block size groups as determined by three saws and four combinations of saws is analyzed.

Parameters of the cumulative distribution functions are estimated and curves for the cumulative distribution functions and density functions are given for the sawing operation. Parameters are estimated and curves drawn for the drying of three wood types. A weighted over-all density function for both sawing and drying is graphed.

An over-all expression for loss minimization is given and equations are derived for the five saw settings. Loss minimizing changes in the saw settings are calculated from these equations.

The method is widely applicable and should be valuable in operations research and systems analysis of random sequential processes.

G. P. O. 794–425/3731

Claxton, H. Dean

1972. **Optimum target sizes for a sequential sawing process.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif., 10 p., illus. (USDA Forest Serv. Res. Paper PSW-87)

A method for solving a class of problems in random sequential processes is presented. Sawing cedar pencil blocks is used to illustrate the method. Equations are developed for the function representing loss from improper sizing of blocks. A weighted over-all distribution for sawing and drying operations is developed and graphed. Loss minimizing changes in the control variables of saw settings are calculated from the developed equations.

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PACIFIC SOUTHWEST Forest and Range Experiment Station

REST SERVICE
.DEPARTMENT OF AGRICULTURE
. BOX 245, BERKELEY, CALIFORNIA 94701

Lee A. Paine

administrative goals and safety standards for hazard control on forested recreation sites

USDA FOREST SERVICE RESEARCH PAPER PSW-88 /1973

Paine, Lee A.

1973. **Administrative goals and safety standards for hazard control on forested recreation sites.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 13 p., illus. (USDA Forest Serv. Res. Paper PSW-88)

For efficient control of tree hazard on recreation sites, a specific administrative goal must be selected. A safety standard designed to achieve the selected goal and a uniform hazard-rating procedure will then promote a consistent level of safety at an acceptable cost. Safety standards can be established with the aid of data for past years, and dollar evaluations are feasible. Cost optimization is possible but impractical with available data. The legal risk in adoption of safety standards is considered acceptable.

Oxford: 907.2: 416: 304(083.7): 624.4.
Retrieval Terms: hazard trees; recreation areas; accident prevention; tree failure; safety standards; management goals; safety engineering.

CONTENTS

The Author

LEE A. PAINE is studying problems in the biology and control of forest tree diseases, particularly in recreation site pathology. A forest pathologist, he has been on the Berkeley Station staff since 1957, when he joined the Forest Service. He holds bachelor's (1943) and master's (1947) degrees in forestry from the University of Idaho and a doctor of science degree (1951) from the Swiss Federal Institute of Technology.

Accidents resulting from the failure of trees occur on most forested recreation sites. On public recreation lands, tree hazard poses serious economic and public relations problems.

Resource management agencies control hazards on developed recreation sites as a matter of public responsibility. Performance of the control programs can be judged by their success in meeting safety policy aims and by the cost of control for a given level of protection. But administrative goals and safety standards have rarely been established. The control of tree hazard is often hampered by an ill-defined policy and inadequate supervision. The success or even the value of a program may be in doubt; when no realistic policy aims have been set, there is little basis for evaluation.

Tree hazard losses and control cost for developed recreation sites are estimated at about $2 million annually on State and Federal lands in California alone. Thus, efficiency in operation is essential even when protection is judged adequate.

This paper describes some of the options available to the administrator in selecting agency goals and standards.

One proposal, described in detail, is recommended for use by public land agencies in managing large administrative units in the United States. The important consideration is the establishment of a definite goal, to which hazard control programs can be tailored, and against which their success can be gauged.

ESTABLISHING GOALS AND SAFETY STANDARDS

Hazard may be defined as the probability of mechanical failure or uprooting of a tree with consequent injury or property loss. It can never be eliminated on forested recreation sites as long as any trees remain standing *(fig. 1)*. Yet, managers of sites to which the public is specifically invited are held responsible for the "elimination" of hazard. Because they are also responsible for maintaining attractive recreation sites in a forest ambient, they must arrive at a balance between too great hazard and too few trees.

To provide for a consistent and economical balance, the administrative office must (a) select a goal in finite terms, (b) set a safety standard based on the

Figure 1—Even relatively sound trees pose a definable hazard on recreation sites.

defined goal, (c) provide a uniform method for rating hazard, and (d) set a hazard rating (hazard control level) below which hazard will not be controlled. Periodically, as conditions change, the hazard control level can be adjusted to satisfy the safety standard.

The need for administrative goals is clear. Administrators must provide the highest level of public safety commensurate with budget restrictions, technical expertise, and esthetic considerations. Vaux[1] notes that "[Goals] are part of the feedback mechanism through which an organization evaluates its performance." Until current performance is evaluated with reference to a reasonable goal, no program can be judged either effective or noneffective.

There is adequate precedent in the field of public safety for finite goals. State and municipal traffic departments characteristically base remedial action on guides limiting the number and severity of accidents. Personnel safety programs in government and industry are also organized to meet practical goals, even though they must be revised from year to year. The establishment of such goals for recreation site hazard management will be beneficial in terms of both economy and public safety.

Definitions and Limitations

To define goals and safety standards, specific terms must be chosen. In this discussion, property damage or personal injury resulting from tree failure is an *accident;* a *failure* has the potential for causing an accident, whether or not it actually does so; an *accident-failure* is a tree failure involved in an accident. The term "failure" does not imply that any defect could necessarily be detected prior to failure. A *nondefective failure* is one in which no defect directly contributing to the failure is detectable.

The Report of Tree Failure *(fig. 2),* currently in use by government agencies, provides data on numbers and types of failures and accidents. From these reports, accident rates were found to be more variable than failure rates. Therefore, although a goal can be stated in terms of allowable accidents, the safety standard is better defined in terms of allowable failures.

The site categories to which a goal and safety standard will apply should also be defined. Responsibility is clearest for sites that are signed and that implicitly or explicitly invite public entry, but other sites may also require control or inspection *(fig. 3).* In general, the defined categories should include (a) developed sites which invite public use, (b) those perimeter areas and volunteer sites on which control is normally practiced, and (c) other sites on which the agency retains a responsibility for inspection.

Sites with no tree cover will logically be excluded when setting or applying standards. A few nonforested sites may be included, however, as part of the defined area for the administrative goal. This will affect the apparent target density (exposure of fixed property or recreationists to failures), but the allowable failures and resulting accidents will not be changed significantly on the forested area.

Goals and safety standards are based on periods when accidents are a potential consequence of failure: (a) the period in which the site is normally in active use (in-season), and (b) out-of-season periods on sites where fixed facilities, improvements, homes, or other properties are subject to potential loss from failures.

It will help if the goal and safety standard are expressed in terms of a unit of recreationist exposure (visitor-days, visits, etc.). This term will vary with the agency, but its use must be consistent. If one-half day use by one person is considered a visitor-day, two visitor-days should imply twice the exposure.

Our ultimate aim is to maintain a given low rate of accidents within an administrative region. The goal, then, can appropriately be defined as the maximum allowable number of accidents per visitor-day per year. The sample selection of a goal described in the following section is based on this definition, although other bases could easily be substituted. For example, the goal could be stated as the total number of allowable accidents per year. Some managers, however, have indicated their preference for a rate expressed in terms of visitor exposure. After the goal has been selected, the safety standard necessary to achieve the goal may be estimated.

With appropriate field procedures, a uniform safety standard will result in consistent levels of hazard control with emphasis on high hazard. In the absence of standards, managers of low hazard sites may use disproportionately large budgets to control hazard to excessively low limits. Valuable trees may be removed in efforts to completely eliminate hazard. Safety standards tend to minimize overcontrol, as well as to insure that public safety is maintained at a reasonable level.

Setting the Goal

Selection of a goal may be guided by the minimum attainable accident rate and the current accident rate. Cost optimization would be possible only if adequate

[1]Vaux, Henry J. *Goal setting: Meeting ground of management and policy.* J. For. 66(10): 799-803. 1968.

REPORT OF TREE FAILURE ①

(Mechanical break, collapse, or uprooting)

Reporting Agency: ____________________

Unit: ____________________

(A) Tree and stand

Species of failing tree: ____

Approximate dbh of tree: ____ inches

Approximate age of tree: ____ years

Forest type: ____

Stand age class: ____ Overmature

____ Mature

____ Young growth

____ All-age

Elevation of site: ____

(B) Class of mechanical failure

____ Upper bole (top half)

____ Lower bole

____ Butt (lower 6 feet)

____ Limb

____ Root, including uprooting

(C) Defect or fault leading to failure ⑥

____ Rot (trunk, limb, or root)

____ Sweep

____ Tree dead – snag

____ Fire wound

____ Leaning

____ Lightning wound

____ Mechanical wound

____ Cracks or splits

____ Fork or multiple top

____ Twin bole or basal fork

____ Dead top or branch

____ Widow-maker or hang-up

____ Canker, rust

____ Canker, mistletoe

____ Other (____________)

____ Unknown or none

(D) Contributing factors

____ Wind

____ Snow

____ Erosion

____ Soil saturation

____ Stream bank erosion

____ Shallow rooting

____ Tree striking tree

____ Other (____________)

____ Unknown or none

(E) Time and location of incident

Approximate hour ____

Month, year: ____

County: ____

State: ____

During season for public use. Yes ____ No ____

(F) Land ownership

____ Federal

____ State

____ Other public (____________)

____ Private

____ Public utility

(G) Site category

____ Established camp or picnic ground

____ Other established public use site ②

____ Volunteer site ③

____ Marked trail

____ Special use site ④ (____________)

____ Roadside

____ Residence site ⑤

____ Other (____________)

(H) Property or person affected

____ Agency

____ Contractor

____ Recreationist

____ Public Utility

____ Forest industry

____ Permittee Concessionaire

____ Other (____________)

(I) Consequences

____ Clean-up work required

____ Property damage (____________)

Loss estimate $ ____

____ Injury

____ Medical attention required

____ Fatality

(J) Comments: ____________________

Name of site ⑦: ____________________

Forest Service Form PSW 4600-3 (Rev 6/72)

Figure 2—Data from the Report of Tree Failure report are a valuable aid to the selection of goals and standards in tree hazard control programs.

①A report should be made for

(1) each tree failure involving property damage or bodily injury;

(2) each failure adjacent to permanent recreation site facilities, home sites, etc., where failures are a threat to property, and;

(3) each failure on recreation sites during the season of public use, whether or not the failure causes damage or injury.

"Recreation sites" refers to those categories listed under (G) Site. Off-season blowdown and other off-season failures are excluded except when individual failures fall under (1) or (2) above. Do not report failures occurring during fire suppression or logging operations

Only failures of a size capable of inflicting some damage or injury, or which required clean-up, should be reported. Minor limb failures should not be reported unless they are potentially dangerous. Do not report simple mortality of a tree or part of a tree unless it resulted in mechanical failure.

②Other established public use site Winter sports, beaches, viewpoints, visitor centers, etc.

③Volunteer site Undeveloped site with concentrated public use.

④Special use site: Resorts, service facilities, etc.

⑤Residence site: Agency, private, or permittee lessor.

⑥Check only those defects and contributing factors which lead to the actual failure.

⑦Published analyses will not indicate the source of specific incidents.

If many failures occur in your area, reports may be limited to sites normally subject to inspection and hazard control. Where information is available, however, reports from volunteer and other noninspected sites will be of equal value.

NOTE A SEPARATE FORM SHOULD BE COMPLETED FOR EACH INDIVIDUAL FAILURE. Inclusion of more than one failure on a report prevents correlation of data

Additional forms may be obtained from your headquarters or by writing to the following address:

Return to: Lee A. Paine
U.S.D.A. Forest Service
P.O. Box 245
Berkeley, California 94701

Phone: 415-841-5121, Ext. 210
FTS: ____-415-841-3210

☆ GPO 791-816

Figure 2— *Continued*

Figure 3—Responsibility for public safety is greatest on formally recognized and signed recreation areas.

data were available. The procedure of cost optimization sheds light on the relation between levels of control and total costs, however, and is illustrated in the Appendix.

To set the goal in terms of an allowable accident rate, reasonable limits must be established. With our present capabilities in the evaluation of tree hazard, a certain proportion of failures are unpredictable and thus set a practical lower limit to accident control. Nondefective failures (defects "Unknown or none," item C, *fig. 2*) are a useful guide to this limit.

Thus, in the calculation below, the lower limit or minimum possible accident rate, r_d, is derived from the number of nondefective accident-failures each year, h_{nd} (using items C and I, *fig. 2*). The current accident rate, r_c, may be taken from the total accident-failures (defective and nondefective) each year (h). More than one year's data should be used, if possible, to provide an average value for recent years. In the following calculations 10 million visitor-days is a convenient exposure rate factor, but any appropriate value can be used.

The lower limit for a goal is thus:

$$r_d = \frac{10^7}{n} \quad \Sigma \left[\frac{h_{nd}}{v}\right] \qquad (1)$$

in which n is the number of years of data, and v is the number of annual visitor-days.

The current accident rate is determined in a similar manner:

$$r_c = \frac{10^7}{n} \Sigma \left[\frac{h}{v}\right] \qquad (2)$$

in which h is the total number of accident-failures per year.

Guided by the minimum and the current accident rates, r_d and r_c, an administrator may select a goal (allowable accident *rate*). The total allowable accidents for the coming year (h_{max}) can then be calculated:

$$h_{max} = \frac{g\ v_e}{10{,}000{,}000} \qquad (3)$$

in which v_e is the estimated visitor-days for the coming year, and g is the allowable number of accidents for 10 million visitor-days.

Whether the goal is selected with the aid of cost optimization, or by the method outlined here, costs must be considered. In addition to property and personal injury losses, total losses include such contingencies as costs of tree replacement, loss of esthetic values and site quality for many years, and damage to public relations. Total losses are very high as compared with those specific losses resulting only from accidents and they accrue from all failures rather than from accident-failures alone. With any method of goal selection, these contingent costs must be weighed. The problem is explored in the section "Dollar Evaluation of the Standard."

Setting the Safety Standard

An administrative safety standard for recreation sites specifies the total failures allowable during the following year, based on total allowable accidents. The safety standard includes all in-season failures and those out-of-season failures which are a potential threat to facilities on areas subject to control or inspection.

Restricting the safety standard to represent only "predictable" failures, rather than total failures, would exclude some failures responsible for accidents, and would require a more specific definition of "predictable." In an accident, the question of whether an individual failure was predictable is often adjustments of the safety standard should be made in increments of two or three allowable failures.

Applying the Safety Standard

Except for cost figures, all data necessary for setting goals and safety standards are available from the Report of Tree Failure *(fig. 2)*. Maintenance of these reports at the administrative headquarters will provide for modifications of the hazard control level, to insure that the safety standard can be met.

A designated hazard control level is the key to economical distribution and use of hazard control funds. Further, a properly chosen and applied control level results in attainment of the same standard of safety over a wide variety of sites. All field units of an administration (to which one safety standard applies) are normally instructed to operate at one control level. Essentially, the control level provides a decision rule. Each tree inspected is given an appropriate rating, and control is carried out only when the rating exceeds the hazard control level. Hazard evaluation and rating are discussed in a separate report.[3]

For the first year, or if the budget is limited, it may be desirable to inspect all hazard ratings from the field before the control level is specified. If the budget permits only limited control work, the control level will be set at a value above which all the most dangerous trees can be treated with available funds.

Thereafter, the control level should be modified (with an adequate budget) so that the designated hazard control level provides satisfactory compliance with the safety standard.

Dollar Evaluation of the Standard

It may be useful to translate the safety standard into a dollar figure representing allowable or anticipated accident losses. This dollar value will vary with the species of tree. Generally the accident rate per failure is about the same for conifers and for oaks (one accident in every four failures). Many more conifer than oak failures are reported, however, and average losses associated with conifers are much higher than for either oaks or other hardwoods *(table 2)*. For other hardwoods, the accident rate per failure is less than one-third as high (only one out of 13).

[3]Paine, Lee A. *Accident hazard evaluation and control decisions on forested recreation sites.* USDA Forest Serv. Res. Paper PSW-68. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 10 p., illus. 1971.

Table 2–*Average accident losses and failure cleanup costs (from reports of 262 accidents, 1,420 failures)*

Species group	Average loss per accident[1]	Average cleanup cost per failure[2]
	Dollars	
Conifers	2,482.41	49.55
Oaks	1,070.98	32.17
Other hardwoods	605.65	47.12

[1]No injuries or fatalities were reported in connection with oak or other hardwood failures. In order to indicate the personal injury potential of these groups, a dollar loss representing one fatality was distributed between the oak and the other hardwood categories in proportion to the average property loss caused by each. The actual property loss per accident in the two groups was 29 percent of the values shown above.

[2]Cleanup costs were assumed, in this example, to be one-fourth of these sample control costs: bole, butt, root–$175 (oak), $200 (other hardwoods and conifers); limb–$75 (oak), $50 (other hardwoods and conifers).

Table 3–*Average loss per accident in 262 accidents*

Tree group	Failure class				
	Upper bole	Lower bole	Butt	Root	Limb
			Dollars		
Conifer	2,095	5,349	2,356	1,850	498
Oak[1]	52	112	345	2,031	966
Other hardwoods[1]	259	204	906	696	615

[1]An arbitrary loss equivalent to one fatality has been distributed between the oak and other hardwood categories in proportion to reported property losses.

The figures given in *table 3* include National Safety Council evaluations of losses resulting from injuries and fatalities. The National Safety Council figures apply specifically to automobile accidents, but loss figures for a fatality or for an injury with more than 1 day disability should apply adequately to forest accident fatalities and to injuries requiring medical treatment.

To arrive at a dollar cost, the allowable number of failures and accidents for each species group should be prorated according to the reported numbers and costs of accidents caused by each species group. Average post-failure cleanup cost per tree, assumed here to be one-fourth of the cost of control (prefailure hazard reduction), can also be derived for each species group and prorated according to frequency of failure classes (*table 2,* footnote 2). For conifers, for example, estimated cleanup costs per failure = [(conifer limb failures) (conifer limb control costs) + (other conifer failures) (other control costs)] [¼] ÷ [total conifer failures].

For the sample data presented earlier, average cleanup costs prorated by failure classes were conifers, \$48.47; oaks, \$40.62; and other hardwoods, \$29.86.

For each species group, the losses for the following year may be estimated as follows: [(Average loss per accident for group) (h_{max}) (h for group) ÷ Σh] + [(Average cleanup cost per failure for group) (f_{max}) (f for group) ÷ Σf]. Average loss per accident here is taken from *table 3.* Average cleanup cost was computed for the example, but *table 3* values may be used. Other values are taken from the data summary *(table 1).* The summation of species groups provides an estimate of expected annual loss:

Conifers
$$\frac{(\$2{,}482.41)\,(20.28)\,(68)}{88} + \frac{(\$48.47)\,(49)\,(148)}{234} = \$40{,}404$$

Oaks
$$\frac{(\$1{,}070.98)\,(20.28)\,(14)}{88} + \frac{(\$40.62)\,(49)\,(54)}{234} = 3{,}915$$

Other hardwoods
$$\frac{(\$605.65)\,(20.28)\,(6)}{88} + \frac{(\$29.86)\,(49)\,(32)}{234} = 1{,}038$$

$$\$45{,}357$$

These values do not include the high contingent losses for each failure, such as cost of replacement and esthetic value. For this example, with a goal of nine allowable accidents per 10 million visitor-days (h_{max} = 20.28, f_{max} = 49), the annual loss estimate of \$45,357 for the expected fifth year visitor load gives a rate of \$20,131 direct loss per 10 million visitor-days. For the years reported, the estimated average annual losses, calculated in the same way, were \$49,015 per year, or \$24,540 per 10 million visitor-days. Thus, the safety standard of 49 allowable failures for the fifth year would provide an estimated 7 percent reduction in total dollar loss below the average for the preceding 4 years—even with 10 percent increase in visitor-days—and an 18 percent loss reduction per 10 million visitor-days.

Using these figures, the average loss per accident during the 4 years may be estimated at \$2,130. This is somewhat lower than the more precise figure of \$2,141 based on *table 3* and the actual distribution of failures.

Legal Implications of Setting Goals

A regional safety standard, based on the administrative goal, makes uniform and economical hazard control possible on recreation sites. Assuming that hazard evaluation and control are carried out in line with the safety standard, some failures and accidents will still occur. Statistically, they will meet the safety standard and the goal. In the example, quite reasonably, the goal was not set at the minimum possible value based on nondefective accident-failures. Such a goal would be extremely expensive to satisfy. We must expect and accept some preventable failures and some preventable accidents. Of course, this is true with or without adminstrative goals. The process of setting a goal simply recognizes the certainty of accidents and establishes a reasonable limit, which may or may not be lower than the existing accident rate.

On the site, some trees will not be controlled because the hazard, though recognized, falls below the designated hazard control level *(fig. 4).* One of these trees may fail and cause an accident resulting in legal action.

Although we cannot foresee the court's reaction, we should expect the court to consider that (a) there is some predictable hazard associated with every tree on a recreation site; (b) intensive examinations result in control of the worst hazard, providing a safer environment for the recreationist *(fig. 5)*; (c) the economic and esthetic costs make lower levels of hazard unattainable or prohibitive; and (d) because the goal cannot be set at zero, a certain number of accidents are necessarily expected.

If we accept the challenge of providing the best available protection to the public, we must also accept the risk that recognized low-hazard trees may cause accidents. It seems a small risk compared with the opportunity for making significant improvements in public safety and reducing property losses and personal injuries at reasonable costs.

Figure 4—Hazard should not necessarily be controlled just because a tree has some recognizable defect.

Figure 5—Highly visible hazard is almost certain to be reduced if a control program is in operation.

SUMMARY

Paine, Lee A.
1973. **Administrative goals and safety standards for hazard control on forested recreation sites.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 13 p., illus. (USDA Forest Serv. Res. Paper PSW-88)

Oxford: 907.2: 461: 304(083.7): 624.4.
Retrieval Terms: hazard trees; recreation areas; accident prevention; tree failure; safety standards; management goals; safety engineering.

The control of hazard associated with defective or faulty trees on recreation sites is an important responsibilty of administrators of public lands. Administrative units, such as Forest Service Regions, need a goal tailored to the philosophy and needs of the unit and capable of translation into effective field directions.

Selection of the goal should involve consideration of personal injury and property losses, esthetic values, site quality, and inspection and control costs. Calculation of the safety standard necessary to achieve a goal is illustrated.

The cost-optimizing procedure outlined in the Appendix emphasizes the relationships that should be considered in goal selection and demonstrates the high contingent costs associated with a control program.

APPENDIX: Cost Optimization

For computation of a goal by cost optimization, costs would include both inspection and control costs; losses would include cleanup costs plus contingent losses associated with all failures, and direct damage losses from each accident.

For illustration, we assume that 1 million trees on recreation sites are inspected and that the cost of inspection varies with the intensity or thoroughness of inspection. In the absence of inspection cost data, we assume that the cost per tree for increasing levels of control will increase slowly at first and then more rapidly to extremely high costs for nearly complete control. The equation y = kx/(1-x) is a curve of this general type, in which y is the inspection cost per tree; x is the proportion of defective potential failures which were detected prior to failure. This curve can be defined with the following data: if the inspection cost is $0.25 per tree for a control level of 1050/1082.5 (defective trees controlled[4] divided by the sum of defective trees controlled plus defective failures),

$$k = \frac{[1-x]\,y}{x} = \frac{\left[1 - \frac{1{,}050}{1{,}082.5}\right]\left[0.25\right]}{\left[\frac{1{,}050}{1{,}082.5}\right]}$$

$$= 0.00773810$$

and

$$y = \frac{[0.00773810]\,x}{[1-x]}$$

For 1 million trees, then, the total inspection cost for any given level of inspection is 1,000,000 y. The average control cost per tree (based on the species and the sample class-of-control costs given in the text, and prorated by actual species and control-class frequencies in the example) was $177.97.

Total inspection and control costs for the 1 million trees, then, will be

$$c = \frac{7{,}738.10\,x}{(1-x)} + 177.97z$$

[4] "Defective potential failures detected" are assumed, in this case, to be the same as "defective trees controlled."

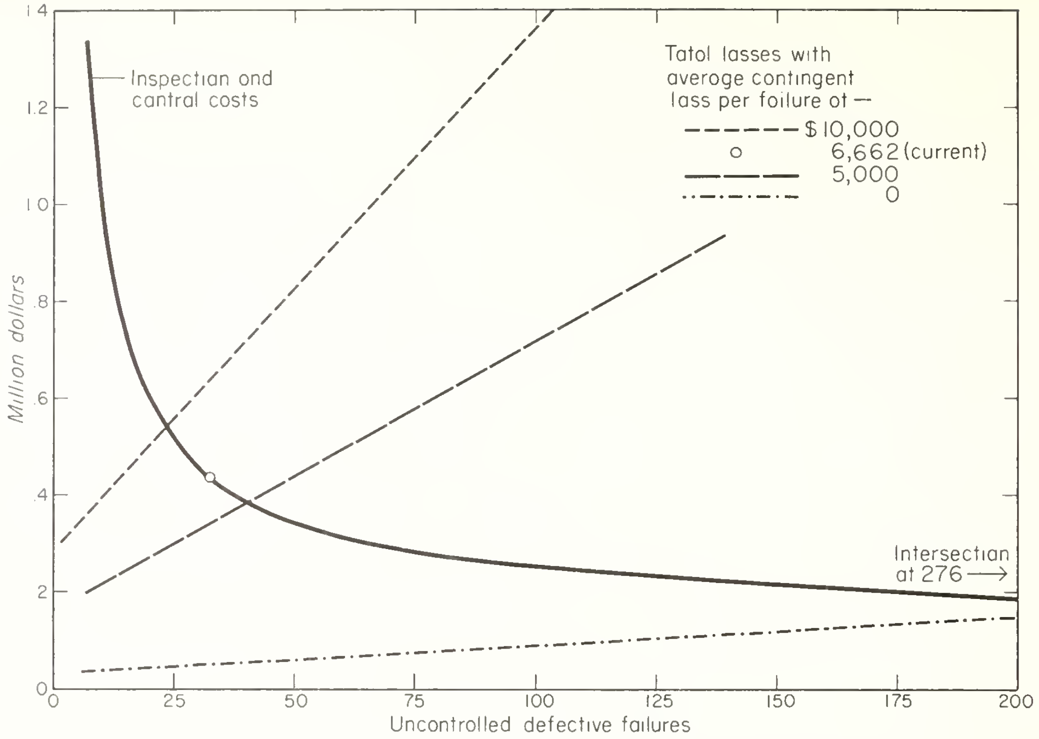

Figure 6—Cost optimization of hazard control. Costs and losses are functions of the number of uncontrolled defective failures.

in which x is the control level (defective trees controlled divided by the sum of defective trees controlled and current defective failures), and z is the number of defective trees controlled for the million trees inspected. The expected number of uncontrolled defective failures, u, for the example is 1,082.5 − z. Inspection and control costs, y, are shown as a function of uncontrolled defective failures, u *(fig. 6)*. In this example, the same inspection cost was assigned to each tree inspected. Other procedures are available for partitioning inspection and control costs more efficiently, but they are not appropriate for use with the limited data available.

Direct accident losses were derived for the example with the aid of *table 3*. The average direct loss per accident was $2,141. Cleanup costs for each failure were assumed to be one-quarter of sample control costs, or an average of $44.49 per failure.

The direct and contingent losses plus cleanup costs are expressed as

$$p = \left[f_d + f_{nd}\right] \left[\text{average cleanup cost} + \text{average contingent loss per failure}\right] + \left[(f_d)\left(\frac{h'_d}{f'_d}\right) + h_{nd}\right] \left[\text{average accident loss}\right].$$

In this equation h'_d/f'_d is the average ratio of defective accident-failures to defective failures, which is 8/32.5 for the example. The total loss, p, as a function of uncontrolled defective failures, u, is drawn for three levels of contingent loss per failure: $0; $5,000; and $10,000 *(fig. 6)*. The point at which the cost and loss curves intersect is designated as the optimum level of operation for a given level of contingent loss per failure. The control level and cost for the optimum level of operation may be read from the x and y axes.

The contingent loss is, in effect, the additional loss per failure (undefined as to source) that would justify inspection and control operations at a given level. A reasonable "optimum" level of control may require a rather high value for contingent losses.

Contingent losses, distributed among such factors as site damage and loss of public confidence, are exceedingly difficult to evaluate at present. Until such evaluations can be made, it would be more appropriate to assign a value that results in optimization at a chosen level of control. It is, however, desirable to be aware of the implied losses which justify the accepted goal.

Assignment of no contingent losses to failures would result in costs balancing losses at 276 total failures (one-quarter of the potential failures) or 75.5 accidents per year.[5] A contingent loss value of $6,662 results in a balance at the current level of control (average 58.5 total failures) at a control cost of $436,900. The defective or "preventable" accident-failures at this level are only 13 percent of the expected defective accident-failures with 276 failures. A $5,000 contingent loss value suggests a level of 66 total failures, whereas a $10,000 value suggests a level of 49 total failures for the example *(fig. 6)*. Total costs are indicated on the y-axis.

Defective failures may be interpreted in terms of expected or allowable accidents for this example as follows:

$$h_{max} = \left[\frac{8}{32.5} f_d\right] + 14.$$

Thus, expected accidents per year are 75.5, 22, 24, and 20, respectively, for defective failure rates of 250, 32.5, 40, and 23. With cost optimization, the optimum level of control would define the goal. The administrative safety standard, however, should still be used for establishing the field hazard control level.

Unfortunately, the preceding figures cannot be accepted as accurate, since the point of cost optimization is influenced by the shape of the cost curve (especially the effect of inspection costs). The relationship $y = kx/(1\text{-}x)$ was used to approximate an inspection-cost curve, but no data are available to confirm such a relationship. If the actual relationship were better approximated by $y = kx/(1\text{-}x)^2$, the optimal costs as indicated by the point of intersection would be lower with even fewer failures. Unless reliable cost figures for the individual administration are available, it will be more productive to select a goal using procedures outlined earlier in this paper.

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[5]Figures include a constant 14 nondefective accident-failures per year. Control costs and total failures include a constant 26 nondefective failures per year.

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Paine, Lee A.
1973. **Administrative goals and safety standards for hazard control on forested recreation sites.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 13 p., illus. (USDA Forest Serv. Res. Paper PSW-88)

For efficient control of tree hazard on recreation sites, a specific administrative goal must be selected. A safety standard designed to achieve the selected goal and a uniform hazard-rating procedure will then promote a consistent level of safety at an acceptable cost. Safety standards can be established with the aid of data for past years, and dollar evaluations are feasible. Cost optimization is possible but impractical with available data. The legal risk in adoption of safety standards is considered acceptable.

Oxford: 907.2: 416: 304(083.7): 624.4.
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REST SERVICE
.DEPARTMENT OF AGRICULTURE
. BOX 245, BERKELEY, CALIFORNIA 94701

Cutting a Young-Growth, Mixed-Conifer Stand to California Forest Practice Act Standards

Philip M. McDonald

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Cutting by the minimum standard of the Rules of California's North Sierra Pine Forest District was evaluated for effects on species composition, seed fall, regeneration, and residual growth at the Challenge Experimental Forest, central California. Cutting removed 74 percent of the stand basal area and 94 percent of the merchantable volume. The heavy cut changed the species composition from primarily ponderosa pine to hardwoods and tolerant conifers. Sound seed was deficient in quantity, although trees in the cut blocks produced more seed than did trees in the control. Regeneration of ponderosa pine was less than that of hardwoods and tolerant conifers. Basal area growth was greater in the cut blocks for all species and diameter classes. About half of this growth in both cut and control was lost in tree mortality. After 5 years, the cut blocks were understocked with mostly slow-growing, currently less valuable species. The minimum standard cutting did not utilize the full potential of the site.

Oxford: 187X426: 221.0: 228.12(794): 174.7 *Pinus ponderosa.*
Retrieval Terms: Pacific ponderosa pine type; cutting method; regeneration; species composition; basal area; seed production.

CONTENTS

Figure 1—This 90-year-old mixed-conifer stand is typical of the Challenge Experimental Forest, Yuba County, California, as it appeared in 1958.

most common hardwood is California black oak *(Quercus kelloggii* Newb.*)*, with tanoak *(Lithocarpus densiflorus* (Hook. & Arn.) Rehd.*)*, and Pacific madrone *(Arbutus menziesii* Pursh*)* about equal in abundance.

Early research objectives at the Experimental Forest were keyed to evaluating various cutting methods in terms of species composition, regeneration, and growth of residual trees. This research also encouraged investigation of a basic concern of silviculture—vegetative succession, not just into the overstory, but into each stand strata.

Logging and Layout of Blocks

In the summer of 1958, three 6-acre rectangular compartments were cut to the minimum standard set by the North Sierra Pine Forest District. This minimum permitted the removal of all merchantable timber at least 20 inches in diameter at breast height (d.b.h.) with no other restrictions.

Each compartment was on relatively level ground (slopes 10 percent or less), supported a stand of conifers and hardwoods which contained nearly 260 square feet of basal area per acre, and was on a generally east-facing exposure *(fig. 2)*. Stand volume of trees larger than 12 inches in diameter averaged slightly over 47,000 board feet per acre (Scribner rule). The logging "chance" consisted of gentle slopes, no rock, and little down timber, but a great many stems.

Flexibility was the rule in logging, and landings were quickly and cheaply constructed on the edge of the compartments at convenient locations. Timber fallers were instructed to cut all conifers above the 20-inch limit in the fastest, most economical way. Skidding was at the discretion of the operators, who used 113-drawbar horsepower, bulldozer-equipped tractors. Loading was also done with a large tractor equipped with hydraulic forks. Large-sized tractors were necessary because the logger was primarily harvesting old-growth timber on land other than the Experimental Forest and had to fit his equipment to the larger trees.

Additional treatments, not specified in the District Rules, were performed to reduce the understory and enhance regeneration of conifers. Combined slash disposal and site preparation was accomplished on about 25 percent of each compartment. Here most of the slash and some of the understory was machine-piled for burning, although advance reproduction and pole-size trees were left wherever possible. Also, cull trees were removed throughout each compartment. These treatments removed many stems—mostly small ones—which represented a relatively small basal area.

Within each compartment, a 4-acre rectangular block was defined, and within each block every tree larger than 3.5 inches d.b.h. was numbered to facilitate remeasurement. Trees were measured before logging in 1958, after logging in 1959, and after five full growing seasons (1963). Tree mortality was recorded annually.

An adjacent compartment of similar size with similar terrain and stand structure was given a light improvement cut in 1958, when about 20 percent of the volume in trees over 12 inches d.b.h. was removed. Site preparation (as described above) was accomplished on about 15 percent of the compartment. This compartment thus seemed well suited as a yardstick against which results on the test blocks could be measured. It also was subdivided into a 4-acre block where all trees larger than 3.5 inches d.b.h. were numbered and recorded.

Figure 2—Before logging, the test cut block contained about 30 merchantable-size trees per acre, 60 percent of which were ponderosa pine. After logging, ponderosa pine was a minor species component in the much more open stand.

RESULTS

In the evaluation of results after 5 years, the comparison between cut and control blocks was emphasized. Changes in stand structure and species composition were evident, and the effects of the cut on productivity were indicated by seed fall estimates, the observed amount of regeneration, and the measured growth of the residual stand.

Stand Structure and Species Composition

Stand tables, by species and 4-inch diameter classes, were prepared for each block in 1958 and 1963. Statistical analyses showed no significant differences in blocks with reference to species or diameter classes for either year (5 percent probability level). This lack of difference among blocks is remarkable because the total sample was large—3,310 trees before logging and 1,235 trees 5 years later. Because differences among blocks continued to be small in 1963, mortality from logging and natural causes was similar in all blocks. Therefore, a composite stand table for both 1958 and 1963 is presented *(table 1).*

After the light cut and slash disposal, the control block contained almost the same number of trees (252 per acre) as the average test cut block before logging (276 trees per acre). A statistical comparison of the control block after the improvement cut and the test cut blocks before logging (based on all species and the same diameter classes noted in *table 1*) showed no significant differences between cut blocks and control (5 percent probability level).

After logging, however, major differences existed between the cut blocks and the control. For example, in the 3.5- to 20-inch diameter range, the control contained twice as many ponderosa pines and incense-cedars as the average cut block, and five times as many hardwoods.

The reduction of trees in the cut blocks was accounted for as follows:

	Trees lost, per acre
Cutting	30
Site preparation-slash disposal—cull removal	134
Natural mortality (1958-1963)	9
Total	173

The change in stand volume and basal area represented by this reduction in numbers indicates the severity of this cutting method. Stand basal area was reduced 74 percent to 67 square feet per acre. Better than half the reduction occurred in the merchantable tree category (above 20 inches d.b.h.). Volume decreased by 94 percent or 44,000 board feet per acre. All of that which remained (3,000 bd. ft. per acre)

Table 1—*Stand table for test cut blocks before logging and 5 years later,*[1] *Challenge Experimental Forest, California*

Species	Trees per acre, by diameter classes (inches) . . .					
	3.5 to 8	8.1 to 12	12.1 to 16	16.1 to 20	20.1+	All Classes
Conifers:						
Ponderosa pine	4 (1)	5 (2)	6 (3)	6 (3)	18 (1)	39 (10)
Sugar pine	2 (1)	1 (1)	1 (1)	1 (1)	4 (0)	9 (4)
Douglas-fir	30 (10)	14 (10)	9 (8)	4 (4)	5 (1)	62 (33)
White fir	6 (1)	3 (1)	2 (1)	1 (1)	2 (0)	14 (4)
Incense-cedar	62 (16)	17 (7)	3 (2)	1 (1)	1 (0)	84 (26)
Total	104 (29)	40 (21)	21 (15)	13 (10)	30 (2)	208 (77)
Hardwoods:						
Tanoak	7 (2)	2 (2)	1 (0)	0 (0)	0 (0)	10 (4)
California black oak	20 (5)	4 (2)	4 (2)	2 (2)	3 (2)	33 (13)
Pacific madrone	17 (4)	7 (4)	1 (1)	0 (0)	0 (0)	25 (9)
Total	44 (11)	13 (8)	6 (3)	2 (2)	3 (2)	68 (26)
Total	148 (40)	53 (29)	27 (18)	15 (12)	33 (4)	276 (103)

[1]Data for 5 years later shown in parentheses. These data include ingrowth into each diameter class.

was submerchantable (12 to 20 inches d.b.h.).

Changes in the species composition of submerchantable and understory (3.5-12 inches d.b.h.) trees were minor during the 5-year period *(table 2)*. The largest increase occurred in Douglas-fir, which gained in both these stand strata. Ponderosa pine decreased markedly in the submerchantable stratum, mostly because of windsnap and insects.

Natural mortality was evaluated by losses in the submerchantable and understory size classes. These were few in number, but had an important effect on species distribution. In the submerchantable class, three trees per acre died, two of which were ponderosa pine. The other was white fir. In the understory class, two Douglas-firs and one each of ponderosa pine, white fir, incense-cedar and hardwood perished. In both classes, windsnap was the most injurious agent. Insects, chiefly the western pine beetle *(Dendroctonus brevicomis* Lec.*)* in ponderosa pine, and the Douglas-fir engraver *(Scolytus unispinosus* Lec.*)* in Douglas-fir, ranked next, with unknown causes far behind.

Natural mortality in the control was remarkably similar to that in the test cut blocks. The same number of trees per acre were affected and the major cause of death to individual species was identical except in ponderosa pine, where insects caused greater losses than windsnap. Losses by individual species were similar except for California black oak, which incurred greater losses in the control. Suppression was the cause.

Trees smaller than 3.5 inches d.b.h. were not tallied specifically, but new trees which grew into this diameter class, or ingrowth, were recorded. Douglas-fir was the most abundant ingrowth species, constituting 32 percent of the new trees. Next were the hardwoods (29 percent), followed by incense-cedar (27 percent), white fir (9 percent), sugar pine (2 percent), and ponderosa pine (1 percent). Altogether ingrowth in the cut blocks averaged eight trees per acre over the 5-year period.

In the control block, ingrowth averaged 16 trees per acre and was of the same species as in the cut blocks. The ranking of species also was similar.

The primary effect of this cut on stand structure and species composition was to eliminate completely the ponderosa pine overstory. A secondary effect was to reduce greatly the number of smaller trees in the lower stand strata while not appreciably changing the species composition. A combined effect was release of these trees and freeing them for better growth.

In the control area, ponderosa pine remained the dominant species. Overstory and understory stood essentially intact. There was little release or lessening of shade, and most trees remained cramped for growing space.

Table 2 *Species composition in lower stand strata of test cut blocks before logging and 5 years later, Challenge Experimental Forest, California*

Species	Percent before logging	Percent after 5 years	Percent change
Understory: 3.5-12 inches d.b.h.			
Ponderosa pine	4	4	0
Sugar pine and white fir	6	5	-1
Douglas-fir	22	30	+8
Incense-cedar	39	33	-6
California black oak	12	11	-1
Tanoak and Pacific madrone	17	17	0
Submerchantable: 12.1-20 inches d.b.h.			
Ponderosa pine	29	21	-8
Sugar pine and white fir	12	12	0
Douglas-fir	29	38	+9
Incense-cedar	12	11	-1
California black oak	12	10	-2
Tanoak and Pacific madrone	6	8	+2

Seed Fall

By allowing the removal of all trees over 20 inches d.b.h., the Forest Practice Rules of the North Sierra Pine Forest District do little to promote natural seed fall. Small ponderosa pines do not produce many cones (Fowells and Schubert 1956, Sundahl 1971). Undoubtedly production is related to the size of the crown, its vigor, and state of development. For example, Fowells and Schubert (1956) found that ponderosa pines and white firs in the intermediate and suppressed crown classes produced almost no cones.

If a tree is injured during logging, as many were in this test cut, its growth rate is affected adversely. Development of the crown and, ultimately, seed production are delayed. Thus, when the overstory is removed, the remaining trees are likely to be erratic seed producers. Some trees produce a surprising quantity of cones, others produce nothing. Timing of cone production is a major concern. Predicting when cones will be produced and in what quantity is nearly impossible.

Figure 3—Cutting in a stand may stimulate remaining trees. This 90-year-old, 18-inch diameter ponderosa pine with a deformed top (old break) had no old cones or cone remnants beneath it before logging in 1958. In 1960, it produced 43 cones and in 1962, 11 cones.

The high moisture and fertility levels of high sites should speed up the cone-producing process, however. Fowells and Schubert (1956) reported data for site indexes 72 and 130 for ponderosa pine and showed that maximum seed production was nearly 30 percent greater on the higher site. After the heavy test cut, even more moisture and nutrients, and increased light, became available to stimulate the remaining trees. Consequently, seed had a good chance of being produced quickly, given the high site and young trees, and this could be important in evaluation of the cut.

Seed fall data were gathered annually for the first 5 years after cutting (1958-1962). Both cone counts and seed traps were used to quantify seed fall. Seed production for all conifers at the Experimental Forest failed completely in 1958 and 1959. In 1960, ponderosa pine generated a bumper seed crop, its only productive year during the study period. Douglas-fir produced cones in 1960, 1961, and 1962. In 1962, white fir yielded some cones and incense-cedar bore a bumper seed crop. Sugar pine produced few cones during the study.

Cone Counts

All cones produced in the study blocks were counted by using tripod-mounted 6 X 30 binoculars. The number of cones observed was increased by a factor of 1.5 for ponderosa pine and white fir (Fowells and Schubert 1956) and by 1.6 for Douglas-fir. Cones of Douglas-fir are difficult to count because they are small, clustered, and often blend with the surrounding foliage. Counting is easiest during the short ripening period when they are yellowish, a fact that led to use of the factor 1.6 instead of 2 as used by Garman (1951).

The 1960 seed year was one of the most productive on record for ponderosa pine throughout northern and central California. More than 100,000 sound ponderosa pine seed per acre were produced by uncut stands at the Experimental Forest that year. In the cut blocks, the ponderosa pine population in 1960 was 112 trees. Of these, 59 produced 1 to 353 cones per tree. Of the cone-producing trees, 14 percent were less than 12 inches in diameter. These small trees produced only 2 percent of the cones.

For comparability, cones of each species in the control were counted only on trees 20 inches d.b.h. and smaller. Although the number of ponderosa pine cone-bearing trees greater than 12 inches in diameter in the control was proportional to those in the average cut block, cone production in the cut was 2-1/2 times that of similar-sized trees in the control. The number of cone-bearing trees less than 12 inches in the control was proportionally fewer than in the cut block, although the yield per tree was about equal. For both size groups combined, the number of cones per producing tree was 39 for the cut and 11 for the control *(fig. 3)*.

In the northern hemisphere, a 3-year interval is required from the time the male and female strobili are initiated until the time that seeds mature (Stanley 1957, p. 583). In this study, new strobili were formed in 1958—before logging. Cutting, then, could not have caused the large numbers of strobili, which eventually led to the bumper seed crop in 1960. The stimulation that did occur probably resulted from the enhanced development and survival of the strobili already present. The release-induced factors of additional light, soil moisture, and nutrients during the cone development period contributed to the stimulation.

No cones were found in the cut blocks in 1961 or 1962. Not only could cutting have stimulated primordial initiation in 1959 and 1960, but also the trees had had sufficient time to develop and respond to their new, more favorable environment. But since no cones developed, the effects of stimulation obviously were short lived.

Douglas-fir cone crops at the Experimental Forest seem to be characterized by frequency rather than size—trees produce light to medium crops biennially. This species also produces cones on trees younger and smaller than cone-producing trees of other species.

Table 3–*Douglas-fir cone production in the test cut blocks for three successive years, Challenge Experimental Forest, California*

Diameter class (inches)	Total trees possible	Total cone-bearing trees	Total cones	Cones per tree
1960				
Under 12	272	32	2,318	72
12 - 20	122	68	22,896	337
Total	394	100	25,214	252
1961				
Under 12	272	5	12	4
12 - 20	122	29	470	26
Total	394	34	482	23
1962				
Under 12	272	34	728	21
12 - 20	[1]122	61	10,227	168
Total	394	95	10,955	115

[1]Several cone-bearing trees died from storm damage in 1962, but after the cone counts were completed.

The 1960 and 1962 Douglas-fir cone crops were similar: (a) about 25 percent of the trees produced cones *(table 3)*; (b) the number of cones per tree varied widely—ranging from 1 to 1,145; (c) diameters of cone-producing trees ranged from 5 to 19 inches d.b.h., with a mean diameter of 13 inches; and (d) most of the cone-producing trees were larger than 12 inches d.b.h. and these yielded most of the cones. The two crops differed mainly in the number of cones per producing tree; the average in 1960 was over twice that of 1962. The 1961 cone crop occurred on larger trees which averaged over 14 inches in diameter at breast height.

Frequency of cone production varied considerably. Some Douglas-firs produced cones for 3 consecutive years (1960, 1961, 1962). Others produced during 2 consecutive years (1960 and 1961 or 1961 and 1962). Most trees yielded cones only once during the study, however. The number of trees bearing cones consecutively for either 2 or 3 years was similar, but four times as many trees produced cones in alternate years (in 1960 and again in 1962).

A difference in Douglas-fir cone production was evident between the average cut block and control, although the number of Douglas-fir trees and their distribution above and below 12 inches were nearly equal. While many trees less than 12 inches in diameter yielded cones in the cut blocks, not one tree in this diameter class produced a single cone in the control for any of the 5 years studied. The number of cone-producing trees 12 inches d.b.h. or greater in the average cut block increased over the control, from the same number in 1960 to three times as many in 1961, and seven times as many in 1962. Total cone production in these trees exceeded that of the control (by a 2:1 ratio) only in 1960, however. In 1961 control trees outproduced trees in the cut blocks by 9:1 and in 1962 by 2:1.

The heavy cut apparently stimulated more small trees to produce cones than usual. The quantity of cones produced, however, could not be linked to any stimulation from cutting. Apparently such factors as weather conditions during flowering and the early formative period (Roeser 1942), and the number of primordia which develop (Owens 1969), quickly surmount any effect of cutting.

About 11 percent of the white fir population in the cut blocks produced cones in 1960. All producing trees were greater than 12 inches d.b.h. Cones averaged about 90 per tree and ranged from 8 to 188. No cones were produced in the control.

Dissection of Douglas-fir cones showed about 50 developed seeds in each. Ponderosa pine cones hold about 70 developed seeds per cone and white fir about 185 (Fowells and Schubert 1956). For the principal seed crops, production was much higher in the cut blocks than in the control *(table 4).*

Seed Traps

Eighteen seed traps, 1 foot square, were systematically arranged (random start) in each block. They produced a statistically reliable sample 19 times out of 20 (Freese 1967) for the principal seed crops of the study period. The traps were emptied annually in winter and cleaned and checked in late summer. No comparison with the control was possible because of inability to differentiate between seed from the control's overstory and trees 3.5 to 20 inches d.b.h.–the size range necessary for comparison to the cut.

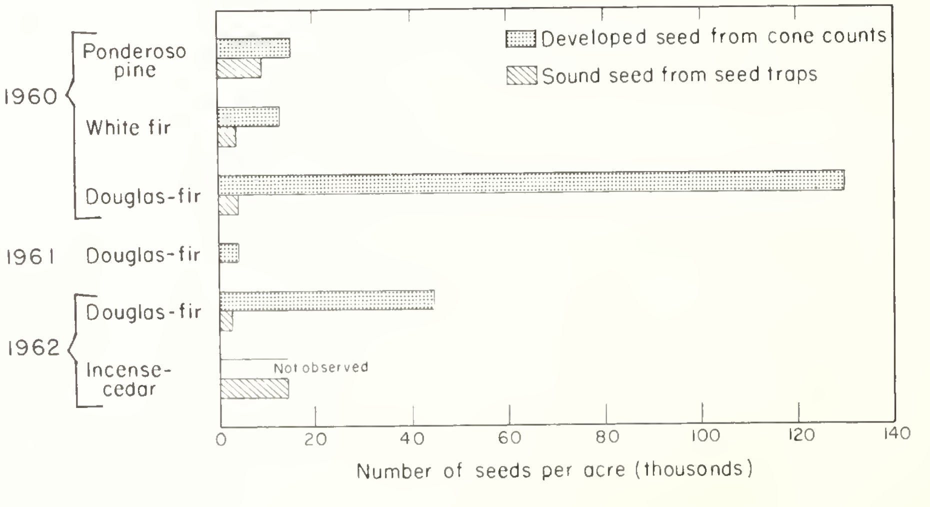
Estimates of seed production from traps were lower than those from cone counts *(fig. 4).* Fowells and Schubert (1956) use the term "developed" for seed from their ponderosa pine and white fir cone counts. I also used it for seed from the Douglas-fir cone count. Sound seed, as determined by cutting test, usually is the gauge of production from seed traps. Because a seed can be fully developed externally, and not filled internally, sound seed is a better measure than developed seed for estimating reproductive potential.

Table 4–*Seed production estimates based on cone counts for principal seed crops in test cut blocks and control, 1958-1962, Challenge Experimental Forest, California*

Species	Year of seed crop	Developed seed per acre . . . Test	Control
Ponderosa pine	1960	15,488	6,720
White fir	1960	12,395	0
Douglas-fir	1960	130,667	16,650
Douglas-fir	1961	3,403	2,912
Douglas-fir	1962	45,063	4,888

Seed production estimates between cones and traps differed most for Douglas-fir. Lack of pollination and insect depredations were probable explanations. Allan (1942) found that Douglas-fir was capable of producing viable seed as early as 20 years. He also noted that in young trees, a high percentage of seed reached full size but was undeveloped internally due to lack of pollen. Roy (1960) found that larger trees also produce large amounts of fully developed, but empty, seed due to lack of fertilization. Insects, chiefly the cone moth larvae *(Barbara colfaxiana* (Kearf.)*)* and the gall midge *(Contarinia* spp.*),* either completely eat the developed seed or cause any remainder to adhere to the cone scales. These two influences illustrate likely sources of discrepancy between seed traps and cone counts for Douglas-fir,

Figure 4–Estimates of seed production derived from cone counts are markedly different from estimates of sound seed obtained from seed traps. These composite data are from test cut blocks.



and to a lesser extent for white fir (Keen 1958). Cone counts cannot measure the amount of "light" seed that blows out of the study area nor that destroyed by insects.

Here seed traps yield the best estimate of seed production. It totaled about 34,000 sound seed over the entire cut area during the study period. Such production is 5 to 10 times lower than seed fall for comparative time spans and areas from uncut stands nearby.

Regeneration

Fifty years ago, Dunning (1923) noted the inadequacy of pine regeneration and the prevalence of fir and incense-cedar following heavy cutting in old-growth timber. In 1951, Fowells and Schubert studied regeneration in central California from old-growth stands from which 40 to 90 percent of the merchantable timber had been removed. Even with five sugar and ponderosa pine seed trees per acre, including one over 30 inches in diameter, seedlings became established at the rate of only 70 per acre. Incense-cedar and white fir seedlings became so dense, however, that pines comprised only 5 percent of the reproduction after 20 years.

Because of this evidence and because it was quite probable that seed fall would be poor or erratic after the cut, techniques that might enhance seedling establishment seemed worthwhile. Thus as described earlier, a site preparation and slash disposal treatment above and beyond the Forest Practice Act requirements was applied. This meant that if regeneration were successful, conclusions on the adequacy of the cutting practice used would be overly favorable. But if regeneration were inadequate or unsuccessful, on this high site, then it would probably be unsuccessful elsewhere.

For sampling, 30 circular milacre subplots per cut block were established along three transects whose points of origin were randomly located. Every subplot was visited each spring and all seedlings, coniferous and hardwood, were recorded. At the first measurement in 1959 only those plants less than 4.5 feet tall rated as "seedlings ". Each hardwood clone was recorded as one plant even though the individual sprouts per clone often were numerous. All new seedlings were "tagged" to denote species and year of origin. Thus the survival of individual seedlings could be followed year by year. Mortality trends also were readily definable. New seedlings were 1 to 2 months old at the time of survey, hence most viable seeds had germinated, but seedling mortality had not yet begun.

Table 5—*Milacre stocking and number of seedlings per acre in 1963 from principal seed crops (composite cut blocks), Challenge Experimental Forest, California*

Species	Age of seedlings (months)		
	2	14	26
Percent stocked			
Tolerant conifers	44		37
Ponderosa pine	–	–	42
Hardwoods	14	28	39
Seedlings per acre			
Tolerant conifers	1,287	–	710
Ponderosa pine	–	–	1,022
Hardwoods	800	400	2,160

Thus seedling abundance was at or near maximum at each measurement.

Regeneration was evaluated by number of seedlings per acre and stocking percent (percentage of milacre plots having one or more seedlings). Results were evaluated for tolerant conifers (Douglas-fir, white fir, and incense-cedar), hardwoods, and ponderosa pine *(table 5)*.

The seed-to-seedling ratio often reflects many of the agents and conditions that affect germination and early seedling survival. In this cut, the ratio for ponderosa pine was 5:1—meaning that for every five sound seed that fell in the fall of 1960, one ponderosa pine seedling was tallied in the spring of 1961. The ratio was 8:1 if based on seed estimates from the cone count. In another study at the Challenge Experimental Forest where the seedbed was mostly bare mineral soil, and rodents were not controlled, 14 sound seeds produced one ponderosa pine seedling (McDonald 1966). Fowells and Schubert (1956) rated the seed-to-seedling ratio at 40:1 for ponderosa pine on seedbeds having a medium-to-heavy cover of vegetation, litter, or logging debris, and several hundred to one with no seedbed or rodent control measures. Therefore, in this cut a remarkable number of ponderosa pine seedlings were produced from the meager seed crop.

Seed-to-seedling ratios for the other seed crops were:

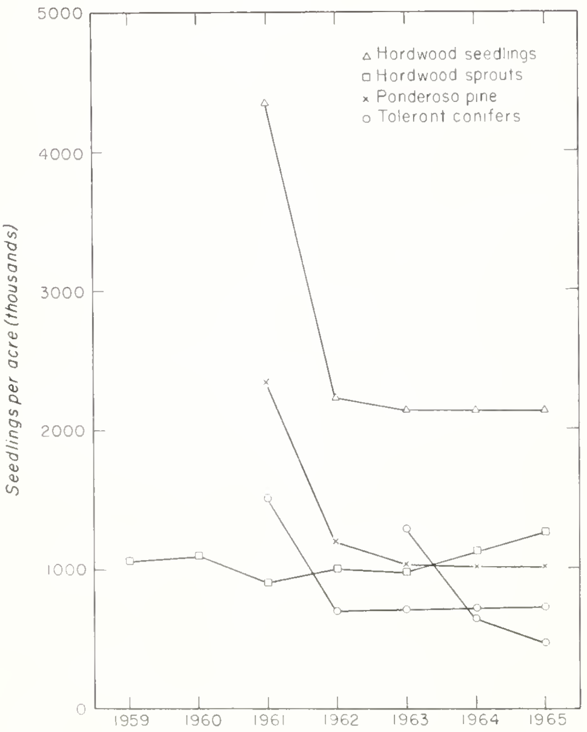
Douglas-fir	1960	8:1
Douglas-fir	1962	12:1
White fir	1960	6:1

A prime reason for the higher efficiency in 1960 was favorable weather. Precipitation during the critical months of February through May was 10.5 inches more than Challenge's 30-year average. February, March, and May all had above-normal precipitation. Temperatures were below normal for this period. Such weather favors seedling survival. Cold, wet weather also could have cut down activity of deer mice *(Peromyscus maniculatus)* and resultant seed losses—a factor vital to regeneration at Challenge.

Deer mice levels were probably near minimum in 1960 because no conifer seed had fallen for the 3 preceding years. McKeever (1961) suggested that deer mice populations often ebb and flow with conifer seed crops. Schmidt and Shearer (1971) found that deer mice populations are affected by the previous year's ponderosa pine and Douglas-fir seed crops. In addition, drought and lack of food reduces the number of sexually active mice (Christian 1956, Louch 1956, McKeever 1959), presumably lowering population levels, and 1959 and 1960 were drought years. For these reasons, similar high seed efficiency probably will be rare in other applications of this cut.

Seedbed conditions differentially affected germination and early seedling survival of the various species. Before logging, the seedbed consisted of a 3- to 4-inch layer of partially decomposed branches, needles, and leaves. The heavy cut disturbed this layer and created small patches of exposed mineral soil. Most of the seedbed, however, became a mixture of soil and organic material, in many cases covered with slash. Residual trees provided partial shade. Together, seedbed and shade formed a favorable regeneration medium for the tolerant conifers and hardwoods.

Figure 5—Seedling survival data (composite cut block) show a pattern of sharp decrease in the first year for the various species. Hardwood sprout survival was more consistent.



Tolerant conifer survival decreased sharply the first 14 months and remained constant thereafter *(fig. 5)*. Survival of the second wave of seedlings was lower than the first because vegetative competition increased.

Regeneration of California black oak, tanoak, and Pacific madrone is unique because it is usually a combination of sprouts, seedling-sprouts, and seedlings. Logging and slash disposal knocked down or severely damaged many small hardwood trees, saplings, and seedlings. These promptly sprouted. Other small seedlings died back to the root crown following logging because of shock from increased sunlight. Most of these became seedling-sprouts. The sprouts and seedling-sprouts numbered about 1,000 per acre *(fig. 5)*. Many gained vigor by sprouting which boosted height growth rates to 12 to 20 inches per year, with similar rates of crown expansion.

New waves of hardwood seedlings became established nearly every year. Tanoak and Pacific madrone are frequent and prolific seed producers.[2] If one species does not have a good crop, the other usually does. In addition, California black oak had a good seed crop in 1958. Thus, as for sprouts, new hardwood seedlings were consistently numerous.

The survival for new hardwoods often decreases rapidly because of poorly distributed seedlings *(fig. 5)*. Frequently 20 to 30 seedlings per milacre plot would spring forth only to be reduced by intense competition. In plots containing from 1 to 5 seedlings, almost no mortality occurred. Altogether, hardwood reproduction was much more numerous than conifer reproduction.

The postlogging seedbed was less favorable to ponderosa pine than to other species because of insufficient mineral soil. Several investigators (Curtis and Lynch 1957, Fowells and Stark 1965) have found that survival of ponderosa pine is poorest on seedbeds lacking exposed mineral soil, other conditions being equal. The high seedling mortality for ponderosa pine

[2]See Roy (1957) and unpublished data on file at Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, Redding, Calif.

(fig. 5) is probably related to this lack. Seedbeds high in organic material often have high surface temperatures deleterious to tender seedling stems. In addition, the mixed-in organic material from the cut impeded the downward-thrusting roots of seedlings, causing them to fall behind the retreating soil moisture front. Consequently, numerous dead seedlings bearing the telltale evidence of drought were often observed during the annual regeneration surveys in the cut blocks. Drought could have been intensified by severe moisture depletion from the well-established hardwood clonal root systems.

Survival is only half the regeneration story; the other half is seedling height growth. On high sites, ponderosa pine can survive in dense shade for a few years *(fig. 6)*. But since the hardwood growth rate is accelerating relative to that of the pine, many overtopped pines will soon die.

Figure 6—This 14-inch-tall ponderosa pine seedling growing beneath a 7-foot-tall California black oak clone (August 1965) has little chance of survival.

Growth of Residual Stand

Because regeneration is left to chance whenever a stand is cut to the minimum standard of the Forest Practice Rules in the North Sierra Pine District, the trees which remain often furnish the chief hope for a future crop. In dense young-growth stands, some of these trees are battered, barked, or broken. Some lack tops, others limbs. Most recover, however, and together with undamaged trees, form the new stand. Stand recovery often is enhanced by a heavy cut and the increased availability of water, nutrients, sunlight, and growing space. In turn, tree growth rates also benefit.

As previously noted, the growth sample consisted of every tree that remained after logging. This amounted to an understocked stand of 103 trees per acre. Of these, 34 per acre were larger than 12 inches d.b.h.; if they were evenly distributed, the spacing interval would be about 35 feet. The 69 smaller trees per acre remaining give a calculated spacing of about 25 by 25 feet. Tree distribution however, was somewhat clumpy—a condition typical of stands having large species diversity. Thus "growing room" was less than ideal for some trees, but on this high site should have been adequate for most. Growth then, was a function of high site and reasonably good spacing, plus the trees' ability to respond to sudden release and various degrees of logging damage *(fig. 7)*.

Five years was selected as the interval necessary to record delayed mortality from logging and also to quantify the growth surge brought about by cutting and release. Growth increment (accretion) during the 5-year period included the basal area growth added to all living trees greater than 3.5 inches d.b.h. and the growth added to trees which died during the measurement period.

Basal area growth per acre was generally proportional to the abundance of each species as shown in *table 1*. Douglas-fir contributed most to total accretion, showing twice the growth of ponderosa pine, the next largest contributor. Incense-cedar, which ranked second in abundance, was fourth in growth. Of the hardwoods, California black oak was only slightly more abundant than Pacific madrone but contributed twice its growth. Tanoak contributed less than any other conifer or hardwood.

Basal area growth rates per tree for each cut block were tested statistically and combined when no significant differences were found. Ranking of growth rates over all diameter classes showed sugar pine and white fir highest, followed by ponderosa pine and

Figure 7—After logging, patches of regeneration of shade-tolerant conifers are evident with scattered poles and some hardwoods. Some firs had broken tops.

Table 6—*Comparative growth rates in cut blocks (composite data) and control, by species and diameter class, 1959-1963,*[1] *Challenge Experimental Forest, California*

Species	Diameter class (inches) . . .				
	3.5 to 8	8.1 to 12	12.1 to 16	16.1 to 20	20.1+
	Square feet per tree				
Conifers:					
Ponderosa pine	0.03 (0.01)	0.08 (0.02)	0.18 (0.07)	0.29 (0.17)	– (0.30)
Sugar pine	.06 –	.11 –	.27 –	.32 –	– (.92)
Douglas-fir	.05 (.03)	.10 (.08)	.17 (.16)	.25 (.26)	– (.47)
White fir	.07 (.03)	.11 (.12)	.21 –	.33 –	– (.42)
Incense-cedar	.02 (.01)	.10 (.04)	.14 (.06)	.22 (.12)	– –
Total	.04 (.02)	.10 (.06)	.18 (.11)	.28 (.18)	– (.32)
Hardwoods:					
Tanoak	.05 (.03)	.08 (.07)	– (.07)	– (.11)	– –
California black oak	.04 (.02)	.06 (.04)	.17 (.09)	.23 (.08)	– (.10)
Pacific madrone	.05 (.02)	.08 (.06)	.08 (.05)	– (.05)	– –
Total	.04 (.02)	.08 (.06)	.14 (.07)	.23 (.08)	– (.10)
Total	.04 (.02)	.09 (.06)	.17 (.09)	.26 (.16)	– (.31)

[1] Data for 5 years later shown in parentheses. These data include ingrowth into each diameter class.

Douglas-fir, with the hardwoods and incense-cedar slowest *(table 6).* Ranking of growth rates over all diameter classes in the control showed Douglas-fir best, followed by ponderosa pine, incense-cedar, and hardwoods, with sugar pine and white fir too few to be tested.

Differences in growth rates between cut and control blocks were highly significant, with ponderosa pine, incense-cedar, and California black oak outgrowing their counterparts in the control. It is notable that Douglas-fir grew at about the same rate in both cut and control and thus was relatively insensitive to release—at least during the study period.

In the cut block, accretion amounted to 10.29 square feet of basal area per acre. In the control, it was 10.43 square feet per acre on trees 3.5 to 20 inches d.b.h. Obviously the growth rate of trees in the cut blocks was much faster than that of trees in the control since the control contained over twice as many trees (103 vs. 220 per acre). Accretion on merchantable trees in the control was an additional 7.32 square feet per acre.

Natural mortality is important in the evaluation of growth with respect to cutting practice. Trees that die after logging are seldom salvaged, and the entire basal area of each tree is thus lost. New increment accruing between the time of initial measurement and the death of the tree also is lost.

In the cut, 5.56 square feet of basal area per acre were lost, against 5.76 square feet in the control. Accretion lost amounted to about 0.1 square foot per acre during the 1958-63 period.

When a tree becomes ingrowth, its initial basal area plus any increment incurred from the time of entry to the end of the measurement period is recorded. Accretion on ingrowth was nearly twice as much in the control as in the cut blocks (1.35 sq. ft. per acre vs. 0.78 sq. ft.), which is logical since there were twice as many ingrowth trees in the control.

Net growth for all species, consisting of ingrowth plus accretion minus mortality, is shown here in square feet per acre for the 5-year period:

	Cut	*Control*
Net growth:		
Accretion	+10.29	+17.75
Accretion on trees that died	+ .10	+ .09
Ingrowth	+ .78	+ 1.35
Mortality	- 5.56	- 5.76
Accretion on trees that died	- .10	- .09
Net	5.51	13.34

Thus, although similar basal area losses occurred in both cut and control, the loss constitutes a far larger proportion in the cut. Furthermore, the cut is less productive than the control by a factor of nearly 2.5.

CONCLUSIONS

As a consequence of following the minimum cutting standard of the North Sierra Pine Forest District, a major change in species composition has taken place. Before logging, ponderosa pine made up 63 percent of the overstory. After logging, ponderosa pine trees exceeding 8 inches in diameter comprised only 14 percent. In contrast, Douglas-fir increased from 16 to 37 percent of the overstory, hardwoods from 0 to 24 percent, and incense-cedar from 3 to 16 percent. The new stand is decidedly different from the old.

Trees in the 3.5- to 8-inch diameter class are in a better position for growth. Before cutting, most were badly suppressed; now many are in codominant and intermediate positions in the stand. The species composition of this diameter class is overbalanced toward the most tolerant species. Incense-cedar is most abundant, followed by hardwoods and Douglas-fir, with only a trace of ponderosa pine, sugar pine, and white fir. The preponderance of the tolerant species further emphasizes the shift away from ponderosa pine. They and the tolerant ingrowth indicate a trend in vegetative succession which, barring catastrophic events, will persevere for years.

Analysis of seed fall in the cut blocks reinforced this trend. Incense-cedar produced 43 percent of the sound seed that fell during the study period. Douglas-fir yielded 21 percent and white fir 10 percent, giving the tolerant species 74 percent of the total coniferous seed fall. Ponderosa pine contributed 26 percent of seed production. In general, seed fall was deficient.

Seed fall could have been stimulated on this high site by the increased availability of soil moisture, nutrients, and light following the heavy cut. Indeed, compared to the control, some stimulation did take place. The general result, however, was that more small trees produced a few cones, as in Douglas-fir, or that a brief increase in cone production was followed by lessened production, as in ponderosa pine. For all species the effect of stimulation was short lived. Its importance was further reduced when cone count results were compared to seed trap data. Large discrepancies between methods indicated major insect damage to Douglas-fir and white fir seed as well as possible lack of pollination or fertilization.

The seed that was produced came at an opportune time when the seedbed was still relatively free of compaction and competitive vegetation. Thus regeneration was better than expected from the small seed crop. Seed-to-seedling ratios for all species ranged from 5:1 for ponderosa pine to 15:1 for incense-cedar. All indicate exceptional seed efficiency—so good, in fact, as to probably be unattainable in other applications of this cutting method, under less favorable weather conditions.

Seedling survival was recorded for 50 months. At the end of this time the hardwoods numbered 3,400 per acre, tolerant conifers 1,180, and ponderosa pines about 1,000 per acre. Subsequent regeneration of ponderosa pine is unlikely because of paucity of seed and because most available mineral soil is now clothed with vegetation. Should existing ponderosa pine seedlings succumb, they have little chance of being replaced. But with time, tolerant conifer and hardwood seed crops will occur. Resultant seedlings will survive and grow because of their ability to become established on duff and litter, among other vegetation, and in shade.

The evaluation of growth and mortality, although covering only the first 5 years after cutting, pointed out the short-term effects of the cut. Except for Douglas-fir, every species in nearly every diameter class responded to the cut, and in terms of basal area growth, outgrew its counterpart in the control. White fir and sugar pine grew best. In general, in spite of some barking and other logging damage, growth rates were near maximum because of understocking and wide spacing. The hardwoods also responded to cutting. For example, California black oak was growing very slowly in the control and some trees were dying of suppression; in the cut scarcely any trees of this species died and many began growing quite well.

Natural mortality, particularly to ponderosa pine, reduced accretion by 54 percent and is considered a serious consequence of the cut. Windsnap was the major cause of mortality, followed by insects.

By 1965, revegetation of these compartments was nearly complete and the forest of the future could be predicted. Ponderosa pine regeneration will probably dominate only in openings 80 to 100 feet in diameter or larger. Elsewhere, the hardwoods and tolerant conifers either are dominant or eventually will be. Although changes in forb and herb communities on the forest floor will constantly take place, the species composition of the stand is set. Hardwoods or tolerant conifers or both rank first in species abundance, followed by ponderosa pine. This arrangement prevails in the overstory, the submerchantable stand, the understory, the ingrowth and the regeneration.

The very species now most abundant (incense-cedar, Douglas-fir, tanoak, and Pacific madrone) are the slowest growing. There are not enough trees, even of them. The stand is understocked owing to cutting, losses from natural causes, and questionable regeneration. A loss in productivity directly attributable to the cut is indicated. This loss seems contradictory to the intent of the Forest Practice Act of "conserving and maintaining the productivity of the State's privately owned timberlands."

The change in value represented by the change in species distribution is open to question. Currently the now-dominant species are generally less valuable than ponderosa pine. In a particular situation, the shift might be desirable, but in general it would be considered to decrease the value of the stand.

A general impression of the control is that of a dense stand having too many trees and a subdued growth rate. Several facts support this conclusion. First, although trees 20 inches in diameter and below were twice as numerous in the control, accretion was about equal in both. Second, California black oak is the species most susceptible to overcrowding and suppression. Much less mortality occurred for this species in the cut than in the control. Also, insects commonly attack the least thrifty trees. Insects caused nearly all the mortality in the control, particularly to ponderosa pine; windsnap caused the damage in the cut. Finally, the basal area growth rate of Douglas-fir was consistent in cut and control. Yet this species outgrew ponderosa pine in the control but only equaled it in the cut. Obviously ponderosa pine was underproducing in the control. Thus productivity of the control, even though 2-1/2 times that of the cut, was far below its full potential.

The control is in need of cutting. But cutting by a more sophisticated method employing sound silvicultural and ecological principles is needed. The seed-tree or group selection cutting methods are both applicable, the choice between them depending on the species of regeneration desired by the landowner.

Today, the demand for housing and other wood products strongly necessitates higher productivity and better forest management practices on small private lands. A cutting method which increases productivity, rather than decreases it, is needed in the North Sierra Pine Forest District. The small private landowners are the group most likely to apply the minimum District rules on their land—lands which are most in need of good forest management.

Dissatisfaction of the public and other organizations with existing Forest Practice Rules was reported by Arvola (1970). Such discontent recently culminated in adoption by three California counties of their own forest practice regulations, prompting Arvola to emphasize "... the urgent necessity of developing further improvements in the basic [Forest Practice] law ...." Results of the present study support that opinion.

SUMMARY

McDonald, Philip M.
1973. **Cutting a young-growth, mixed-conifer stand to California Forest Practice Act Standards.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif., 16 p., illus. (USDA Forest Serv. Res. Paper PSW-89)

Oxford: 187X426: 221.0: 228.12(794): 174.7 *Pinus ponderosa.*
Retrieval Terms: Pacific ponderosa pine type; cutting method; regeneration; species composition; basal area; seed production.

In 1958 a high-site mixed-conifer stand on the Challenge Experimental Forest, central California, was logged to the minimum standard of the Forest Practice Rules of the North Sierra Pine Forest District of California. Some site preparation, not called for specifically, was also done to improve chances for regeneration. The cutting was evaluated in terms of its effect on present and future stand structure. In addition each structural component was compared to that in a control block.

Cutting removed 74 percent of the stand basal area and 94 percent of the merchantable volume. The heavy cut changed the species composition from primarily ponderosa pine to hardwoods and tolerant conifers (Douglas-fir, white fir, and incense-cedar). Since the submerchantable stand, understory, and ingrowth became stocked with a higher proportion of shade-tolerant trees, this shift in species composition will be more pronounced in the future.

Natural mortality was highest for ponderosa pine in the submerchantable diameter class. Windsnap was the leading cause.

Seed fall was estimated both by cone counts and seed traps and was found deficient. The heavy cut briefly stimulated residual trees to produce more cones than comparable species and tree sizes in the control block. Much of the seed was unsound, however.

Most seed fell after logging when the mineral soil was relatively free of competing vegetation. This factor, plus near-optimal weather and lack of rodents, resulted in an exceptional amount of ponderosa pine regeneration from little seed. Nevertheless, regeneration of ponderosa pine was less than that of hardwoods and tolerant conifers. Consequently, the proportional amount of ponderosa pine in the future stand is expected to decrease.

Basal area growth of residual trees for a 5-year period exceeded that of the control block for nearly all conifer and hardwood species and diameter classes present. About half of the growth increment was lost through natural tree mortality, however, in both cut and control blocks. Cutting to the minimum standard of the Forest Practice Rules of the North Sierra Pine Forest District produced an understocked stand of slow-growing, currently less valuable species. The study indicates that this cutting practice did not utilize the full potential of the site.

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REST SERVICE
S.DEPARTMENT OF AGRICULTURE
O. BOX 245, BERKELEY, CALIFORNIA 94701

PACIFIC SOUTHWEST Forest and Range Experiment Station

DAMAGE from WIND and OTHER CAUSES in MIXED WHITE FIR-RED FIR stands adjacent to CLEARCUTTINGS

Donald T. Gordon

USDA FOREST SERVICE RESEARCH PAPER PSW-90 /1973

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1973. **Damage from wind and other causes in mixed white fir-red fir stands adjacent to clearcuttings.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 22 p., illus. (USDA Forest Serv. Res. Paper PSW-90)

Damage to timber surrounding clearcuttings and in one light selection cutting in mixed white fir-red fir stands was monitored for 6 years in northeastern California. In some years, bark beetles apparently killed more trees than did wind damage, but in two of the study years, severe wind storms caused much damage. One storm produced mainly breakage, apparently influenced by snow load. The other, a hurricane, produced mainly windthrow. Relation of damage to tree size, crown class, and relative location reveals some trends. Study of height of breaks suggests that a mechanical stress point is influenced by tree size and crown class and other factors. Snow was the third most prevalent cause of damage, but applied only to smaller trees. Some indications for management of fir stands can be found in study results.

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CONTENTS

The Author

DONALD T. GORDON is doing research on the silviculture of Sierra Nevada forest types, with headquarters at Redding, Calif. Native of Oxnard, Calif., he was educated at the University of California, Berkeley (B.S. in forestry, 1939), and joined the U.S. Forest Service in 1940. He became a member of the Station's research staff in 1946.

Severe or catastrophic wind damage to trees has been often reported in Europe and North America. Some investigators have related damage to specific storms, to harvest or cultural practices, or to general geographic areas. Others have related wind effects to topography, soil moisture content, depth of soil, and tree species (Sutton 1969). In general terms, those studies of wind damage concerned most closely with topographic influences and with harvest and cultural practices furnish the most useful background for forest management decisions (e.g., Alexander 1964, Gratkowski 1956, Neustein 1965, Ruth and Yoder 1953, U.S. Forest Service 1964). More detailed studies usually are required to satisfy needs for information on local species, wind patterns, and relevant silviculture.

In the late 1950's, the Pacific Southwest Forest and Range Experiment Station began a continuing research effort applicable to California's true fir stands. Investigation of natural regeneration was given high priority (Gordon 1970), but other studies were carried out to the extent that research funds permitted.

This paper reports a study of wind damage in stands of overmature white fir *(Abies concolor* [Gord. & Glend.] Lindl.*)* and red fir *(A. magnifica* A. Murr.*)* bordering clearcuttings. The data, only some of which relate to cutting patterns, were collected during a study 3 years old when severe wind damage first occurred, in the winter of 1961-62. The study area was struck again on October 12, 1962, by a hurricane—a rare event on the Pacific Coast north of Mexico.

Besides the usual gross kinds of information on volume, number of trees damaged, wind direction, and relative location of damage from wind, this paper contains new kinds of detail for the species, general location, and the broad subject of wind damage. Specific data are given on heights of breaks of trees by diameter class and crown class; proportion of diameter decayed at stem breaks; per-acre totals of stem length of windthrown or broken pieces on the ground (as a rough index of wildfire fuel hazard); and sizes of fire scars as related to breakage. These and other data provide land managers with information that may be useful for long-term planning for similar timber types.

Data influenced by cutting patterns are derived primarily from areas adjacent to clearcuttings. Additional studies on stand damage and mortality were started in 1971 within research cuttings in progress at Swain Mountain Experimental Forest, in northeastern California, and other coordinated studies are planned.

The effects of wind in or adjacent to cutting areas were of primary interest in this study. Additonal interest lay in other causes of damage or mortality in the same areas, as well as in uncut stands, and whether adjacent cutting patterns influenced them. To this end, we recorded all kinds of major damage found on study areas.

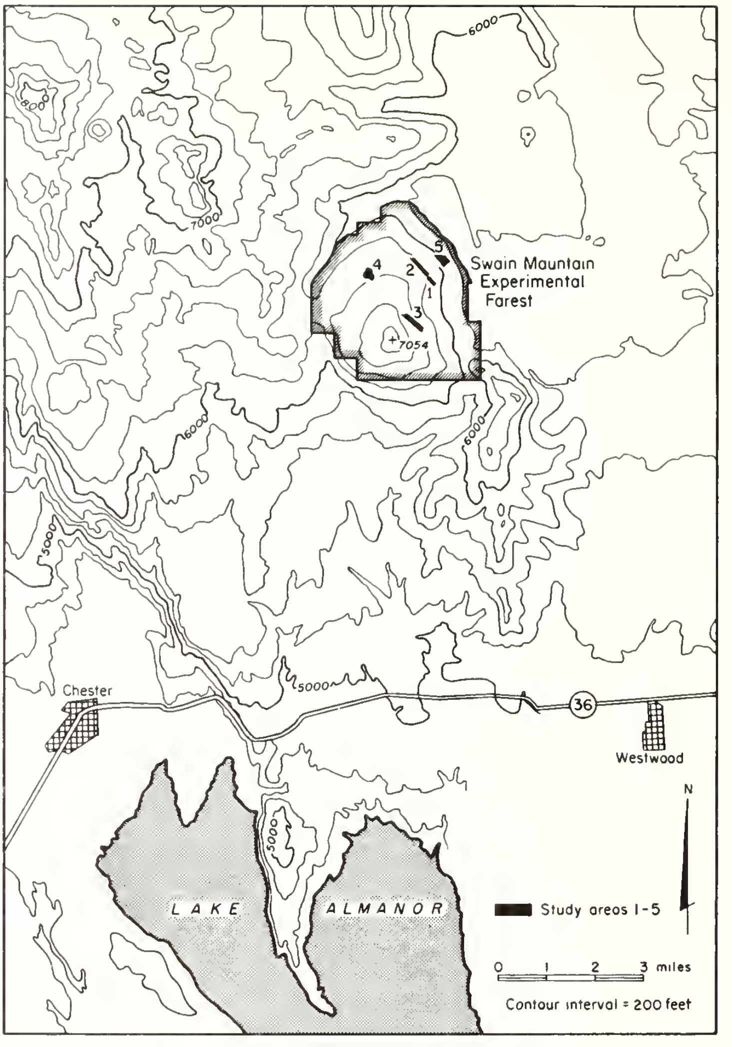
STUDY AREA

The Swain Mountain Experimental Forest is about 10 miles north of Lake Almanor. Swain Mountain is a volcanic cone, with slopes averaging between 10 and 15 percent. The summit's elevation is 7,054 feet; the lowest part of the experimental area is about 5,700 feet. Soil, derived from vesicular andesite, is 3 to 8 feet deep over most of the area.

Precipitation is mainly snow. Surveys during four winters recorded normal maximum snowpack depths of 8 to 10 feet; 40 to 50 inches of water equivalent have been recorded in typical years since 1957-58.

The five areas studied lie on the northeast quadrant of the mountain. Most strong storm winds here come from the southwest. Moving toward Swain Mountain, they traverse a general upward and uniform slope extending for about 10 miles from the north shore of Lake Almanor and the flat ground around Chester *(fig. 1)*. This smooth slope, and the saddles at the west and southeast sides of Swain Mountain, may allow storm winds of greater-than-average velocity for the general area to develop over the Experimental Forest. No good velocity data are

Figure 1—The topography of Swain Mountain Experimental Forest, in northeastern California, and the surrounding area partly determined the amount and kind of damage to trees.



available to document this conjecture, because the area is remote from any regularly manned weather station.

White and red fir dominate the area. Near the summit of the mountain, red fir is the exclusive species, but white fir becomes increasingly abundant on the lower slopes. Scattered Jeffrey and sugar pines *(Pinus jeffreyi* Grev. and Balf., and *P. lambertiana* Dougl.*)* are present. In a sale of 12 million board feet, white and red fir accounted for over 99 percent of the volume. Lodgepole pine *(P. contorta* Dougl.*)* grows in a narrow belt adjacent to Robbers Creek, which runs near the north and east boundaries of the Experimental Forest. Lodgepole pine also appears in relatively small patches in a few wet drainages within the Forest, and in other patches where its presence is probably related to past fires. Tolerant fir usually is present beneath the pine, or overtops it. Fir is definitely the climax vegetation here.

Differences in stand structure within mature and overmature cutting areas resulted in a variety of recorded gross volumes per acre, decreasing from 147,000 board feet (Scribner Scale). Dense overmature and mature stands have no understory. As density of the overmature overstory decreases through mortality, reproduction becomes established abundantly in the released growing space.

METHODS

General knowledge of mature fir stands indicated that wind damage to uncut trees could be anticipated either where clearcut openings were wide, or where partial cuttings left relatively few trees. Keeping clearcut strips narrow, to widths not exceeding twice the height of dominant trees in the upper canopy, was expected to minimize wind damage along lee cutting edges. As the height of dominants averaged 150 feet, 5-chain and 3-chain wide clearcut strips were early choices for logging dense stands.

Initially, the only planned selection cuttings were a sequence of trials in which light to heavier amounts of volume, or numbers of stems, were to be removed from dense old stands. The objective was to determine the approximate cutting level at which wind damage might become significantly different from that found adjacent to clearcuttings or in uncut stands. Only two degrees of light cutting were tried before our research funds were reduced.

Observations in this study were made in four areas surrounding clearcuts and within the one area that had been lightly cut. The clearcuts were:

1. One strip 3 chains wide by 20 chains long, clearcut through a dense overmature stand in 1958;
2. and 3. Two strips, 5 chains wide by 34 chains long, one clearcut in 1958, the other in 1959, through old stands of heavy to moderate density;
4. One irregularly-shaped 17-acre block, about 17 chains across at its greatest dimension, clearcut in 1958, when the medium density overstory was removed to release an abundant understory.

In all but the irregularly-shaped block, two sides of the cutting were oriented northwest-southeast, perpendicular to the direction of most strong storm winds. Strip cuttings were located so that the timber behind uncut edges was essentially the same as that cut on the strips themselves. The irregularly shaped block, however, was a homogeneous stand unit, and surrounding timber varied in size and density along the boundary.

Surveyed lines with numbered stakes set at intervals of 5 chains or less served as cutting boundaries for all but the irregularly shaped block. After cutting, the average irregular crown drip lines along cutting edges of all clearcut strips and the block were mapped by stadia and planetable.

Additional staked and brushed survey lines were installed two chains inside the uncut stands and parallel to the cutting boundaries. In the block, and at the ends of strips, a meander line was staked approximately 2 chains from the mapped drip line *(fig. 2)*. Numbered stakes served as reference points for mapping damaged trees in the study. As the study progressed, mapped and tagged trees also were used as reference points.

The area between the cutting edge and the line 2 chains inside the uncut stand was designated as the *inner* observation zone. The *outer* observation zone extended 2 chains beyond the inner zone. Damaged trees were classed as being in one of the two zones. (Because so little wind damage was expected, I considered chances good that results in the outer zone could be utilized eventually as control data. This later proved to be untrue. Sufficient manpower was not available to survey wind damage in other areas that could serve as control.)

The fifth area consisted of two contiguous parts, 10 chains wide. In one of the parts which covered 10 acres, two dominant noncull trees had been cut from each 2-chain-square unit (5 trees per acre); in the other part, 11.5 acres, one dominant noncull tree had been cut from each 0.4-acre unit (2.5 trees per acre); both parts were logged in 1959. The area was oriented northwest-southeast.

Field data collected during the study period permitted plotting of each damaged tree on a map. The direction of fall, bend, or lean of any uprooted or otherwise damaged whole trees was recorded, as was direction of fall for any broken piece of stem on the ground. Lengths of trees or parts of trees on the ground were measured, as were the heights of breaks.

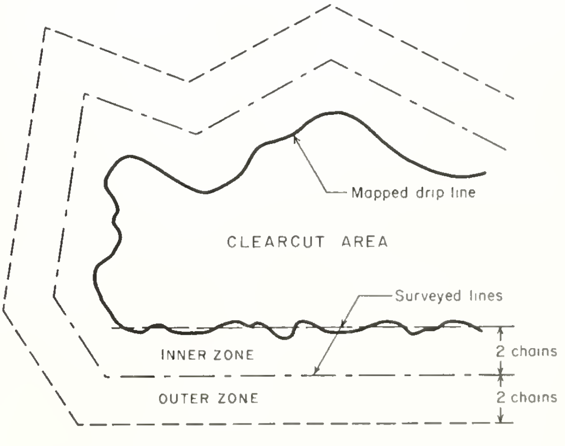


Figure 2—A zoning system was used for classifying locations of observations.

Causes of damage were categorized, and only one primary or immediate cause was recorded for each tree. More than one secondary or contributory cause might be recorded. For example: *primary* cause—wind breakage; *secondary* causes—(1) live bayonet-top, (2) bole rot. A primary cause could, of course, be recorded without a secondary cause.

Minimum tree size set for observation was 4.0 inches d.b.h. For trees from 4.0 to 12.0 inches d.b.h., 1-inch diameter classes were established, with 2-inch class for larger trees. Neither board foot nor cubic foot volume was computed for trees under 12 inches d.b.h.

Gross board foot volume of *whole trees* over 11 inches d.b.h. was determined from (a) local diameter-class volume tables for white and red fir[1] or (b) diameter-class volume tables for California old-growth timber (Dunning 1945). Gross and net volumes of broken trees having no remaining live limbs, and of pieces of stems on the ground, were determined from form-class volume tables (Clements, Stevens, and Roy 1949), or by scaling (U.S. Forest Service, California Region 1940). No net volume was computed for the live standing part of a broken tree, irrespective of location of stem break within the crown. The intent of the system was to show for trees over 11 inches d.b.h., first, the gross volume affected in any way, and, second, the definite salvageable net volume. A number of large trees with bole breaks just above live crown bases eventually died, and these could more properly have been added to the recorded net volume.

Because Swain Mountain is relatively remote, difficult to visit in the winter, and subject to high-intensity snow storms, no reliable method was found for obtaining records of winter wind velocities there. All high-elevation weather observation stations (fire lookouts) in the vicinity are closed during the winter, and factors such as screening by young trees at lower elevation stations may make their wind records useless for other higher locations only a few miles distant. For example, wind velocities vary greatly between Chester, approximately 10 miles southwest of Swain Mountain *(fig. 1)*, and Mt. Harkness, 10 miles due west of Swain Mountain *(table 1)*. Chester is at 4,500 feet elevation, Mt. Harkness at 8,000 feet, and Swain Mountain at 7,000 feet.

RESULTS

Wind, insects, and snow, in that order, were the principal primary tree-damaging agents. Observed effect of insects was always as mortality. Other agents accounted for only a small part of total observations *(table 2)*.

Unusually severe wind damage during two of the six winters of the study gave this agent abnormal prominence, and permitted unusual observations. Had wind damage continued at the low level of the first three winters, insect-caused mortality would have led the list by a wide margin during the study period.

Tree mortality caused by several species of beetles increased greatly, then decreased, during the study period. Fluctuation of the insect population is discussed below in the section on Insect Damage.

Precipitation as measured in a storage gage at Swain Mountain did not vary greatly during the years of the study:

Years	*Precipitation (inches)*
1958-1959	41
1959-1960	44
1960-1961	47
1961-1962	51
1962-1963	49
1963-1964	41

Although drought was marked from 1959 to 1962 in nearby parts of northeastern California, it probably had no bearing on any part of this study.

Wind Damage

Of the total of all kinds of damage during the study, wind was the primary cause of 60 percent of the damaged trees, 77 percent of gross volume loss, and 60 percent of net volume loss.

Wind damage was classed as direct or indirect. Direct damage consisted of stems broken, or partially or wholly uprooted, by direct force of the wind. This class contained 71 percent of the wind-damaged trees, 91 percent of gross volume loss, and 90 percent of net volume loss.

[1] Hallin, W. E. *Swain Mountain volume table–site II, white fir and red fir.* (Unpublished report on file at Pacific Southwest Forest and Range Exp. Stn., Redding, Calif.)

Table 1–*Wind velocities at two mountain locations, California, September 1959*[1]

Day and hour	Wind velocity	
	Chester (El. 4,500 ft.)	Mt. Harkness (El. 8,000 ft.)
	Miles per hour	
Sept. 17-18:		
All night	–	[2]55
Sept. 18:		
0700	–	55
1300	8	47
1500	8	40
1700	8	34
Sept. 19:		
1300	12	14
1530	9	17

[1]Data furnished Sept. 23, 1959 by District Ranger, Almanor Ranger District, Lassen National Forest.

[2]Steady (estimated).

Table 2–*Primary causes of damage or mortality for all trees and locations, Swain Mountain Experimental Forest, California*

Cause	Trees damaged, all sizes	Volume[1]	
		Gross	Net
		Bd. ft.	
Wind	1,333	729,060	312,825
Insect	661	195,620	190,730
Snow	137	240	90
Other	93	26,020	14,790
Total	2,224	950,940	518,435

[1]Calculated for whole trees 12 inches d.b.h. and larger, or broken pieces of stems on ground (Scribner Scale).

Indirect wind damage accounted for 29 percent of wind-damaged trees, 9 percent of gross volume, and 10 percent of net volume. A tree in this class was nearly always struck by another wind-damaged tree. Only 37 percent of these trees were larger than 11 inches; 85 percent were in intermediate and suppressed crown classes. Only 21 percent were broken or uprooted. The remainder were damaged by being held down by other trees, by bark scarring, by loss of limbs, and other conditions. When first examined, 53 percent of stems were live, 47 percent were dead.

Ratios of small stems (under 12 inches d.b.h.) to large stems were greatly different for the direct (1 to 3.6) and indirect (1 to 0.6) wind damage classes. The ratio for direct damage probably reflects the common observation that small trees (saplings and poles) constituting advance growth are inherently more resistant than large trees to wind damage. It also reflects a study area condition–small trees were usually shielded from wind by large trees. The ratio for indirect damage reflects another condition–that understory trees (where they did exist) were more numerous than overstory trees. Therefore, when a large tree fell there was good probability for damage to more than one small tree.

Nearly half the trees affected by direct wind damage were in the intermediate crown class, whereas suppressed trees received the brunt of indirect wind damage:

	Damaged directly (percent)	*Damaged indirectly (percent)*
Crown class:		
Dominant	17	2
Codominant	23	13
Intermediate	47	27
Suppressed	13	58

Volume of trees in both the direct and indirect wind damage categories was concentrated in dominant and codominant crown classes:

	Damaged directly (percent)	*Damaged indirectly (percent)*
Crown class:		
Dominant	59	26
Codominant	28	55
Intermediate	11	18
Suppressed	2	1

During the period of observation, wind damage affected 9.3 trees, 5,070 gross board feet, and 2,175 net board feet per acre. A rough comparison with volumes removed from cutting areas in the study is helpful, as no estimate of volume of timber on the study areas themselves is available. Whole clearcut areas yielded from 56,000 to 105,000 gross board feet per acre. Therefore, wind-damaged trees did not exceed 9 percent of even the lighest stand volume.

Of the directly damaged stems, 69 percent were classed as single events. Such stems damaged no other trees when they fell, and did not appear to be related to any group damage. Trees in the other 31 percent were considered group damage, because they either struck other trees or were associated with other damaged trees. Examples of such association were near-simultaneous uprooting of two large trees separated by not more than about two feet, but usually falling in different directions, and concentrated direct damage to several stems, like that resulting from a wind eddy of especially high velocity.

Direct wind action caused more broken boles than uprooted trees *(table 3)*. "Leaners" and "hangups" were relatively rare. Trees less than 12 inches in diameter seldom were windthrown, but one-fourth of the total trees broken were in this size class.

Direct wind effects in the two most damaging winters present a strong contrast. In winter 1961-62, breakage far exceeded uprooting; in winter 1962-63, uprooting was dominant *(fig. 3)*. Heavy snow loading appeared to have contributed to the amount and kind of breakage in 1961-62. Because it was not actually seen, however, snow was not generally recorded as a contributory factor at the time most breakage was observed in the field. Snow was not present on trees when the hurricane struck on October 12, 1962, although about 2 feet of snow fell at Swain Mountain after the wind abated. More to the point, 3 or 4 inches of rain during two days before the wind struck probably softened the soil.

The relative size of trees and the structure of stands in the study, as well as the susceptibility of

Table 3—*Trees uprooted or broken by direct wind action, by diameter classes, Swain Mountain Experimental Forest, California*

Diameter class (inches)	Trees damaged	Volume[1] Gross	Volume[1] Net
		— Bd. ft. —	
	Uprooted[2]		
04-07	10	–	–
08-11	31	–	–
12-20	129	19,520	17,620
22-30	74	54,540	48,920
32-40	45	84,820	74,740
42+	20	72,340	52,610
All classes	309	231,220	193,890
	Broken		
04-07	74	–	–
08-11	89	–	–
12-20	242	35,060	7,560
22-30	112	82,050	17,165
32-40	77	146,220	27,890
42+	40	170,200	34,130
All classes	634	433,530	86,745
Total	943	664,750	280,635

[1]Calculated for whole trees 12 inches d.b.h. and larger, or broken pieces of stems on ground (Scribner Scale).

[2]Includes trees down, leaning, and hung up. Leaners and hangups each constituted only 1 percent of direct wind-damaged trees.

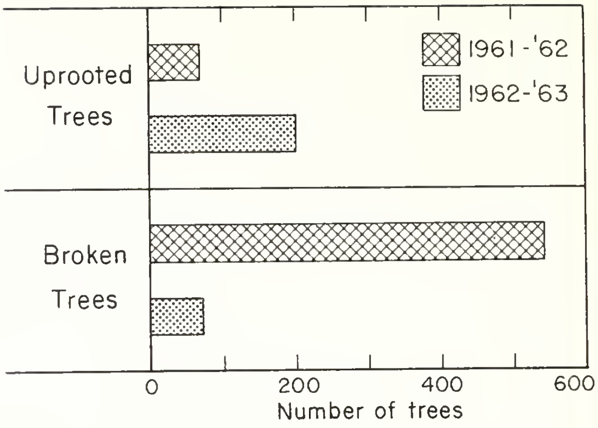


Figure 3—Direct wind action resulted in different kinds of damage in the two most destructive winters.

certain trees to direct wind damage, are indicated by the breakdown of data in *table 4*. Under conditions encountered in the study, the diameter class showing greatest damage decreased by one 10-inch class through dominant, codominant, and intermediate crown classes, and about the same for the suppressed crown class. By far the largest part of merchantable stand volume appeared in dominant and codominant trees—an important consideration in management of current residual stands. Equally important for management concerned with the more distant future is the large number of intermediate trees damaged. Further observation and study of trees in this class—especially those in the 12- to 20-inch diameter class—appears desirable.

Contributory Causes of Wind Damage

The main contributory causes of primary direct damage were sometimes impossible to determine. Although only a single primary cause of damage was recorded, more than one contributory cause might be found. A tree broken at its base by direct wind action might have both fire scar and severe decay. At the moment the tree broke, what was the real or most important contributory cause? The contributory cause could sometimes be identified easily, however. A few trees were so reduced in size at the base by severe scars that presence of a relatively thin layer of associated decayed wood was insignificant.

Most trees indirectly damaged by wind were simply in the way of other falling trees. For only 12 percent of 390 trees indirectly damaged could any contributory cause be determined, without which the trees might have escaped or resisted the primary damage. Over half the trees in the 12-percent portion were judged to be previously bent by snow. They

Table 4–*Trees damaged by direct wind action, by crown class and diameter class, Swain Mountain Experimental Forest, California*

Crown and diameter class (inches)	Trees damaged	Volume[1] Gross	Volume[1] Net
		– *Bd. ft.* –	
Dominant:			
04-07	–	–	–
08-11	1	–	–
12-20	6	520	360
22-30	28	26,300	19,580
32-40	70	138,080	74,930
42+	57	232,220	85,050
Subtotals	162	397,120	179,920
Codominant:			
04-07	–	–	–
08-11	5	–	–
12-20	54	9,950	6,070
22-30	109	83,200	37,545
32-40	49	88,300	27,450
42+	3	10,320	1,690
Subtotals	220	191,770	72,755
Intermediate:			
04-07	23	–	–
08-11	72	–	–
12-20	291	42,920	18,340
22-30	49	27,090	8,960
32-40	3	4,660	250
42+	–	–	–
Subtotals	438	74,670	27,550
Suppressed:			
04-07	61	–	–
08-11	42	–	–
12-20	20	1,190	410
22-30	–	–	–
32-40	–	–	–
42+	–	–	–
Subtotals	123	1,190	410
Total	943	664,750	280,635

[1]Calculated for whole trees 12 inches d.b.h. and larger, or broken pieces of stems on ground (Scribner Scale).

Table 5–*Contributory causes of direct wind damage; all trees, areas, years, Swain Mountain Experimental Forest, California*

Contributory cause	Trees damaged	Trees per acre	Volume per acre[1] Gross	Volume per acre[1] Net
			– *Bd. ft.* –	
Bole rot	99	0.69	1,670	557
Fire scar	63	.44	1,069	457
Root rot	59	.40	750	604
Other:				
Broken (live) bayonet[2]	32	.22	305	35
Dwarf mistletoe in bole	28	.19	361	131
Snow bend	6	.04	0	0
Shallow soil	[3]18	.12	147	140
Logging damage	25	.17	25	19
Total other	330	2.27	4,327	1,943

[1]Calculated for whole trees 12 inches d.b.h. and larger, or broken pieces of stems on ground (Scribner Scale).

[2]Includes both sound and partly decayed broken bayonet tops or forks.

[3]In 14, root growth was restricted at depth of 1 or 2 feet, in the rest at 3 to 5 feet.

simply occupied so much horizontal space that they had a greater chance than did erect trees of being struck by falling trees. Reduction in stem or root strength by fire scars or decay was the contributory cause of nearly all other indirect wind damage.

Bole rot–Bole rot was a less frequent contributory cause of breakage than expected. Records on sale of 12 million board feet of old-growth timber from Swain Mountain Experimental Forest had indicated a difference of 20 to 25 percent between tree volume and net log scale, most of the defect being decayed wood. Yet only 16 percent of breaks caused by direct wind action were judged to have been influenced by bole rot. Because of the size of some trees in this damage category, however, the volume affected was substantial *(table 5)*.

Trends in the data show, not surprisingly, that breakage increased with the proportion of the diameter that was rotten *(fig. 4)*. Increase of breakage was gradual up to the point where 0.6 of the bole diameter was decayed. Incidence of breakage then rose sharply to the 0.8 level. Beyond that point, frequency of breakage declined sharply–suggesting that most stems break before they reach such an advanced stage of decay. The general shape of the trend line in *figure 4* seems real. Theoretically, the line should terminate at the right at intersection of X = 1.0, Y = 0, because no tree could stand until totally rotten.

Fire scars–Determination of the contributory cause of basal breakage of trees as fire scar rather than bole rot was the result of judgment of the evidence. Some indicators considered were the apparent strength of wood around a break, compression failure, and splits and their locations. Fire scars frequently had splits through their apexes, and appeared to be susceptible to twisting forces. Not all fire scars were

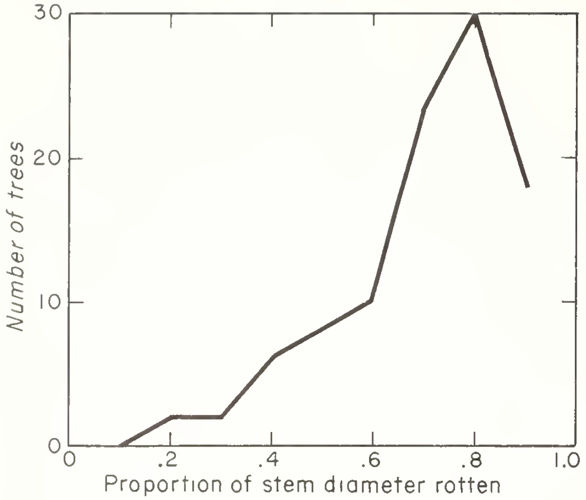


Figure 4—Stem breakage increases with amount of decay.

considered—only those judged to have had an influence on breakage. Some fire scars probably were not seen, being hidden beneath broken stems.

As most fire scars on fir trees were shaped like rough triangles or nearly pointed parabolas, their areas were computed simply as triangles. These areas were arranged in arbitrary square-foot size classes of unequal band width *(table 6)*, primarily to reveal whether the smallest fire scars (less than 1 square foot) had any effect on breakage, for, in the field, they appeared most numerous.

Large trees (over 30 inches d.b.h.) predominated in the fire scar damage category. There appeared to be no relationship between scar size and tree size.

At Swain Mountain, relatively young trees with diameters less than about 20 inches have scarcely any fire scars. A fire exclusion policy since the early 1900's has been beneficial from the standpoint of reducing degrade from scars and rot. Tolerant firs do not need natural fires (or like effects) to maintain the species as climax vegetation.

The relative frequency of broken trees having smallest fire scars *(table 6)* indicates that the smallest fire scars had an appreciable effect, but the implication is disturbing. That a fire scar of less than 1 square foot could seriously affect the mechanical strength of a large tree seems questionable. Large scars on large trees should have a definite weakening effect, and data so indicate. Nevertheless, these data need verification. Some of the "fire scar" observations might have been placed more properly in the bole rot category.

Root rot—Records of root rot necessarily were restricted to uprooted trees. I found that 21 percent of all trees thrown by direct wind action had decay in major roots. This proportion is probably low, as not all roots of some trees could be seen. Data indicate, predictably, that trees with decay in all major roots were more apt to be windthrown than trees with less rot *(table 7)*. Other than that, no well-defined pattern of damage (such as increasing windthrow with increasing proportion of root decay) is evident. Other factors, including relative position of one tree with respect to others, were evidently more important than root rot in causing susceptibility to windthrow. *Armillaria mellea* Vahl ex Fr. was the prevalent root rot noted by H. R. Offord and D. R. Miller, U.S. Forest Service pathologists, in their examination of exposed roots in 1963.

Table 6—*Size of fire scar as a contributory cause of direct wind damage; all trees, areas, years; Swain Mountain Experimental Forest, California*

Size of scar (sq. ft.)	Trees damaged	Trees per acre	Volume per acre[1]	
			Gross	Net
			– Bd. ft. –	
0.1-1	17	0.12	287	116
1.1-3	13	.09	195	82
3.1-5	13	.09	159	84
5.1 and above	20	.14	428	175
Total	63	.44	1,069	457

[1] Scribner Scale; all trees were larger than 12 inches d.b.h.

Table 7—*Amount of root rot as a contributory cause of direct wind damage; all trees, areas, years; Swain Mountain Experimental Forest, California*

Proportion of major roots rotten (tenths)	Trees[1]	Trees per acre	Volume[2]	
			Gross	Net
			Bd. ft. per acre	
1	3	0.02	28	26
2	4	.03	45	32
3	9	.06	152	131
4	1	.01	12	11
5	8	.06	106	84
6	9	.06	93	73
7	3	.02	23	14
8	2	.01	12	12
9	6	.04	84	66
10	14	.09	195	155
Total	59	.40	750	604

[1] Includes one tree smaller than 12 inches d.b.h.
[2] Scribner scale.

Other contributory causes—Several other contributory causes of direct wind damage accounted for 33 percent of the number of trees damaged, but only 19 percent of the damaged gross volume per acre under all contributory causes *(table 5).* Both sound and partly decayed broken bayonets (live offset tops) or forks are included in one category. Also, sound and partly decayed dwarf mistletoe bole infections are grouped. Observations of proportion of decay in broken bayonets or dwarf mistletoe swellings were included with other data in the section on bole rot. A few trees were downed by wind following previous damage classed as permanent snow bend. All such trees were smaller than 12 inches d.b.h. Damage resulting from snow bend or break is much more common among trees in more extensive pole stands than those encountered in this study.

Most observations of the effect of shallow soil were randomly scattered through the study area rather than concentrated in one or two locations.

Logging damage effect was mostly confined to small trees which were scarred and later broke, or had part of their major roots cut.

Relation of Break Height to Crown and Size Class

Heights of breaks were studied to determine whether any patterns of this damage were evident in trees of different crown class and size. Only trees broken by direct wind action were considered. Secondary causes of damage (such as bole rot or fire scar) were not considered. Segregation by crown classes gave this distribution: dominant—13 percent; codominant—22 percent; intermediate—51 percent; suppressed—14 percent.

When broken trees are segregated into arbitrary classes by height of break *(fig. 5)* a potential trend is seen for a computed "mean height of break" for any one class: if height of break is random for trees in a class, each class mean will be at the center of the class. In this part of the study, height-of-break class limits were established to account for a 2-foot stump plus one 16-foot log length, two more log lengths, then multiples of 50 feet (each of which equals approximately three 16-foot log lengths).

For dominant and codominant trees, the height of break anywhere within the first three log lengths appears to be random. The incidence of breakage in the first log is low—14 percent of breaks in these two crown classes.

A supplemental analysis of the stem breakage class below 18 feet yielded interesting information. Here, causes contributory to breakage were again considered. Of all trees in the 18-foot class broken by direct wind action, only 28 percent were listed as having breaks influenced by bole rot or fire scars. Many trees with fire scars still stand at Swain Mountain. Distribution of the contributory causes of damage was:

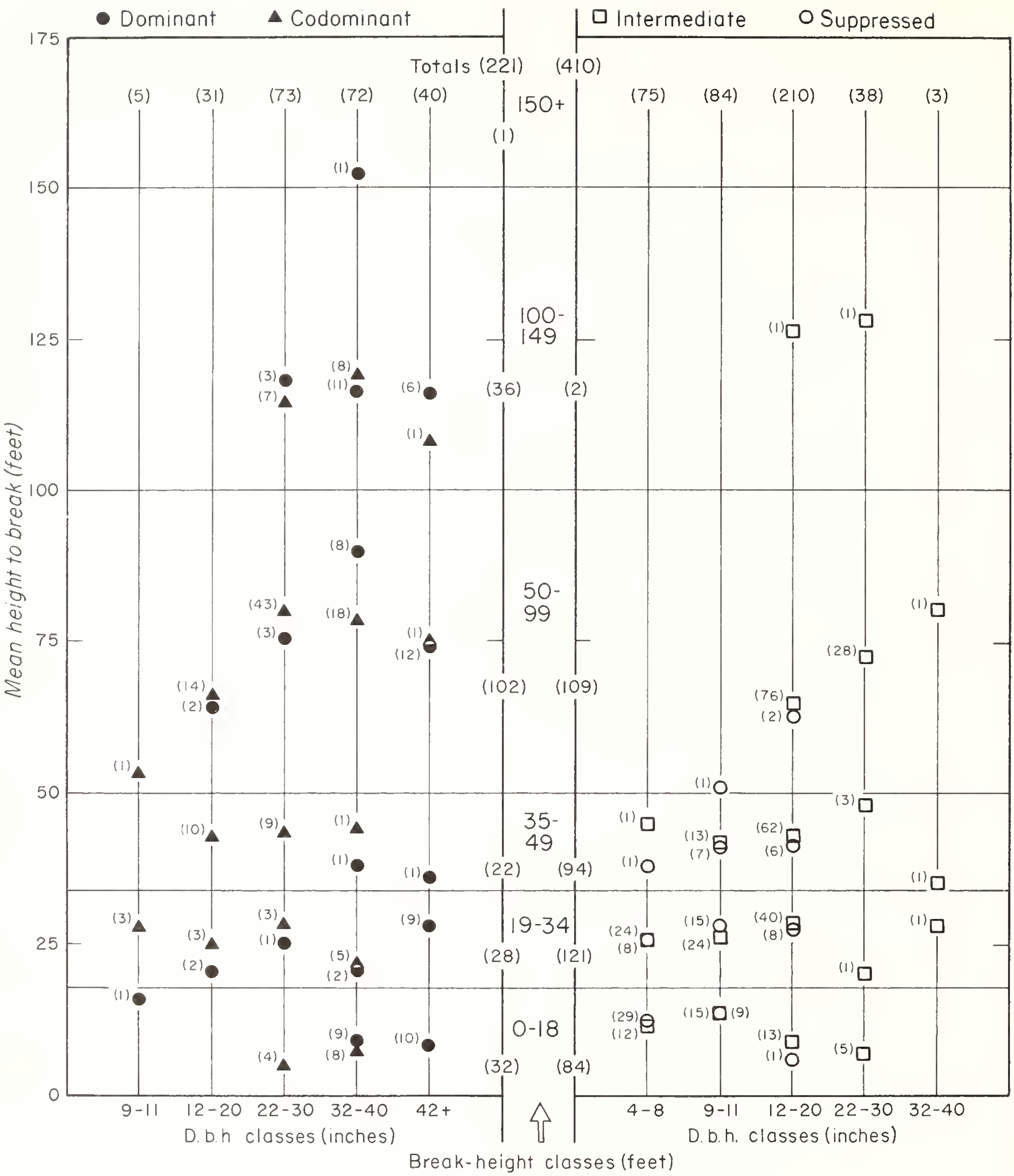
Contributory cause:	*Trees damaged*	*Average gross volume per tree (bd. ft.)*
All trees in class (all crown classes)	116	738
Trees with fire scar only	2	2,225
Trees with bole rot only	8	2,086
Trees with bole rot and fire scar	22	2,078

Nearly half the breakage in dominant and codominant trees was in the 51 to 100-foot height-to-break class. This was not the result of a high incidence of rot in that part of the bole. Because the trend of breakage in this height class is upward with increasing diameter (and presumed increasing total height of tree), an upward height trend of a mechanical stress point with increased tree height and diameter can be assumed. This assumed stress point probably is not the result of a simple relationship of height and diameter. It is undoubtedly influenced by crown size, shape, and density. Fons and Pong (1957) reported on the measured energy necessary to break or uproot ponderosa pines with breast-height diameters of 8 to 24 inches. They included quantitative estimates of stress distribution along the stem for different points of loading and predictions of the probable position of failure. Curtis (1943) indicated that stress from wind is concentrated at the form point (one-third of the distance from base of crown to top of tree).

Dominant trees 150 to 200 feet tall are not uncommon in study areas. They showed little breakage of the uppermost boles. Some of the tallest trees at cutting edges had neither broken nor become windthrown. This observation seemed so unusual that some of those trees were examined. Such trees appear to have been in dominant, relatively unprotected positions for a long time (say 100 to 200 years). Rooting probably is strong, and boles are relatively sound. These trees are usually good seed producers, so their resistance to wind damage makes them the best seed trees for natural regeneration.

Broken dominant and codominant trees smaller than 22 inches in diameter were only 16 percent of the total stems in these crown classes. They were in young groups scattered through older stands.

About half the broken trees in intermediate and suppressed crown classes were in the 12- to 20-inch



Note: Numbers in parentheses are the number of trees.

Figure 5—The mean height of wind-caused breaks, when plotted for tree diameter classes, shows a trend in some break height classes. Left, in dominant and codominant trees, breakage in the 50- to 100-foot class shows an upward trend with increasing diameter. Right, in intermediate and suppressed trees, the breakage point moves downward in the lower 18-foot section. Tree numbers are shown beside data points, with class totals in parentheses.

d.b.h. class, and most other broken stems in those crown classes were smaller. These tree sizes will probably constitute most managed young growth stands in the future. Trees in these two crown classes were protected from wind to a certain extent by large old trees, yet some broke. They were either small suppressed trees of the same age as overstory, or relatively young understory trees. At present we can only speculate on the susceptibility to windbreak of trees this size when grown in absence of any large old trees.

Many trees in intermediate and suppressed crown classes broke between 51 and 100 feet, but the breakage point moved upward in height with increasing diameter—just as it did in dominant and codominant crown classes. In the lower 18-foot section, the height of break decreased in larger diameter classes. Reasons for this trend are obscure, as trees less than 20-inches in diameter seldom had rot. In the two height classes from 19 to 50 feet, data indicate random location of breaks.

Influences on Wind Damage

Weather and wind direction—Damage by wind was nominal during the first three winters of study, but in each of the next two winters, wind heavily damaged the stands:

Winter	*Trees damaged*
1958-59	22
1959-60	34
1960-61	14
1961-62	765
1962-63	486
1963-64	2
Total	1,323

Yet, as discussed elsewhere, total wind damage in six winters did not exceed 9 percent of the lighest stand volume encountered on cutting areas. This can scarcely be considered catastrophic. Negligible loss in the sixth winter probably reflected the condition that trees most susceptible were damaged by wind during the previous few winters.

Surveys of old windfalls before the 1958-60 cuttings indicated that most damage to the virgin stand had been caused by southwest storm winds and that past damage had been light. This lack of evidence of prior heavy wind damage is important to consider in relation to the level of damage reported in this study.

In the remaining discussion on wind direction, it must be noted that not all wind-damaged trees are included in the data—only those damaged by direct wind force, and, further, only those judged in the field to be "pertinent" to this part of the survey. A fairly common example of excluded data would be tree 1 in the following damage sequence: tree 1 was uprooted by direct wind action; in falling, it struck and uprooted in sequence trees 2 and 3; the initial direction of fall for tree 1 could not be determined from its final position, or from evidence supplied by the locations of trees 2 and 3, or scars upon them. (Trees 2 and 3 would also be excluded, since they were classed as "indirect" wind damage.)

The damage patterns of the first three post-cutting winters *(fig. 6)* can be considered "normal." Damage patterns changed abruptly for each of the next two winters. Damage was caused by north winds in 1961-62, and by south winds in 1962-63. Direct wind damage was near zero in the sixth winter.

The apparent north-to-northwest wind which caused heavy damage during winter 1961-62 was unusual in direction and effect. After discovering the damage in spring 1962, I obtained weather data from some of the nearest year-long weather stations and

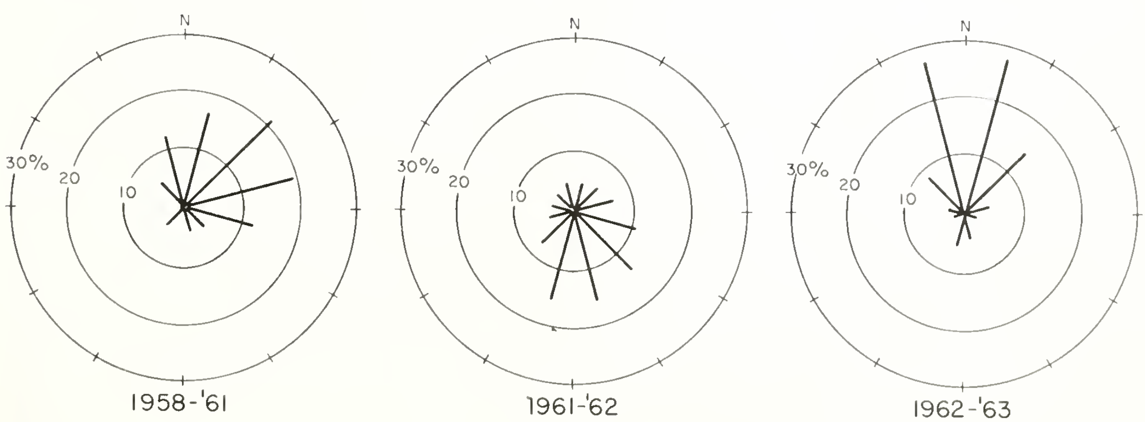


Figure 6—Direction of fall of trees or broken pieces of stems was unusual during heavy storm periods. The percent of total direct wind damage is shown for the first three winters combined, and for the following two winters separately. Bars are at centers of 30° azimuth classes.

Figure 7—Groups of large trees in dense old-growth stands were found uprooted by strong winds during winters of 1961-62 and 1962-63.

electric utility companies. Weather conditions responsible for observed damage could not be isolated in the data. Damage of similar intensity did not extend far beyond Swain Mountain, so some unknown localized weather conditions were assumed to be responsible.

Of all directional wind damage, 66 percent occurred during the 1961-62 winter. It included much stem breakage, especially in the tops of trees. Evidence indicated that the main probable cause of damage was strong gusts of wind striking trees loaded heavily with wet or frozen snow. Some small trees (15 to 40 feet tall) appeared to have been crushed by masses of snow falling from the overstory.

Damage in the fifth winter (1962-63) occurred mostly on one day—October 12, 1962. This well-documented "Columbus Day Storm" caused heavy damage at many places in California and farther north. Records from weather stations in the vicinity indicate that 3 or 4 inches of rain probably fell at Swain Mountain during the two days before maximum winds of the storm system struck at midafternoon. Wind at Swain Mountain blew from the south. Two high and exposed fire lookouts (Seven Lakes and Black Mountain), about 50 or more miles southeast, recorded wind speeds of 78 and 70 miles an hour. These locations were near the eastern edge of the storm. Wind speeds at Swain Mountain were likely higher, with violent gusts. Group damage observed away from any cutting gave evidence of high-speed eddy currents *(fig. 7).* Twenty-eight percent of directional damage occurred during this fifth winter. Very probably, much heavier damage to wind-susceptible trees would have been recorded this winter if many trees had not already been damaged the previous year.

Wind damage during the fourth and fifth winters was heavy, caused by winds from opposite directions, and not aligned with normal storm wind direction. This damage pattern might seem reason enough for ignoring wind direction as a determinant in cutting strip orientation. Yet the imposition of a particular cutting pattern (clearcut or otherwise) must be influenced by consideration of "average worst" or "average best" conditions, which may be partly determined by chances for seed dispersal by wind, or snow deposition and melt, as well as wind damage. Future recurrence of heavy damage in two successive winters is presumed unlikely.

During the first three winters, only 52 stems were included in directional damage records. This is less than 6 percent of the total of direction-pertinent damage in the study. Because wind damage was low during the first three winters, orientation of cutting strips perpendicular to normal storm winds appears to have been a reasonable decision.

Location—All comparisons of wind damage by locations must be on the basis of units per acre, since size and shape of cutting areas differed. Because primary interest is in effects of direct wind force on the areas, indirect wind damage by location will not be reported.

A characteristic of a single cutting area—the 17-acre block—affects interpretation of data. There, stand structure to a 4-chain depth from cutting edge was more variable than that adjacent to any other cutting area. A few groups of poles, and groups of trees in the 12- to 20-inch diameter class, accounted for most of the difference.

Whole study areas adjoining different cutting units had distinctly different amounts of wind damage *(table 8)*. Lightest damage was associated with the very light partial cuttings and the strip 3 chains wide. Even after the two most damaging winters, damage on or adjacent to these areas was visually no different from that on areas remote from roads or cutting units.

Although the two clearcut strips 5 chains wide did not incur equal amounts of damage, they may not be different statistically. Insufficient data are available for fully descriptive stand structure comparisons against which to measure the damage differences. Also, one 5-chain strip, area 3 *(fig. 1)*, lies only a few chains north of a brush field which occupied about 1,000 acres of the Experimental Forest—from the summit of the mountain to the south boundary (and beyond). At this location, wind from the southerly hurricane of 1962 may have created effects on strip 3 which were different from those on the other 5-chain strip.

In the field, the visual difference in wind damage near the 3-chain strip and either of the 5-chain strips was striking. Strong differences were also noticeable on cursory examination of other 3- and 5-chain wide strips not in the study.

Orientation of clearcut strips at Swain Mountain originally was intended to reduce potential damage from normal strong storm winds. The two longest sides of strips were the southwest and northeast cutting edges. Ends of strips were classed as northwest and southeast edges. An irregular-shaped clearcut block determined the size and shape of one surrounding study area. Appropriate segments of the block cutting edge were classed as being equivalent to one of the four orientations specified for strips. The two degrees of partial cuttings (five trees and two and one-half trees per acre), designed to test effects of such cuttings on wind damage, also enter the comparisons made.

Cutting edge orientation had a marked effect on direct wind damage *(table 9)*. Northeast and southwest edges received 75 percent of the direct damage. This crude statistic, however, means little without close examination of the data.

An important finding was the low level of wind damage during the first three winters. The clearcuttings tried did not create an immediate high risk from normal winter wind conditions. And, since 86 percent of damage during the first three winters occurred on the northeast side, orientation of strips seems appropriate. Data *(table 9)* include records from the clearcut block, but wind damage pattern for sides of the block was the same as for strips. The light partial cuttings were damaged only nominally at the beginning of the study period.

Northerly wind in 1961-62 caused greatest damage to southwest sides. During the same winter, and

Table 8—*Direct wind damage on study areas associated with different cutting areas, Swain Mountain Experimental Forest, California*

Area number[1]	Cutting area[1]	Trees per acre	Volume per acre[2] Gross	Net
			– *Bd. ft.* –	
1.	Clearcut strip, 3 chains wide	4.97	5,241	1,845
2.	Clearcut strip, 5 chains wide	6.96	6,254	2,498
3.	Clearcut strip, 5 chains wide	9.05	4,253	2,253
4.	Clearcut block, 17 acres	6.31	4,106	1,782
5.	Light partial cut,[3] 21.5 acres	3.49	2,441	810

[1] See map, figure 1.

[2] Calculated for whole trees 12 inches d.b.h. and larger, or broken pieces of stems on ground (Scribner Scale).

[3] Combined data from removal of five trees and two and one-half trees per acre.

perhaps during the same storm condition, damage at the northeast sides was surprisingly high. Evidence indicated that most damage occurred at one time. At the same time, southeast and northwest edge damage was much less than for the other two sides. It is unlikely that wind direction had no particular effect that winter, yet the relationship of damage at northeast and southwest sides is obscure.

Table 9–*Direct wind damage to trees according to their relation to cutting edges, 1958-1963, Swain Mountain Experimental Forest, California*

Tree location	Trees damaged per acre			
	1958-61	1961-62	1962-63	All years[1]
At edge of clear-cut area:				
Northeast	0.90	3.63	2.93	7.45
Southeast	.07	3.64	.93	4.64
Southwest	.12	6.15	.77	7.04
Northwest	.07	4.49	3.69	8.24
Within partial cuttings:				
Five trees per acre	.30	3.30	.30	3.90
Two-and-a-half trees per acre	.09	2.09	.70	2.87

[1]Does not include 2 trees damaged in 1963-64. Discrepancies are due to rounding.

Table 10–*Trees broken or uprooted by direct force of wind according to adjacent clearcut area and distance from edge of uncut stand, Swain Mountain Experimental Forest, California*

Cutting area and zone[1]	Trees damaged per acre[2]	
	Broken	Uprooted
1. Clearcut strip, 3 chains wide		
Inner	4.88	1.10
Outer	3.55	.54
2. Clearcut strip, 5 chains wide		
Inner	4.60	3.64
Outer	4.23	1.44
3. Clearcut strip, 5 chains wide		
Inner	4.04	4.84
Outer	6.79	2.41
4. Clearcut block, 17 acres		
Inner	4.14	2.31
Outer	4.81	1.37

[1]Inner zone: up to 2 chains from edge; outer zone: 2 to 4 chains from edge.

[2]Uprooting difference, by zones, significantly different at the 5 percent level; breakage difference, by zones, not statistically significant.

Damage occurring in the 1962-63 winter followed an understandable pattern. The south wind of the October hurricane struck both the northeast and northwest edges of clearcuttings with great force. Damage this winter would have been higher had there not been, comparatively, so much damage in the preceding winter.

Even during the most severe winters, light partial cuttings received comparatively little damage.

Areas close to clearcut edges were subject to significantly (5 percent level) more uprooting than areas farther from edges *(fig. 8, table 10).* Uprooting differences by cutting area also varied considerably but stem breakage was relatively uniform everywhere.

Insect Damage

Trends of damage in this study suggest that stand losses apparently caused by insect attacks may exceed all others. The two occurrences of heavy damage from wind placed an abnormal emphasis on that agent.

It is possible that the insect attack to which tree losses were attributed was itself only a symptom of physiological stress caused by root diseases, availability of soil moisture, and other factors. Such influences could not be evaluated as this project was construct-

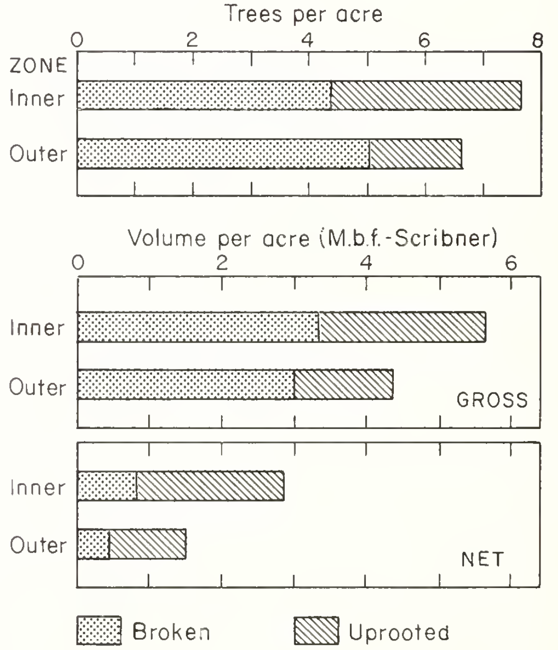


Figure 8—At any distance from cutting edge, more trees were broken than uprooted. But uprooting and its effects were more prevalent close to cutting edges than at greater distances.

ed. Insects were a significant and easily found potential cause of mortality where no other primary cause was evident.

Assignment of tree mortality to insects—and especially to specific insects—was based on the best evidence obtained during examination of dead trees. Bark samples to determine insect activity could be hacked only from the lower 7 feet of tree boles. Insects found at the base of a tree could be secondary, the primary attacking insect remaining undetected at a greater height. No trees were felled to determine insect species throughout the bole.

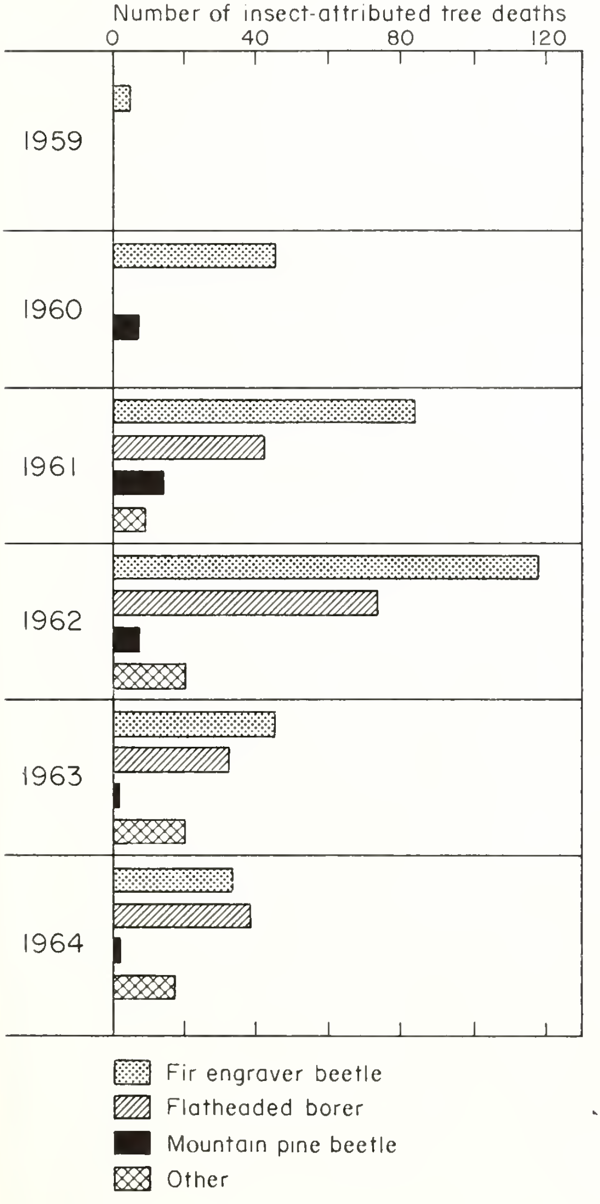


Figure 9—Tree mortality attributed to insect attack fluctuated during the study years. When 1962 storms made slash available for breeding, insect pressure on live trees may have lessened.

Inner bark was examined to determine intensity of insect attack. Patterns of egg galleries, larval mines, and frass were used to classify work of the fir engraver beetle *(Scolytus ventralis* Lec.*)*, flatheaded borers (possibly *Melanophila drummondi* Kby.), mountain pine beetle *(Dendroctonus monticolae* Hopk.*)* (on lodgepole pine), and "other." Mortality assigned to beetles classed as "other" was found almost entirely in small trees (less than 8 inches d.b.h.) of the understory, often weakened by dwarf mistletoe *(Arceuthobium* spp.*)*. Damage appeared to be caused by wood engravers *(Pityogenes* spp.*)*, fir twig beetles *(Pityophthorus* spp.*)*, and fir bark beetles *(Pseudohylesinus* spp.*)*.

Tree mortality attributed to fir engravers and flatheaded borers gradually rose, then fell again, during the study *(fig. 9)*. Unburned logging slash created by the 1958-60 Swain Mountain cuttings furnished breeding material for a potential increase in beetle populations. This may account for the rise in mortality at study sites. Wickman (1965) suggested that new slash created by the storms of 1962 furnished such abundant breeding material that insect pressure on live trees was relieved. In addition, he thought the relatively cool summer of 1963 might have slowed activity of some insects. Both suggestions may help explain the reduced tree mortality counts in 1963 and 1964. I suggest, too, that some trees physiologically stressed and mechanically weakened by root rot and other conditions became sudden victims of the 1962 storms. Had there been no such storms, these trees might well have been part of insect-caused mortality statistics.

During the study, fir engraver beetles apparently killed more trees than did flatheaded borers *(fig. 10)*. Borer attacks were found at bases of larger trees, as is indicated by the greater volume attributed to them.

Trees near cutting edges (inner zone) were slightly more subject to insect attack than trees at greater distances (outer zone). Analysis of differences between zones indicated statistical significance at levels between 20 and 10 percent.

Figure 10 includes only the data from the zones around clearcuttings. Also, although mountain pine beetles attacked lodgepole pine, I have not included the data in the figure. Lodgepole pine occurred principally in infrequent groups on study areas, and to prorate its mortality on an acreage basis would be erroneous.

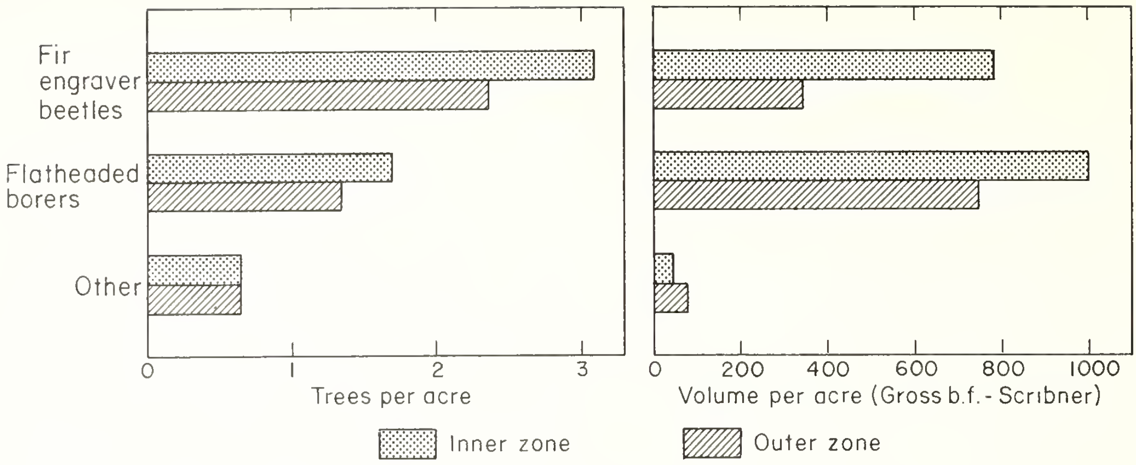


Figure 10—Fir engraver beetles apparently killed more trees than any other insect, but board-foot mortality assigned to flatheaded borers was greatest. Tree numbers and volume lost were higher near clearcut edges (inner zone) than at greater distance (outer zone).

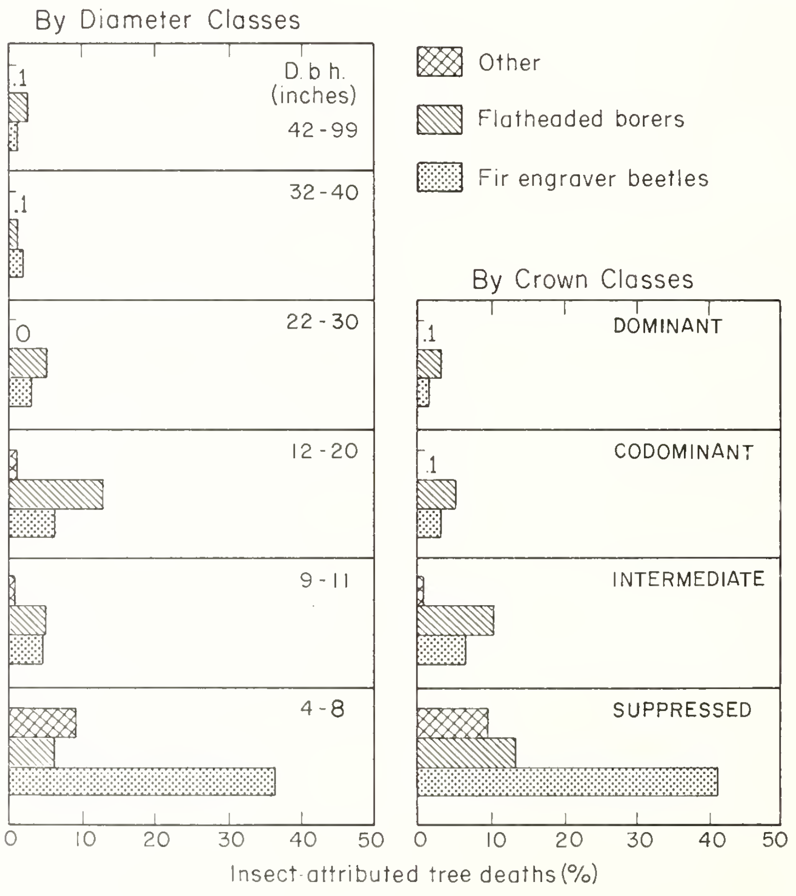


Figure 11—Tree mortality assigned to different insect species varied by tree diameter classes, but showed a common trend. By tree crown classes, the trend is more consistent.

Beetles apparently killed many more small trees than large trees *(fig. 11)*. When insect preferences are related to tree crown classes, the trend is more consistent than by tree diameter classes.

In a large proportion (44 percent) of trees attacked by insects, there was no readily apparent reason for the attack except general poor vigor, probably caused often by stress resulting from suppressed crown position. Dwarf mistletoe infections were judged to have reduced severely the vigor of 34 percent of trees killed by beetles. Many of these same trees were also small and otherwise suppressed. Reduction of tree numbers in such ways appears to be quite natural, and subject to continuous or periodic insect population pressure. Nevertheless, adequate numbers of trees always seem to survive in natural stands. Damage from logging (7 percent), snow (6 percent), and other factors (9 percent) was judged to have induced insect attacks on less than one-fourth of the insect-killed trees.

Losses attributed to insects were by no means catastrophic: in the 4-chain wide area around clear-cuttings, insects apparently killed an average of about 5 trees and 1,500 board feet per acre in 6 years. This does not seem great for stands often exceeding 100,000 board feet per acre, and of an age when deterioration may begin.

Snow Damage

A positive case of snow damage is sometimes difficult to establish. Snow damage might be recorded when there was some influence of wind on heavily laden trees. Observation during snow surveys and at other times confirms, however, that some relatively small trees simply become loaded with snow and are bent over and sometimes broken. Evidence also showed that some small trees immediately under crown edges of overstory dominant or codominant trees are crushed by dense, heavy snow loads falling from the taller trees. Craters in the snowpack, caused by such masses of falling snow, are sometimes 10 to 12 feet across and 2 feet deep.

Snow damaged only 6 percent of total trees recorded in this study and affected only a nominal volume. But this kind of damage is particularly applicable to trees of less than 12 inches d.b.h., and may have a greater impact on future fir silviculture than results of this study indicate. Because study areas occupied sites supporting essentially heavy stands of old-growth fir, relatively few trees of sizes commonly damaged by snow were found. The following values on trees per acre, by diameter class, are indicative:

	Less than 12 inches d.b.h.	*More than 12 inches d.b.h.*
Trees		
Bent	0.48	0.01
Broken	.44	.02
Total	.92	.03

Trees with complete or partial stem breakage die immediately, or within a very few years. Permanent bending usually causes delayed mortality, perhaps through a change in crown class. Trees are affected either singly or in close-spaced groups.

The term "snow damage" more appropriately might be "snow effects." Snow commonly thins dense fir pole stands, particularly in California's snow belt above 5,500 or 6,000 feet elevation. There, maximum winter snow packs usually exceed 6 or 8 feet, and snow deposition from a single storm is frequently more than 1 or 2 feet.

Denseness and good growth rate of natural older age groups of fir furnish abundant evidence that cumulative thinning of pole stands by snow seldom becomes excessive. This suggests that precommercial thinning of young fir may be economically questionable—at least until thinning studies are reported.

Other Primary Damage

Damage from other causes observed in this study constituted only 4 percent of the total of trees, and was due to several agents *(table 11)*. All this damage was classed as mortality.

Dwarf mistletoe was designated as a primary cause of death for only two trees, of 4- and 6-inch diameter. The designation may have been accurate, or it may have been made because dwarf mistletoe infection was heavy and there was no observable insect activity. Dwarf mistletoe has been treated in this paper predominantly as a secondary cause of death or damage, weakening trees to the point that insects were attracted to them in sufficient numbers to kill them.

The "unknown" primary damage category included 29 trees. For one-fifth of these, no secondary cause of damage was listed, but some of these trees may have been killed by insects whose effects were not recognized. Of the remaining four-fifths, a few stems were listed in each of these categories of contributory causes of death: fire scar, bole rot, dwarf mistletoe, snow, and logging.

The contributory logging damage included effects of roadbuilding activities. The principal observable damage was severance of large roots by bulldozing and log skidding, occurring mainly at timber edges.

Table 11—*Damage from minor causes, Swain Mountain Experimental Forest, California*

Cause of damage	Trees damaged per acre		Volume per acre (bd. ft.)[1]	
	Less than 12 in. d.b.h.	More than 12 in. d.b.h.	Gross	Net
Dwarf mistletoe	(2)	0	0	0
Unknown	0.05	0.15	103	74
Logging	.06	.03	11	2
Fire (slash burning)	.09	.03	12	11
Lightning	0	0	0	0
All other	.08	.03	3	3

[1]Calculated for whole trees 12 inches d.b.h. and larger, or broken pieces of stems on ground (Scribner Scale).

[2]Two trees only.

Cleanup of roadside slash piles by burning after fall precipitation caused two or three small fires to run short distances in normal litter accumulation. These fires created enough heat at the bases of a few trees to scar and kill them.

Fire control personnel have documented that lightning strikes on Swain Mountain Experimental Forest are more numerous than on surrounding areas. However, study areas were not large enough to supply evidence of any strikes.

The catchall damage category—all other——contained considerably less than 1 percent of trees.

Salvage and Potential Losses

The kinds of damage reported in this study are commonly known, but have been quantified in several ways for the study areas. During the first 3 years of the study, tree losses did not appear to be worth salvaging. At the lightest levels of salvage, the values recovered often are not enough to pay the cost of road maintenance.

Most insect-attributed mortality in merchantable tree sizes was not readily visible until tree foliage faded. Crown density within uncut stands limited visibility and made necessary diligent search for dead trees. A regular aerial survey could only partially overcome this difficulty.

As soon as the first severe wind damage was found (spring 1962), the Ranger District included the Experimental Forest in a salvage logging contract. The contract was extended later to remove damage caused by the October 1962 storm. The existing road system in the Experimental Forest was not extensive, but most of the severely damaged merchantable trees were removed from areas within 400 to 500 feet of roadways and cutting areas. Three normal benefits from this action were obtained: usable wood was sold, insect breeding material was reduced, and eventual fire hazard was reduced.

The effect of salvaging usable wood probably would show up in this study indirectly as an influence on amount of insect damage. None of the available data furnish a measure of influence, however.

Fire hazard from downed fuels increased during the study. Some new fuel concentrations were more hazardous than others, and of course differences by cutting areas became apparent, as with wind damage. The length of all downed trees and broken pieces serves as an index of material which, when dry, would contribute to fire hazard:

	Lineal feet down per acre
Study area adjacent to. . .	
3-chain strip clearcut	378
5-chain strip clearcut	677
5-chain strip clearcut	615
Irregular block clearcut	456
Very light selection cuttings	273

Although salvage logging reduced this lineal footage, there are no data to relate the reduction to specific areas.

DISCUSSION

True fir stands like those in this study have been in the initial stages of conversion from a natural to a managed state for about 25 years. Results here were obtained peripherally to the main thrust of our earliest investigations at Swain Mountain—regenerating old growth stands. Yet, these findings, insofar as they deal with tree sizes found in young-growth stands, furnish some guidance for management decisions.

A greater research effort to improve management opportunities is long overdue, particularly with respect to the relationship of insects and true firs. Because insects appear to exert a normal pressure against tree survival greater than that of wind, stand manipulation might change the tree-insect relationship considerably. If salvage is attempted, large trees killed by insects should always be salvaged quickly. Otherwise, several species of borers, and fungi and molds, will make timber worthless for some purposes. (A few dead trees should be left in place to provide nesting and perching sites for birds and small mammals.)

Our results here indicate that within the narrow range of post-cutting conditions monitored, wind damage to residual stands generally increased through light selection cutting and in areas adjacent to the 17-acre cut block, the 3-chain-wide cut strip, and the 5-chain-wide cut strips *(table 12)*. The timber adjacent to the narrowest clearcutting had relatively the greatest damage, however, when average damage to uncut stands was related to adjoining area actually cut. This is an admittedly skimpy sample of cutting areas on which to base comparisons, but the general relationships of areas, as shown in the table, were about the same for a period of light damage (first 3 years) as well as total damage for six winters.

I believe that the relatively low damage sustained by the timber around the 17-acre block is due to the location of its irregular edge on natural (and therefore probably windfirm) tree group boundaries. This kind of boundary may be exposed by liberation or release cuttings of certain stand structures, but is seldom available for use in establishing first stage regeneration area edges within dense old-growth patches.

In stands investigated by Alexander (1964) and Neustein (1965), wind damage was clearly shown to be comparatively less where uncut areas were adjacent to large clearcuts rather than small ones. Alexander's data were derived from spruce-fir forests of the Rocky Mountains in Colorado—Engelmann spruce *(Picea engelmannii* Parry*)* and subalpine fir *(Abies lasiocarpa* [Hook.] Nutt.*)*. They were obtained adjacent to clearcuts consisting of (1) patches of less than 5 to more than 100 acres, (2) alternate strips 150 to 200 feet wide at right angles to the contour, and (3) alternate strips 200 to 400 feet wide parallel to the contour. Neustein's data apply to 30-year-old planted stands of Sitka spruce *(Picea sitchensis* [Bong.] Carr.*)* in the Forest of Ae, Dumfriesshire, Scotland. The experimental area consisted of replication of circular clearcuttings of 0.1, 0.3, 1, and 10 acres. Neustein measured windrun (distance/time) at midcrown height in the clearings and recorded wind damage in the uncut stands. Windrun was less in small clearings, but this was not reflected in smaller numbers of windthrown trees on an acreage basis. The greater length of perimeter felled per unit of area for small clearcuttings outweighed the apparent reduction in windspeed.

Wind damage results as analyzed by different size or kind of cutting areas in the present study are in

Table 12—*Wind damage in relation to time period and kind of cutting area, Swain Mountain Experimental Forest, California*

Related cutting area	Trees damaged per acre in study area		Index of damage per acre[1]	
	First three winters	Six winters	First three winters	Six winters
Clearcut strip, 3 chains wide	0.80	6.97	0.16	1.42
Clearcut strip, 5 chains wide	1.92	10.18	.10	.54
Clearcut strip, 5 chains wide	.94	13.07	.06	.77
Clearcut block, 17 acres	.58	8.46	.03	.49
Light partial cut,[2] 21.5 acres	.19	4.46	–	–

[1]Index = Damaged trees per acre in uncut stand divided by related cutting area acreage.

[2]Combined data from removal of five trees and two and one-half trees per acre.

general agreement with the findings of Alexander and Neustein, in spite of pronounced stand differences. But the Swain Mountain data definitely suggest that the relative level of wind damage in "normal" years should not be prohibitive around small clearcuttings. Such cuttings could be used cautiously if the forest manager is seeking to obtain natural regeneration, to reduce impact on scenic values, or to achieve some other land-use objective.

Constraints other than wind damage must be considered in cutting and other management plans. Although large clearcut areas may be entirely satisfactory for reducing wind damage to cutting-edge timber, and just as satisfactory for artificial regeneration, they do have drawbacks. In the first place, many large clearcuttings in true fir have not regenerated naturally. Small areas have a much higher probability of becoming regenerated naturally. And secondly, large clearcuttings are objectionable to those who are more concerned about the esthetics of a forest than its other values, and to some wildlife enthusiasts who are concerned about support for animal life in the forest. A large clearcutting may not be pleasing in appearance, but this can be a temporary condition. Low vegetation established in open regenerating areas supports far more animal life than does the closed conifer forest which it temporarily replaces.

In this connection, some suggestions that have been made relative to timber management for preservation of scenic values may be misleading. The use of irregular boundaries for clearcuttings would certainly improve scenic impact, but some regrettable results might follow the practice of leaving narrow stringers of timber extending into clearcuttings, and V-shaped cut areas extending into uncut stands. Less abrupt departures from conventional unimaginative straight cutting lines would be helpful. Forestry literature contains numerous examples of severe wind damage resulting from abrupt change in direction of cutting edges.

Edges of small clearcuttings for regeneration usually should not be static. As soon as newly established regeneration allows it (probably not more than 10 years after cutting), edges should be cut back for two reasons: to regenerate adjoining areas, and to prevent the usual dwarf mistletoe infection from spreading from tall trees at cutting edges to newly established seedlings. An added benefit will be that the ratio (perimeter exposed/opening created) will be reduced periodically. Possible disadvantages could also develop through successively widening originally narrow strips or other small clearcuttings: enlarged areas would allow winds of greater force to strike cutting edges, and snow deposition and melt characteristics associated with openings would be changed.

In spite of the forester's care, any abrupt cutting edge, at any relative location or orientation, may at some time be subject to damaging force from a freak wind storm. And the longer any given edge remains, the greater is the chance that disaster may strike it.

The ability to balance all aspects of true fir regeneration cuttings has not yet been acquired. The overriding consideration is establishment of new seedlings. Other aims must be accorded priorities in order of local importance. Part of any long-range management planning should be facilitation of salvage of possible timber losses.

Red fir, particularly since it is a relatively high elevation species, is probably more subject than white fir to wind exposure on ridges and abrupt changes of topography. A summary of the recommendations for locating cutting lines, by Alexander (1964), although specific to spruce-fir forests in the Rocky Mountains, very probably fits many conditions encountered in our true fir forests in the Sierra Nevada and Cascade Ranges.

Where choice of leave trees is possible along cutting edges, avoid these kinds of trees:

1. Intermediate or suppressed crown classes.
2. Heavy leaners.
3. Those with obvious decay (in butts, "mistletoe cankers," etc.).
4. Those with large fire scars.
5. "Twinned trees," that is, those close-grown (because of usual scars and butt rot, and incomplete root systems).

Retain these kinds of trees:

1. Dominant and codominant crown classes, and particularly those trees which have had free growing space for a long time.
2. Those with perfect tops (for cone production).
3. Those having relatively light or no dwarf mistletoe infections in crowns or stems.

Most data for the present study were obtained at edges of clearcuttings for release or regeneration. To survey possibilities of true fir regeneration more completely, we have started numerous replications of shelterwood and small clearcuttings at Swain Mountain. Damage in and adjacent to these areas will be studied closely.

SUMMARY

Gordon, Donald T.
1973. **Damage from wind and other causes in mixed white fir-red fir stands adjacent to clearcuttings.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 22 p., illus. (USDA Forest Serv. Res. Paper PSW-90)

Oxford: 174.7(794): *Abies* spp.: 221.1:421:423.4:453.
Retrieval Terms: Abies magnifica; Abies concolor; wind damage; wind stability; clearcutting; snow damage: insect damage.

Damage to true fir stands was studied during 6 years at Swain Mountain Experimental Forest in northeastern California. Four study areas adjoined clearcuttings; one study area lay within light partial cuttings.

During the first 3 years, insect-attributed mortality dominated timber losses. Sometime during the fourth winter, northerly winds caused much damage, chiefly stem breakage. Evidence indicated that tree crowns were heavily laden with snow when wind struck them. The hurricane of October 12, 1962, blowing from the south, caused additional heavy wind damage at the beginning of the fifth winter, less than a year after the other destructive storm. Trees were known to have no snow loads when the hurricane struck, and damage from windthrow far exceeded breakage. In the sixth winter, wind damage was almost absent.

Causes contributing to wind damage included bole rot, root rot, and fire scars. Damage increased with proportion of tree diameter rotted. Size of fire scar apparently influenced damage, but no reliable trend was evident in the sample studied.

Height of break was analyzed in relation to size and crown classes of trees damaged. A mechanical stress point is the apparent primary factor in breakage; it appears to move upward as tree size increases, and is influenced by other factors.

The number of insect-attacked dead trees rose and fell during the study. It seems probable that slash from logging, and later from wind damage, increased breeding material and influenced subsequent populations. Insects mainly attacked small unmerchantable fir trees, particularly those in suppressed crown positions, rather than large ones.

Snow damage was found to be confined mainly to small, unmerchantable trees. Poles (4 to 12 inches d.b.h.) were particularly affected. Study areas consisted principally of old-growth stands, however, and opportunity for detailed investigation of this class of damage was restricted.

Some of the wind-damaged trees were removed in salvage logging, reducing insect breeding material and fire hazard.

Findings of the study are in agreement with results reported by other investigators and indicate that damage outside of unusual storm effects should not create an obstacle to true fir management. To reduce wind damage where possible, care should be taken to see that leave trees are relatively windfirm, and that topographic influences on wind currents are not ignored.

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Damage to timber surrounding clearcuttings and in one light selection cutting in mixed white fir-red fir stands was monitored for 6 years in northeastern California. In some years, bark beetles apparently killed more trees than did wind damage, but in two of the study years, severe wind storms caused much damage. One storm produced mainly breakage, apparently influenced by snow load. The other, a hurricane, produced mainly windthrow. Relation of damage to tree size, crown class, and relative location reveals some trends. Study of height of breaks suggests that a mechanical stress point is influenced by tree size and crown class and other factors. Snow was the third most prevalent cause of damage, but applied only to smaller trees. Some indications for management of fir stands can be found in study results.

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LANDSCAPE CONTROL POINTS:
a procedure for predicting and monitoring visual impacts

R. Burton Litton, Jr.

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CONTENTS

THE AUTHOR

R. BURTON LITTON, JR., holds appointments with both the Forest Service and the University of California. He is a landscape architect with the Station's forest recreation research unit, and professor and chairman of the University's Department of Landscape Architecture, at Berkeley. He earned a bachelor of science degree in landscape architecture (1941) at the University of California, Berkeley, and a master of landscape architecture degree (1948) at Iowa State University. He joined the University faculty in 1948 and the Forest Service in 1969.

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Generalizations about esthetics and protection of "natural beauty" are of small help to the land manager. He needs some way to anticipate the visual impacts of management alternatives, some way of assessing the sensitivity of the landscape as it may be affected by possible alterations. In planning for multiple use of the land, he needs a procedure that can accommodate the different perceptions of changes in the landscape that are inherent in various disciplines.

An approach that may be helpful is to use a network of Landscape Control Points (LCP)—backed up by plots of visible areas shown on topographic maps, panoramic photographs, sketches, and overlays. The network has two purposes: (a) to emphasize the landscape as a scenic resource; and (b) to contribute to more effective control of change through an orderly process of direct field review. This approach can help the land manager visualize alternatives and enable him to choose those most fitting in a given situation.

An individual LCP is a fixed station from which a broad, intermediately distant view of the landscape may be seen. In an earlier report, I described three locations of the observer as he looks upon a visual objective: "observer inferior"—if he is below it, "observer normal"—if he is at the same level, and "observer superior"—if he is above it (Litton 1968, p. 5-10).

In *figure 1,* the observer is in a "normal" position and the distance is that of the "middle ground," defined as a distance range of one-half to 5 miles or more to the ridge (Litton 1968, p. 3-4). Other observer positions ("inferior or superior") would do as well just so long as there is an unobstructed view of the landscape's main structure—its form and space. Variables in the objectives' size and shape, color brilliance, and atmospheric and light conditions make it difficult and misleading to give set distance limitations. In another example *(fig. 2),* a square selective cut, ½ mile by ½ mile, is readily visible—yet subtle—at a distance of 9 miles. Arbitrary rules for fixing point locations or defining view characteristics cannot substitute judgment to be exercised in specific regions and places.

This paper outlines a five-step procedure for locating and using Landscape Control Points to study landscape and the visual impacts of alterations, describes the criteria for locating such points, explains three different ways of plotting the visible landscape, and offers a case study of how the procedure was applied on the Teton National Forest in Wyoming.

FIVE-STEP PROCEDURE

Establish Landscape Control Points

• *Step 1*: Establish a network of LCPs to give a reasonably continuous view of an extended area.

As an example, a set of viewing stations along the highways and roads of a National Forest provides a visual sampling of that Forest. The landscape seen would be but a small part of the Forest's total area, but it would represent a significant image most readily available to the public. Ideally, the LCPs should overlap with one another so the comprehensiveness of a continuous visual corridor is developed. It is also desirable for LCPs to give different views of the same landscape segment—especially for segments judged to be scenically significant or more vulnerable to impacts of use than others.

A network could also be built upon other means of coverage, such as using points on a grid system or selecting good viewing points from topographic maps and stereoscopic air photos.

Plot Visible Landscape

• *Step 2:* Plot on a topographic map the limits of the visible area seen from each LCP.

This plotting can be done in the field by translating observed visual boundaries into lines on a map. The areas seen from each viewing station are joined together so that a generally continuous plot of visibility is obtained. At the same time, what can be seen from each LCP can be identified.

Several more refined methods of determining the limits of visual areas and their map location are also possible: (a) the use of hand-drawn sections devel-

Figure 1—View of an intermediately distance landscape from a Landscape Control Point. The observer is in a "normal position," seeing the object at the same level. (Pat O'Hara Mountain, Park County, Wyoming)

Figure 2—Square selective cut, one-half mile square, on private land in the Hayfork Ranger District, Shasta-Trinity National Forests, California. The observer can see a distance of 9 miles.

oped as rays from a Landscape Control Point; and (b) application of the VIEWIT computer mapping technique (Amidon and Elsner 1968). Both of these techniques have certain advantages of convenience and accuracy compared to field plotting. Working in the field does, however, provide the additional opportunity for making qualitative observations about the particular landscapes involved. A combination and balance between field and office methods of plotting should be the goal.

Photograph Panoramic View

• *Step 3:* Photograph a panoramic view from each of the LCPs, selecting a suitable time of day and season for each situation.

Replication of the same view at different seasons of the year will be needed to represent changing emphasis in the way the landscape looks. The photographic view serves as a general record taken from a specific station at a specific time. It will also be useful as a base for sketch overlays which result from studies of various project proposals. As a guide to recording the photo data, see the publication by Magill and Twiss (1965).

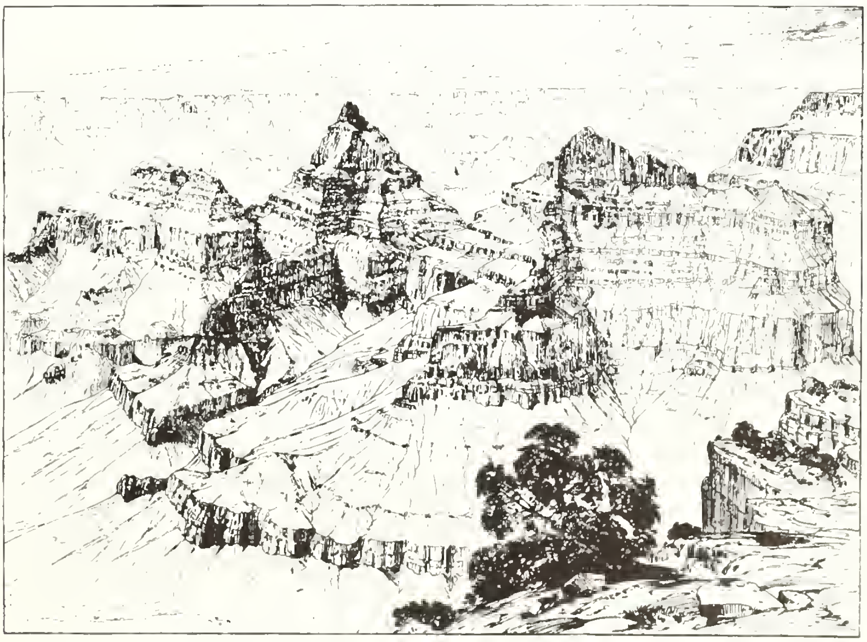
Equipment such as 2¼- by 2¼-inch twin lens reflex camera mounted on a pan head with level bubble will produce both good normal photographs (about 45° angle of view) from single negatives as well as broad view panoramic mosaics from a set of negatives. More specialized cameras, such as the Widelux (Panon Camera Shoko Co., Ltd.) or Panoram 120 (Burke & James, Inc.) produce wide angle views (140° and 120°, respectively) from a single negative.[1]

Prepare Perspective Sketches

• *Step 4:* For more specific parts of a broad photographic panorama, prepare perspective field sketches as a base for more precise or finer grained studies of possible changes and alternatives.

A sketch might well direct attention to the particularly sensitive landscape related to a feature, such as a dominant mountain peak or lake. Drawings of this kind do require a certain expertise, but they offer a means of concentrating upon major compositional aspects of the landscape while at the same time simplifying certain complexities associated with detail. In the realm of scientific art—not to be compared to "field sketches"—the remarkable Grand Canyon drawings of William Henry Holmes show how well the landscape may be interpreted through drawings (Dutton 1882) *(fig. 3)*.

[1]Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.



igure 3—William Henry Holmes' drawngs of the Grand Canyon in Arizona, itled "Vishnu's Temple," shows how vell landscape can be interpreted hrough this medium.

Project Impact of Change

• *Step 5:* As elements of a management plan or a Forest Service multiple-use plan are studied and proposed, use the Landscape Control Points and the graphic information derived from them to project the possible impacts of planned proposals.

While ideas for the physical change are still tentative, their consideration and discussion of implications might well take place on the ground at the pertinent LCPs. As plans change from ideas to specific alternatives of physical design, projected graphic versions may be prepared as overlays to the photographic record (Step 3) or overlays to the sketch record (Step 4). Then prepared visual displays may be considered on the ground, at the pertinent LCPs.

The results of carrying through to Step 5 should provide greater recognition that various resource management decisions carry seeds of different visual changes in the landscape. Not all professional disciplines are used to thinking in terms of visual end products. And the integration—in some degree—of the various inputs of different disciplines could be aided through this use of visual devices related to the landscape.

LOCATING LANDSCAPE CONTROL POINTS

Criteria for LCPs affecting their location and use involve relationships to: (a) roads and trails, air routes; (b) areas of congregation and concentrated use; (c) overviews covering landscapes of special value; (d) places and conditions offering best viewing opportunities; and (e) overlapping fields of view and different views of the same landscape segment.

Roads and Trails

Roads are more than a route between points; they are a viewing platform giving a visiting observer major impressions of a National Forest or other wildlands. The moving viewer can receive a complex set of images about the landscape that cannot be duplicated by the view from a single static point. Yet an individual LCP can represent, in some generality, a summary aspect from a particular section of road *(fig. 4)*.

The type of road offers a clue as to relative importance of particular viewing points. A Federal highway, for example, is more critical than a local Forest system road because of larger traffic volume. Yet overviews from Federal or State highways within National Forests show no immunity from impacts of use that lie heavily on the land *(fig. 18)*. So also with local roads. All roads have importance, however, in providing a comprehensive sense of a region and in demonstrating the visual aspects of resource management—whether compatible with the landscape or not.

The length of time a particular landscape can be seen from one or more segments of road (Atkinsen 1965) and the number of times that an objective area may be sighted (Elsner 1971) should both figure in the selection of LCPs *(figs. 7,8)*.

Trails, because of pedestrian rate of travel and opportunity for concentration upon nearviews or de-

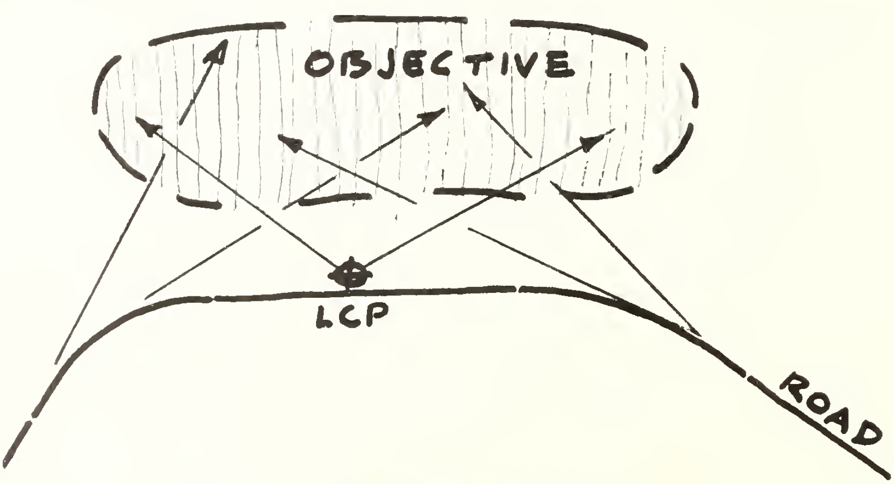


Figure 4—One Landscape Control Point can represent several views from a road or a section of it.

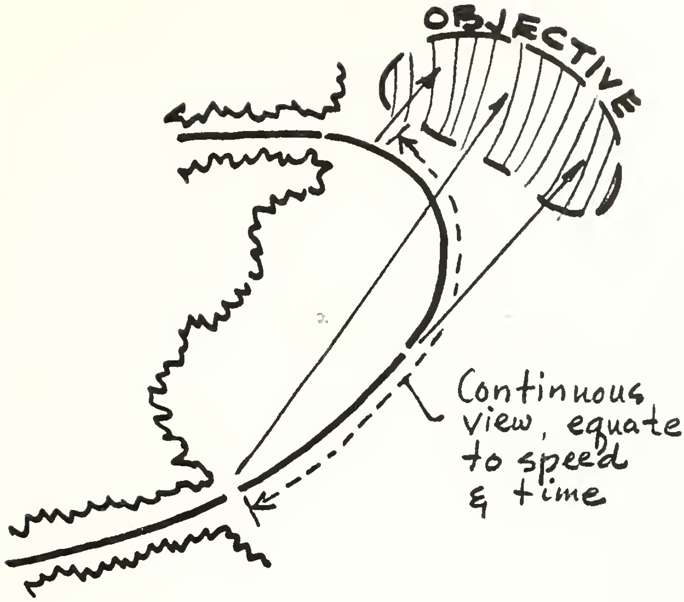


Figure 7—Continuous road viewing of one objective area.

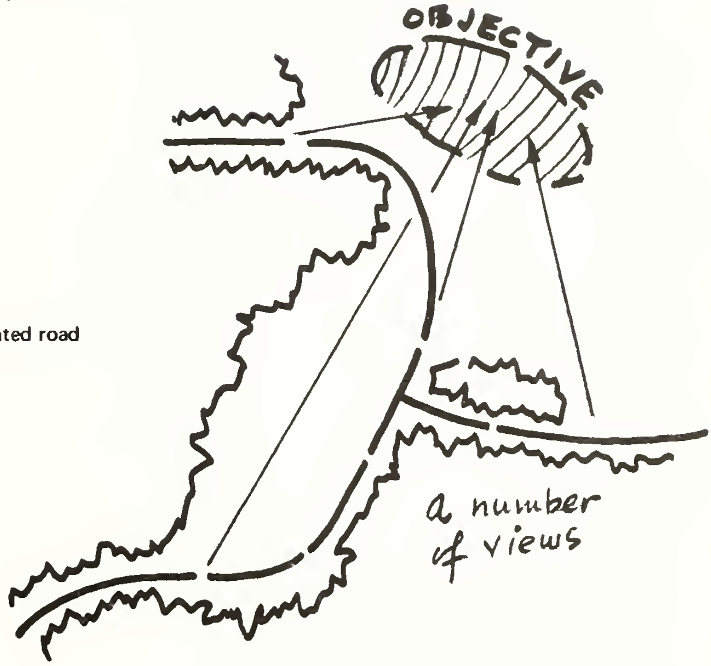


Figure 8—Intermittent and repeated road viewing of one objective area.

tail, are also important as the sites for viewing stations. A number of significant situations can be identified. Trailheads, where car travel stops and travel by slower means begins, represent a pedestrian concentration that may coincide with an important outview. Trails within Wilderness Areas—especially near forest boundaries—often include views into areas where timber cutting or road building are allowable. From such wild area points it must be assumed that sightseers will be especially sensitive to signs of manmade change that may be incompatible with the landscape (Lucas 1964). Thus it appears that trail LCPs from wilderness into the thresholds of wilderness serve a special purpose. Then, too, with trails representing slow travel and ease of stopping, vista points might well be used for longer periods of time and perhaps more critically than view points related to roads. LCPs associated with trails represent another link in the build-up of an over-all regional understanding.

The scope of this study has been limited to ground viewing. Visibility from air routes should also be taken into account and would add another measure of criticality. Techniques for visual monitoring by air have not been included here.

Areas of Concentrated Use

Congregation areas and points of concentrated or extended use indicate likely locations for LCPs. Scenic viewpoints or rest stops along roads are exam-

Figure 5—Panoramic landscape, a compositional type, as seen along a heavily traveled highway, on the Grand Mesa National Forest, Colorado.

Figure 6—Feature landscape, a composition type, as seen along a heavily used highway, near Challis, Idaho.

ples of short term viewer congregations—a number of these have been used in the case study. Recreational facilities, such as ski areas (base areas and lifts in particular) or swimming beaches, represent concentrations of users who will have extended stays and numerous opportunities to view their surroundings. Campgrounds, where recreationists may "live" for a few days or a few weeks, should be represented by LCP locations if significant outviews are obtainable. Areas which are privately held, where people live or where urbanization exists, should be recognized as sensitive to the visual impacts which may come within view (USDA Forest Service 1970); these need to be included as critical locations for LCPs. Urbanization which expands into new places also can enlarge the total area that can be seen.

Landscapes of Special Value

Landscapes that can be recognized for their special merits must be accounted for in locating LCPs. Scenic outlook points along a road, for example, tend to use "observer superior" or "observer normal" positions which typically offer a comprehensive overview of some one of four types of landscape compositions (Litton 1968, p. 23-35). These compositions are identified as panoramic, feature, enclosed, or focal landscapes *(figs. 5,6,9,10)*. Each one may be looked upon as having particular kinds or zones of sensitivity where visual impacts of manipulation will be conspicuous. In these circumstances, the LCP enables the observer to have directed surveillance where disruptions or distractions would be most damaging: (a)

Figure 9—Enclosed landscape is a compositional type that is particularly sensitive to the visual impact of manipulation. (Tomales Bay State Park, California)

Figure 10—Focal landscape is another compositional type in which the visual impact of manipulation would be conspicuous. (Machias River, Washington County, Maine)

near the closeby elements of a panoramic landscape; (b) toward a feature itself or areas (i.e., vegetation patterns) near or closely linked with the dominant feature of a feature landscape; (c) toward the expanse of floor and walls (their integrity) of an enclosed landscape; and (d) at the focal zone (convergence area) of a focal landscape.

LCPs can and should be located to account for such visual nodes as these specific landscape compositions. The higher the observer position may be, the more complete (and useful) the landscape view will be. These views need not bear any relationship to designated observation spots along a road or trail.

Conditions Affecting Viewing

Seasonal changes and the variations of sunlight angles during the course of a day will enter into how effective a particular LCP may be. Winter aspects may include the maximum color value (brightness) contrasts between reflective snow patterns and dark conifer cover. Or the presence of conifer patterns within deciduous hardwoods will be revealed in winter—a relationship apt to be obscure in summer. Spring and fall can present some other insights into vegetation pattern because of heightened contrasts in foliage color. The mosaic of various surfaces visible in combination needs to be considered for variations of seasonal change or annual stability: mineralized or barren surfaces, grassland and forbs, brushland or chaparral, conifer forest, hardwoods, and water bodies.

For a comprehensive sense of how contrasts in the landscape change through the year, photographic documentation should record that range. It is a key point that the visual image which is the most vivid—the one containing maximum seasonal contrasts—should be the most graphic record of the landscape.

The orientation of terrain and relationship to sun angle will contribute to clarity or obscurity of visual images from a given LCP, affecting both direct observation and photography. The north-facing slope tends to be obscured during mid-day by the shadows of backlighting–it will be better revealed as it may be directly lit during early morning or late afternoon. South-facing terrain with front and side lighting can be expected to show up clearly during the mid-day hours–and with more modeling early and late in the day. Westerly faces can best be viewed in the afternoon hours, while morning will be a better time for east facing surfaces.

Overlapping Fields of View

Certain segments of the landscape can typically be seen from a number of different observer positions and a variety of orientations. LCPs as tools for visual management need to reflect these differences. The characteristics of a frontal view can be so dissimilar from a sharply foreshortened one that the two may seem to have little in common. One view (one LCP) may also be judged to hold priority over another. Judgment of priority could be based on factors, such as seeing a greater expanse, having more relationships among parts revealed, or an advantageous orientation. This judgment carries over into the nature of how proposed manipulations will be seen–what disappears in one aspect can be conspicuous–perhaps degrading –from another viewing station. Making use of several LCPs should be expected to lead to possible relocation of proposed manipulations or to alteration of their form or scale.

PLOTTING THE VISIBLE LANDSCAPE

Plotting the plan coverage of areas visible from a Landscape Control Point may be done three different ways:

1. By direct field observation and reference to a topographic map.
2. By drawing a series of sections radiating from the LCP, transferring points from section to topographic map, and connnecting points into visual limit lines on the map to form a "sectional" plot.
3. By employing a computerized technique, such as VIEWIT, which computes the area visible from one LCP (or many) and produces an overlay map (Elsner 1971).

Each of these methods offers certain advantages or disadvantages, such as requiring more time or less, greater accuracy or less. As an example, compare results from the three procedures, and their differences based on a common LCP *(fig. 11)*.

Direct Field Plotting

By taking a topographic map into the field and going to a selected LCP, the observer may transfer the visual limits of his observation to the map. This procedure will be familiar to anyone who has used a topographic map for location and orientation. It merely goes a step further in which visual boundaries are estimated relative to land forms and other elements, and those boundaries are set down as lines on the map.

The U.S. Geological Survey 7½-minute maps (1:24,000 or 1 inch = 2,000 ft.) are most desirable as base maps. Portrayal of land forms and features is normally clear enough and at sufficiently large scale so that locating visual limits can be done with relative ease and accuracy. These maps reduced 50 percent to a scale of 1:48,000 (1 inch = 4,000 ft.) can also be used and offer the convenience of smaller size. However, 15-minute topographic maps (1:62,500 or 1 inch = approx. 1 mile) are considerably more difficult to use because of possible errors in land form identification and problems of making the small scale plot. Therefore, their utility should be considered marginal.

A number of factors will affect the results of plotting in the field. Selection should be made of those times of day which will give the advantages of positive sun angle.

For any given LCP–which establishes a general orientation of view–sidelighting should be most advantageous. The flatness of front lighting makes it somewhat less desirable because land forms tend to merge with one another. Back lighting should be avoided, because of the obscurity it casts upon specific parts of the landscape. Weather or atmospheric conditions will also be recognized for the effects they have on visibility and can affect the quality of field work to be expected. The seasonal aspects of regional weather should enter into selection of better times for this particular kind of exercise.

Apart from direct plotting, it may also be the purpose of field work to compare a VIEWIT overlay or "sectional" plot to the actual landscape involved. This would be followed by photography (Step 3) and sketches (Step 4).

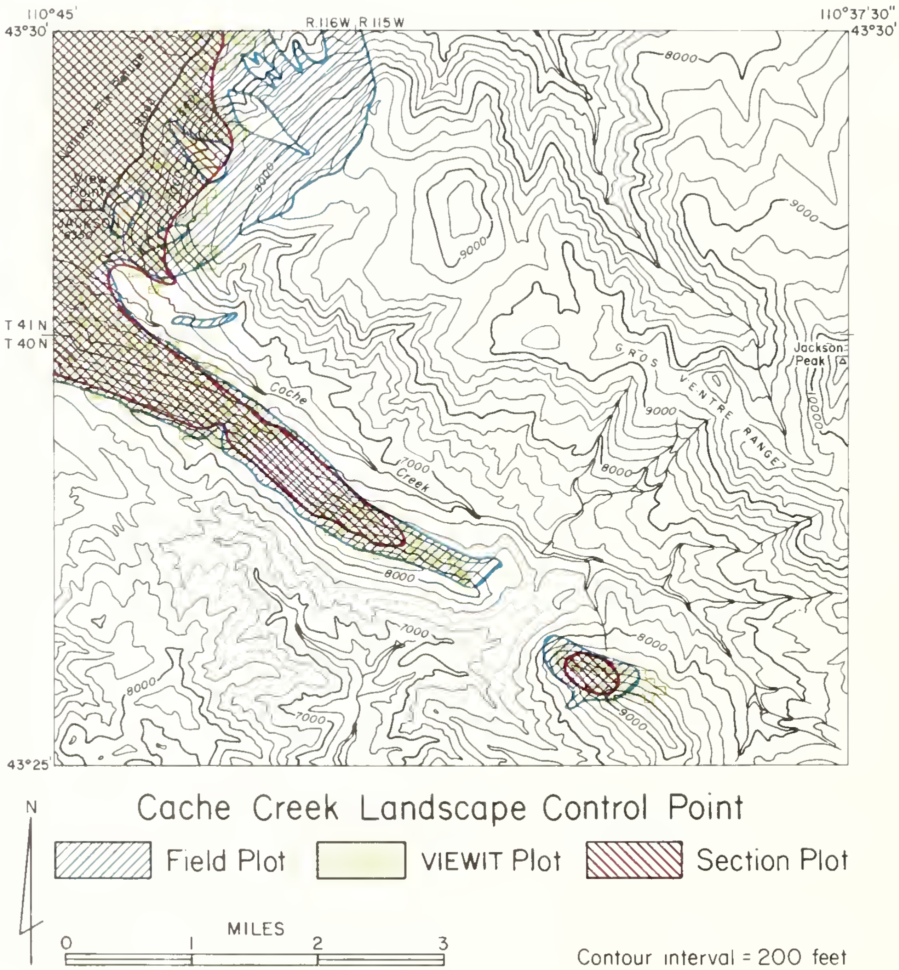


Figure 11—Three ways of map plotting areas visible from a Landscape Control Point: (1) field plotting—direct observations and mapping the visual limits of what is observed; (2) plotting with sections—from a series of sections, lines of sight are drawn to determine visible and invisible areas; (3) computerized plotting, such as VIEWIT—using data on elevations, viewing location, and length of sight line to produce overlays. Photo mosaic shows what is seen from a Landscape Control Point at Cache Creek, Jackson, Wyoming.

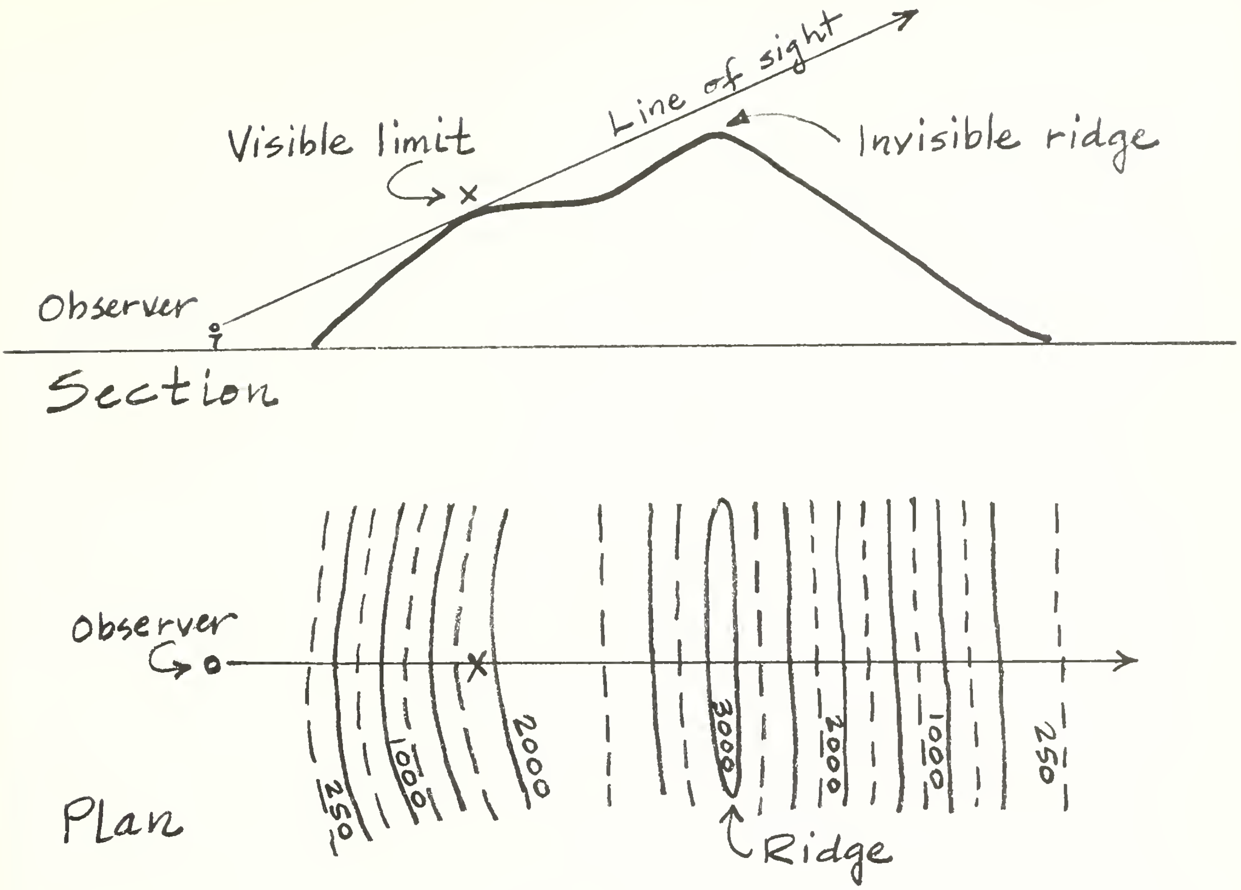


Figure 12—Common error in field plotting. The visible shoulder line is mistaken here for the ridge line.

Direct plotting has certain advantages. The individuals who are doing the work (several people can assist one another in confirming what is observed) must examine the landscape carefully. Peripherally, this approach may be thought of as drawing attention to the landscape as a scenic resource and could serve as an introduction to inventorying the landscape.

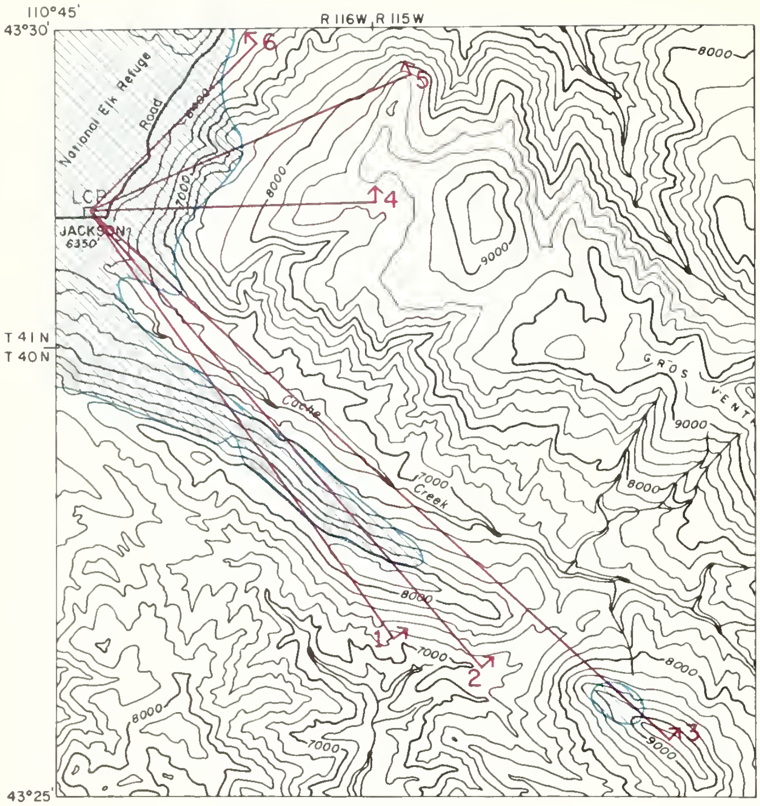
Plotting the sighted visual boundaries should take but little time. The field plot shown in *fig. 11* took 45 minutes at the site. Photography will best be done at the same time as the visual plot so that the two will show similar limits.

Some disadvantages to field plotting may also be noted. It may not be possible or practical to visit the site. Excessive distance or bad weather can well be impediments. Field plotting is done with variable accuracy and efficiency, depending upon the capacity and tendency of individuals. Furthermore the method is imprecise. The identification of all small invisible pockets should be considered impossible. And even if it were accomplished, it would not materially improve upon the generalized location of sighted limits. Plotting visual boundaries is only a means of indicating a particular area which may be subjected to various future manipulations.

Observers in the field will tend to overestimate visible limits. In *fig. 11,* the field plot embraces a larger area than either of the plots made by other two methods. This is most apt to be explained by thinking that ridge lines rather than shoulder lines are visual limits as the plotter looks for coordination between the map and the observed landscape *(fig. 12).* Additionally, invisible pockets—or some of them—are not readily apparent in the field.

Plotting with Sections

Visual limits may be plotted from a series of sections laid out as rays from a single LCP *(fig. 13).* With a U.S.G.S. 7½-minute topographic map, an LCP serves as the point of origin for whatever number of sections may be needed to define and locate a visual



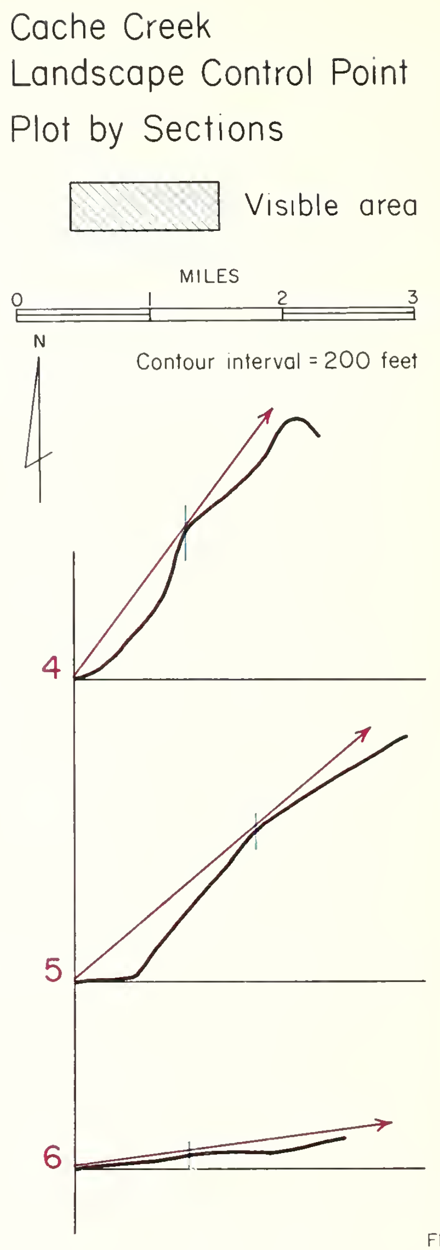
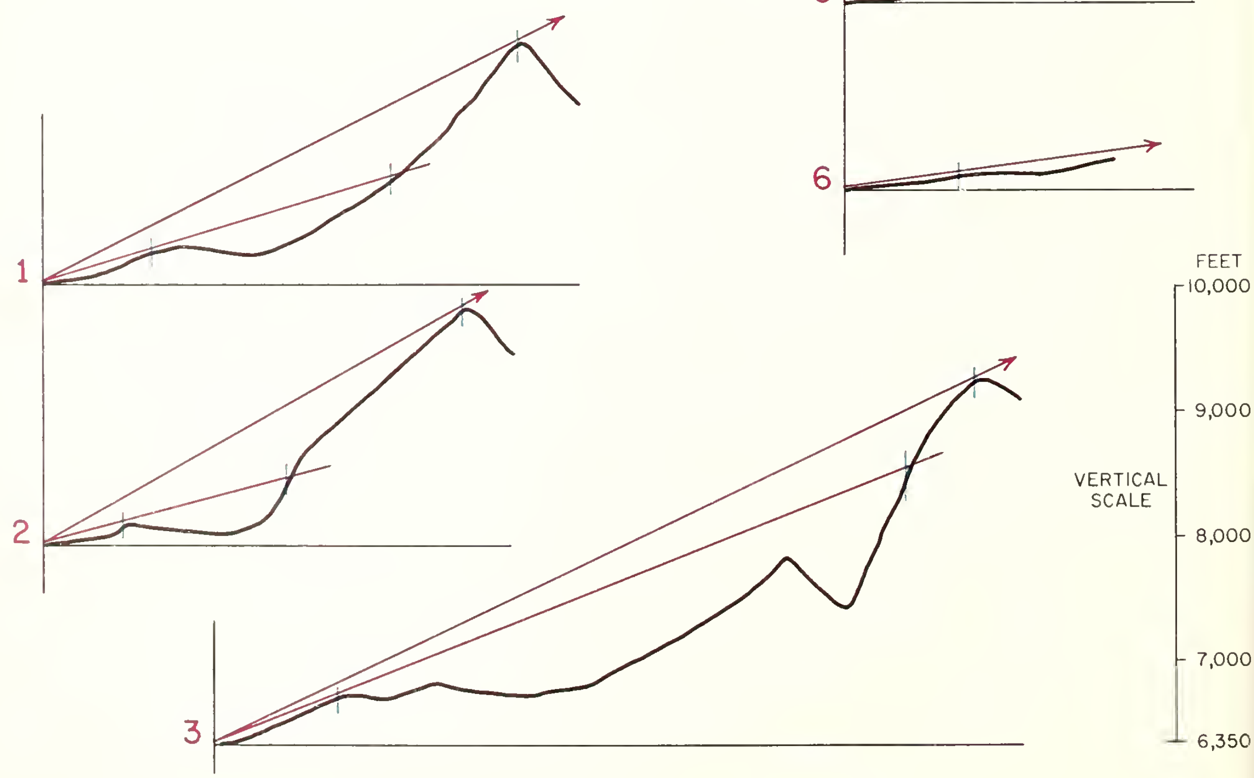


Figure 13—Plotting with sections from a Landscape Control Point at Cache Creek, Jackson, Wyoming. A series of sections are laid out as rays from the LCP. Lines of sight extend from each section. Extent of visible areas is plotted on a topographic map.



boundary in plan. On each section, lines of sight are drawn so that the extent of both visible and invisible areas may be determined. These results are then transferred back to the plan (topographic map) and point locations are connected by lines.

How many sections are needed to locate a plan line? Close examination of the particular topography involved will serve as a guide to both location and number of sections. Placement should particularly reflect characteristics of ridges: Their peaks, saddles and low points, beginnings or ends and changes of direction. Where valleys (enclosed landscapes or lake basins) may be screened by surrounding land forms, sections need to be located so that hidden pockets can be defined. So that topographic variations may be better reflected in sections for more accurate plan plotting, graphic sections should be vertically exaggerated two to five times the horizontal scale. (At a vertical scale of 1 inch = 800 ft., graphic accuracy in plotting will be about ± 20 feet in elevation.)

Although it is possible to make a visibility plot by exclusive use of sections, they may also be useful in an auxiliary way. A field plot could be completed or its accuracy checked by constructing sections. This method combines several advantages–field reality (sense of the landscape) with the control of the graphic sections.

Sectional plotting can be done in the office. Travel to the actual area is not necessary. Therefore, both travel time and cost are avoided. Those necessary weather conditions for satisfactory field work do not have to be met since the office procedure can be a rainy day job.

The construction of sections and their application to defining visible areas is a simple undertaking. Only a minimum of instruction and minimum drafting ability are required. Drafting tools and supplies are those that would normally be on hand in any office. More tenacity than skill is involved. The only absolute necessity for going ahead is availability of topographic maps.

Plotting with sections has certain limitations. Sections and their related LCP determined wholly from a topographic map may not reflect actual landscape visibility. The LCP could be screened by vegetation or by terrain detail going undetected because of a gross contour interval. This limitation should again confirm desirability of combining the sectioning procedure with some knowledge of field conditions so as to avoid errors of judgment.

Sectional plotting in the office avoids cost and time spent in travel to a field point, but is a time-consuming job. Amidon and Elsner (1968) indicate that "the cost of constructing hundreds of profiles (sections) would be. . .prohibitive." Cost comparisons among the three plotting methods are not known except that for *fig. 11* (Cache Creek LCP), the field plot took 45 minutes and the sectioning plot (eight sections) took 1½ hours. Coding the Cache Creek 7½-minute quadrangle map required 8 hours, and the computer time for the single LCP printout was 15 seconds. In addition, the computer data base may be used for 11,288 different visibility plots as each coded cell may represent an LCP (i.e., another plot) while each of the other two methods gives only one plot.

Computerized Plotting

Computation of terrain visible from a given point can be done by employing VIEWIT, a FORTRAN subprogram developed by Amidon and Elsner (1968). The input consists of elevations put into a coordinate system, and the selection of a viewing point, location and length of sight line. The end product is an overlay map.

In principle, plotting by sections and the VIEWIT procedure are similar. Lines of sight scan surrounding land forms and higher elements screen out lower elements.

The 7½-minute topographic map is again the source of data *(fig. 14)*. A grid is prepared with coordinates corresponding to the printing scale of six characters per inch vertically and five per inch horizontally. In this case, the grid or cell size is equal to two characters and covers 3.1 acres. For each cell, elevation was estimated by interpolation to the nearest 100 feet and is represented by two digits.

Translation of the topographic data may also be through the digitizer tracing contours. Each cell which is intersected by a contour is given that particular elevation to the nearest foot. Empty cells can be filled by interpolation of data in surrounding cells. The digitizer will simplify and speed up the elevation coding.

The major advantage of the VIEWIT procedure is the flexibility offered in plotting viewed areas as seen from any observation point (any cell) of a given matrix which has been coded. Once the elevational information has been gathered, any LCP and viewing distance may be chosen.

Other advantages are similar to those for sectional plotting. VIEWIT is an office procedure; it is economical in its efficiency, speed and flexibility. In theory, it requires no field work, but in practical application it should be used with field observations–materially shortening and simplifying field work.

The disadvantages of the VIEWIT procedure are, again, similar to those for sectional plotting. Actual visibility from a selected LCP may be screened by topography or vegetation that is not shown on the base map. For known vegetation, allowances can be made.

With more facilities obtaining computer services all the time, the potential for putting the VIEWIT program into effect is easier now than it has ever been.

Figure 14—Computerized plotting by VIEWIT program, from a Landscape Control Point at Cache Creek, Jackson, Wyoming. Lines of sight scan the visible area. Data on elevations, by coordinates, are obtained from maps. Each cell in the grid covers 3.1 acres. For each cell, elevation is established by interpolation. The computer produces an overlay that shows the maximum area visible from the LCP.

A CASE STUDY

Teton National Forest

How the five-step procedure in visual analysis can be applied is illustrated by a case study on the Teton National Forest in Wyoming. The choice of that Forest was suggested by a number of reasons. Very heavy tourist and recreation use of the Grand Teton and Yellowstone National Parks directly and indirectly involve the Teton Forest. More than 160 miles of State and Federal highways converging upon Jackson Hole and within it either pass through or provide views into this Forest. Air routes coming in and out of Jackson Hole give sweeping overviews of the area.

Jackson Hole is used as a focus and limitation within this report—treating more area only tends to be repetitious. It is of visual significance because it is common to both Grand Teton National Park and the Teton Forest. The basin is readily recognized to be a well defined space. Its floor is primarily open grasslands or sagebrush, providing unincumbered views of the Teton Range on the west and the lower ridges of the Gros Ventre Range on the east. From 55 percent (72 miles) of the 130 miles of improved or paved roads in Grand Teton Park, it is possible to see an enclosing ridge of the Forest on the east side. Because of heavy travel, it is significant that almost all of the 20 miles of Highway 89-187 between Gros Ventre River and Moran Junction affords eastward views of the Forest. Besides views originating from park roads and turnouts, there are the even more numerous opportunities of observation from pedestrian locations. Air views, while not emphasized in this paper, are also added to the ground views. It it not unusual to find National Parks surrounded by National Forest lands, but the degree of intervisibility between these two is particularly noteworthy.

Simply because certain areas are visible does not necessarily make them subject to alteration from timber cutting, road construction, or other activities. From within Jackson Hole, four kinds of activities can be observed on the visible slopes of the Forest: roads (State Highway 22, for example), powerline clearings, ski area clearings, and timber cutting. All of them cause visible changes in the surface pattern of the land through removal of vegetation and exposure of soil or sub-soil.

Areas of harvestable trees do remain and are subject to future cutting. A set of strip cuts in lodgepole pine (Curtis Canyon Timber Sale) made between 1956-1963 is visible along Highway 89-187 and especially from the Grand Teton National Park overlook. Public criticism of these conspicuous, manmade strips led to the Forest Supervisor's decision that they should be altered to fit better with the landscape. Such a recut poses what might be called a detail within management of the Teton Forest, yet it also raises the general problem of visual control. Additionally, it carries with it the need to recognize and control the visual changes which take place over time as successive cuttings of a working circle occur. This specific recut detail, then, contributed to the suitability of this particular Forest for study.

Application

To cover most of the Teton Forest that may be seen from within Jackson Hole, I set up nine LCPs. Locations were chosen primarily in relation to roads but also to reflect scenic turnouts and other points affording comprehensive views. Where certain views were essentially similar except for the difference of shorter or longer distance to terminal elements, I chose the shorter. As an example, the view toward Sheep Mountain and Jackson Peak from an LCP at Teton Village or one at the south boundary turnout of Grand Teton National Park (at Highway 89-187) is much the same, the difference being that the latter LCP is 5 miles closer to Sheep Mountain and Jackson Peak. From Signal Mountain (LCP No. 2) the maximum sightline distance is 12 miles. However, for all other LCPs, maximum sighting distance varies from 4 to 8 miles. Distances between LCPs are as much as 13 miles and as little as 3½ miles; their combination accounts for a continuously visible strip of landscape, although it contains invisible pockets (or visual voids).

No control points were established along Highway 89 north of Moran Junction, in the vicinity of Jackson Lake. This is because of virtually complete tree screening along the east and the nearby presence of the Teton Wilderness. But the Teton Forest "corridor"—the National Forest land area between the two national parks along this road—represents an especially sensitive management situation which would be a logical area for extension of the Jackson Hole LCP system.

One map *(fig. 15)* includes the framework made by the series of LCPs set up around the perimeter of Jackson Hole. The location of each viewing station and the relationship of one to another can be seen. The scope of view (a range of 75° to 205°) and the area visible from each point can also be seen. Since the map scale is small, a name was given to each LCP to confirm identity and general location.

Another map with photographic view *(fig. 16)* shows a single LCP imposed on a topographic map of larger scale than *fig. 15*. This LCP is an enlarged version of LCP No. 1 on the framework map. The larger scale plot (approximately 1/2-inch = 1 mile) makes identification possible as based on terrain characteristics. In practice this should be a workable scale for recording LCP coverage and the framework as well. The limitations of size imposed by this study's format precluded showing more than a sample of the LCP plot at this practically useful scale.

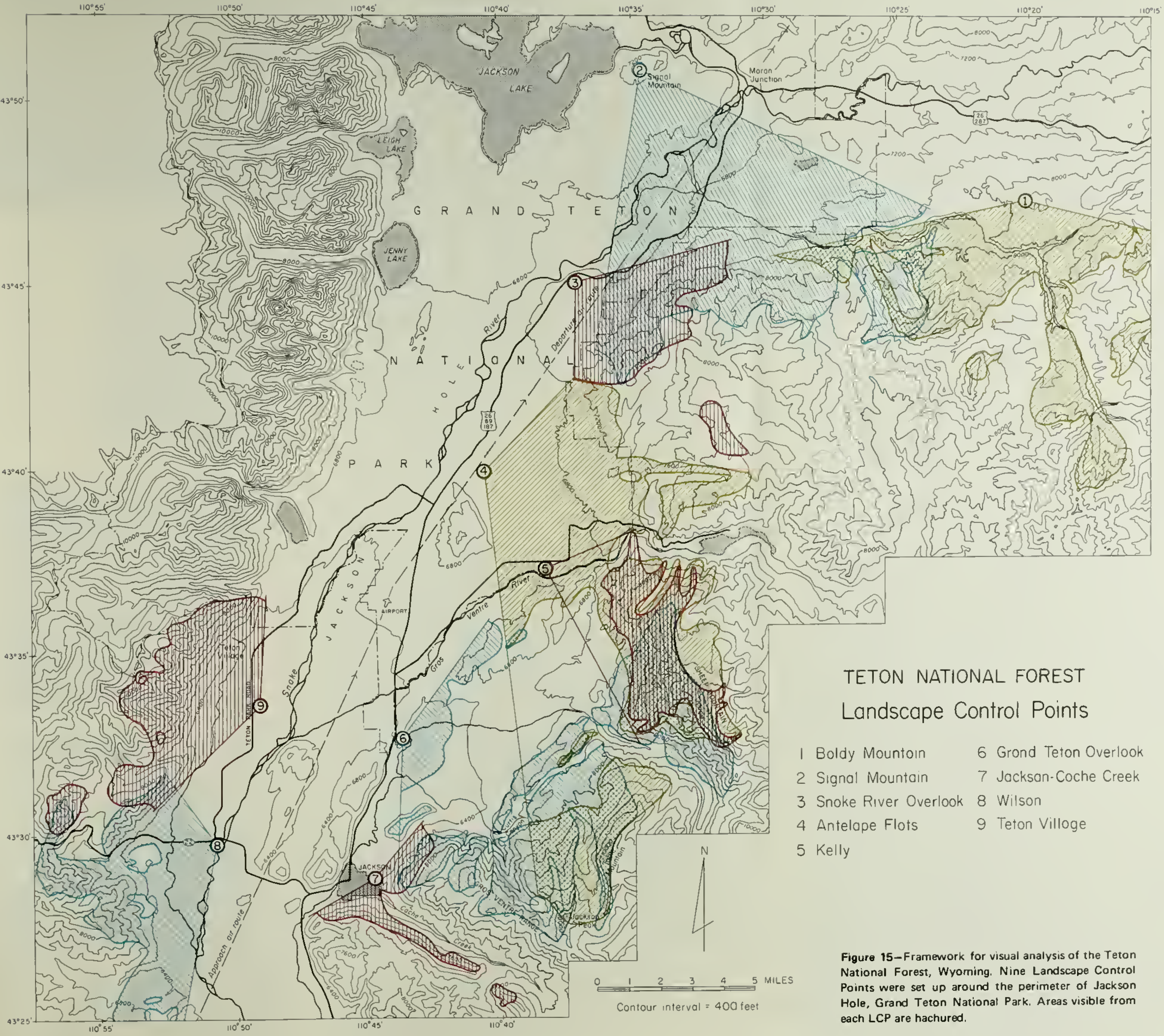
A set of four photographic panoramas *(fig. 17)* correspond to the views from four contiguous LCPs numbered 3-6 on the framework map. While these represent only a sample of the LCP views from the framework, they do show connected segments. These photographic panoramas are reduced for printing to a smaller size than practical in actual use. Even the photographic view *(fig. 16)* is only 1/3 the size of a panorama that would be useful in practice. The "working" panorama view needs to show characteristics of the landscape in such size and detail that overlays showing possible alterations are reasonably easy to prepare.

Two field sketches *(figs. 18, 19)* portray detail views taken from LCP No. 6 at the Grand Teton National Park overlook on Highway 187 near the fish hatchery. These pencil studies concentrate on the visual relationships of the Curtis Canyon clearcut strips upon the west slopes of Table Mountain. The cut strips stand out for their own pattern and also assume importance because they occupy a position close to Jackson Peak—a conspicuous feature along this ridge. Detail views may also be prepared photographically by use of a telescopic lens, but there are some advantages to freehand drawings. Sketches can abstract, simplify, and emphasize major characteristics in ways that photographs may not. The sketches are not intended to distort what they represent, but drawings can be a most helpful tool in providing interpretation of significant landscape characteristics.

Two revised sketches *(figs. 20, 21)* show possible ways in which the Curtis Canyon strip cuts *(fig. 19)* may be altered. Since the basic purpose of adopting a recut pattern here is to achieve a better fit with the landscape, certain of the visual design criteria used need explanation. In looking at the immediate surroundings, the most obvious natural characteristic is the expression of horizontal lines—transverse to the strip direction. The long and essentially level lines will be seen in the ridges above and below the cuttings, in the vegetation edges meeting the upper scree surfaces and in the edges of the lower grass lands contrasted to conifer forests. Natural openings seen here display continuity—the connection of one opening to another. The natural openings also tend to have and repeat a lens-like shape as well as a common alignment.

Because the man-made cuttings have a pattern which contrast strongly to that of the surroundings, they stand out. The suggested sketches rely heavily upon developing both horizontal line emphasis and a connection between openings. The changes, then, seek a unification that can emerge from repeating the concepts seen in certain landscape characteristics of this particular place.

The problem of reworking strip cuts represents a small and atypical application of this visual review procedure, but it does offer a specific demonstration of the concept. Most importantly, the review and criticism of visual alternatives such as these are not merely for selection of the solution which is judged to "look best." The examination of visual displays can, however, lead to constructive refinements incorporating the expertise of various disciplines. If graphic portrayals suggest such impacts as questionable regeneration conditions or erosive runoff, for example, then corrections should be made accordingly.

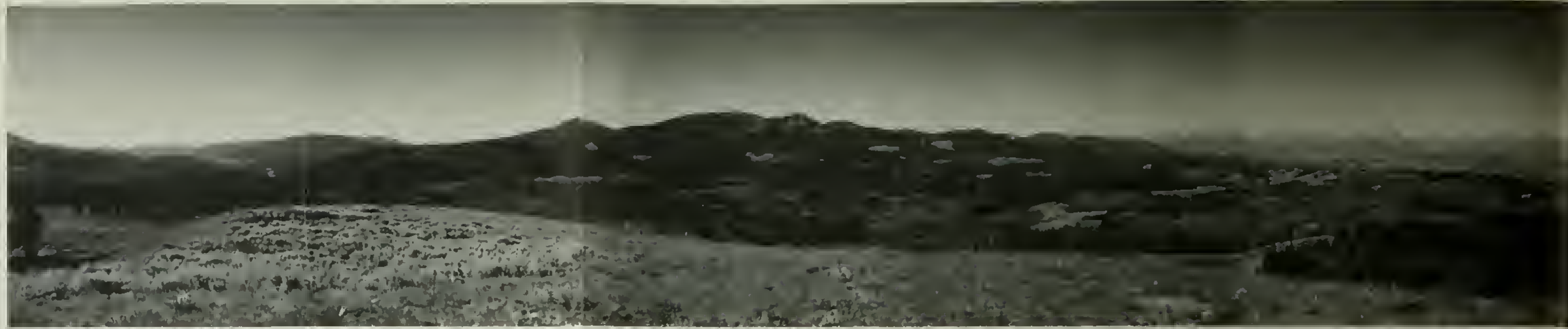


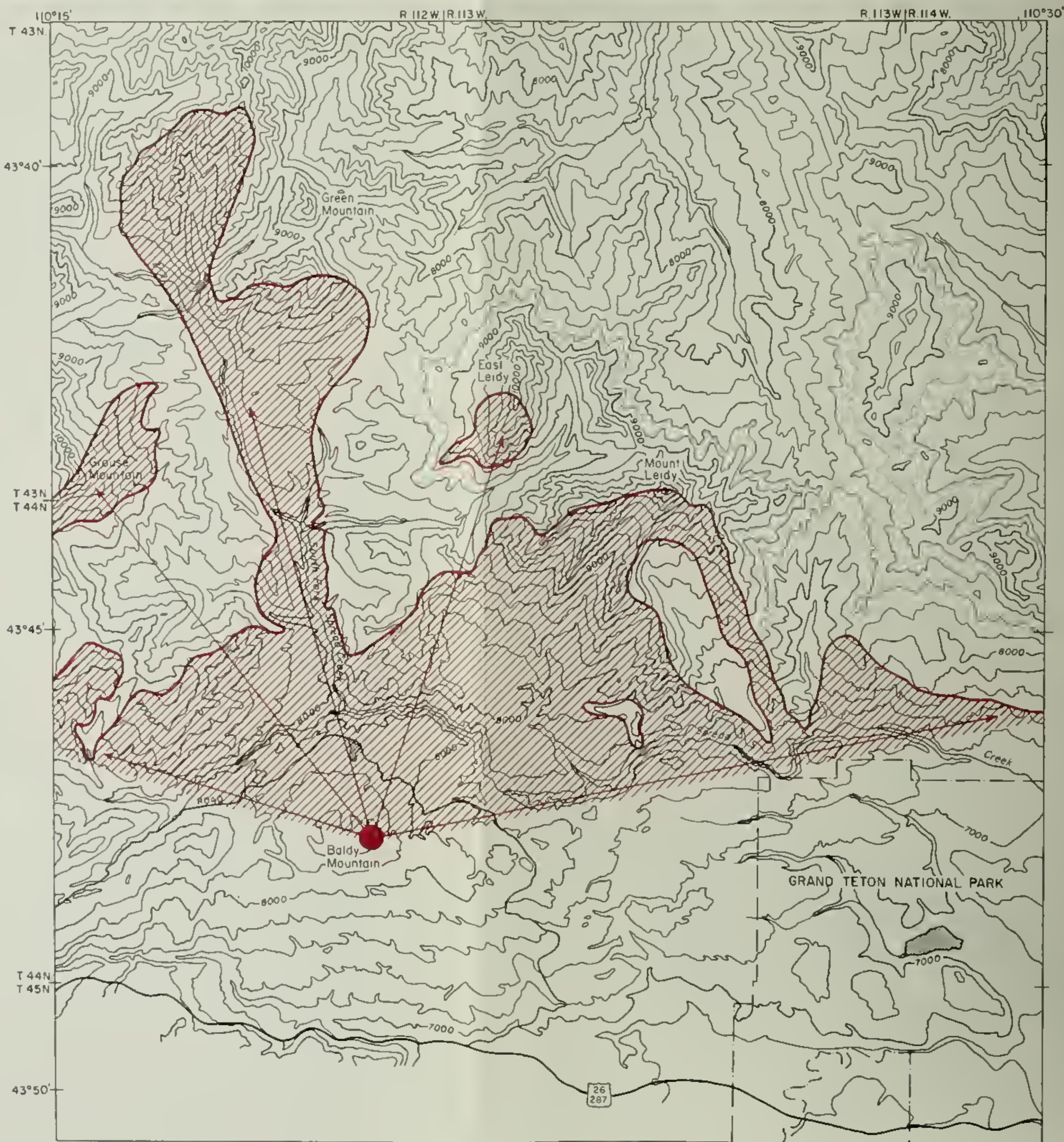
TETON NATIONAL FOREST

Landscape Control Points

1 Baldy Mountain
2 Signal Mountain
3 Snake River Overlook
4 Antelope Flats
5 Kelly
6 Grand Teton Overlook
7 Jackson-Cache Creek
8 Wilson
9 Teton Village

Figure 15—Framework for visual analysis of the Teton National Forest, Wyoming. Nine Landscape Control Points were set up around the perimeter of Jackson Hole, Grand Teton National Park. Areas visible from each LCP are hachured.





Baldy Mountain Landscape Control Point

Figure 16—Landscape Control Point at Baldy Mountain, Teton National Forest, Wyoming, with panoramic view of what can be seen from there. The LCP is an enlarged version of LCP No. 1 in *figure 15.*

LCP No. 3

LCP No. 4

LCP No. 5

LCP No. 6

Figure 17—Four photographic panoramas corresponding to views from four contiguous Landscape Control Points (Nos. 3-6 in *figure 15*), Jackson Hole, Grand Teton National Park, Wyoming.

Figure 18—Harvest cuttings at Curtis Canyon, Teton National Forest, Wyoming, as sketched from Landscape Control Point No. 6 (Jackson Peak, and Table Mountain shown) Grand Teton National Park.

Figure 19—Harvest cuttings at Curtis Canyon, Teton National Forest, Wyoming, as sketched from Landscape Control Point No. 6 (Table Mountain shown) Grand Teton National Park.

Figure 20—Possible way in which cuttings at Curtis Canyon, Teton National Forest, Wyoming, could have been altered.

Figure 21—Another alternative in the pattern of cuttings at Curtis Canyon, Teton National Forest, Wyoming, so as to achieve a better fit with the landscape.

SUMMARY AND CONCLUSIONS

Litton, R. Burton, Jr.
1973. **Landscape control points: a procedure for predicting and monitoring visual impacts.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 22 p., illus. (USDA Forest Serv. Res. Paper PSW-91)

Oxford: 907.1:U712.01.
Retrieval Terms: landscape management; visual impact; recreation areas; landscape control points; Teton National Forest.

Landscape Control Points—a network of permanently established observation sites—provide the forest manager with the means of studying the visual impact of alterations to the landscape. Observations are supported by topographic maps, panoramic photographs, sketches, and overlays. Visual analysis of the landscape is done by a five-step procedure: (1) establish a net of Landscape Control Points to provide a reasonably continuous view of the extended area; (2) plot on a topographic map the limits of the visual area seen from each LCP; (3) photograph a panoramic view from each LCP, selecting a suitable time of day and season for each situation; (4) prepare perspective field sketches as a base for more precise studies of possible changes and alternatives; and (5) use the LCPs and graphic information derived from them to project the possible impacts of planned changes.

Criteria for LCPs affecting their location and use involve relationships to roads, trail, air routes, areas of concentrated use, overview covering landscapes of special value, conditions that affect viewing, and overlapping fields of view and different views of the same landscape segment.

Several methods of plotting the visible landscape are available to the forest manager. They include: (a) direct field observation and reference to a topographic map; (b) drawing a series of sections radiating from an LCP, transferring points to a topographic map, and connecting points on the map to form a "sectional plot"; or (c) computing the area visible from one or several LCPs and producing an overlay map by computerized technique.

Use of the LCP framework is primarily concerned with predicting a range of alternative visual impacts upon the landscape. It can also demonstrate that some landscapes (as portrayed from a set of LCPs) are more sensitive to change than others. A case study of visual analysis on the Teton National Forest, Wyoming, illustrates this condition. As the characteristics of sensitive landscapes are better defined and better known, it should lead to better criteria and more exacting management.

Studying alternative kinds of changes, as presented graphically from a specific LCP, allows different disciplines to assess impacts as they may be interpreted from visual displays. This evaluation should offer an opportunity for thinking in visual terms—especially if this is not a typical concern for a given discipline. Using the examples of *fig. 20* and *fig. 21* as but two ways in which cutting patterns might be executed, what might your response be if your field was wildlife management? Silviculture? Hydrology? Engineering and logging technology? Landscape architecture?

If you prefer *fig. 20* over *fig. 21,* the reasons behind your response are what will be of value, not the mere preference. Those representing wildlife, logging systems, fire, and landscape architecture could be expected to have concern for the handling of edges or the relationships between margins and topography. Those representing silviculture, road engineering, soils, disease control, and landscape architecture could be expected to have concern for the size of cuttings, their location and distribution as related to the terrain. Points of agreement, disagreement, and open choice should lead to solutions which combine multidisciplinary objectives within visual end-products.

A visual display by itself may not present enough (or useful) information to a particular respondent. There will be the need to examine the scope of the problem which goes beyond the isolation of the display. Or there may be the need to investigate details that cannot be portrayed by graphically generalized images of the landscape.

Use of the LCP framework and procedure should lead to different disciplines getting together on choices. The more desirable alternatives may result from criteria which come out of the pilot LCP studies or sample applications in specific situations. The feasibility of blanketing a whole forest with LCPs is questionable, and the selection of both typical and critical samples may well be the best way of trying out this means of visual control. If issues are not considered sufficiently critical to warrant a complete survey, the LCP method could be applied in a more casual way—yet accounting for special problem situations.

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The visual impacts of alterations to the landscape can be studied by setting up Landscape Control Points—a network of permanently established observation sites. Such observations enable the forest manager to anticipate visual impacts of management decision, select from a choice of alternative solutions, cover an area for comprehensive viewing, and establish a method to integrate visual analysis with multiple-use planning. The visible landscape can be plotted by direct field observations, by laying out a series of sections as rays from a single LCP, or by a computerized mapping technique. Photographs and sketches document landscape characteristics. A case study describes a visual analysis of the Teton National Forest in Wyoming.

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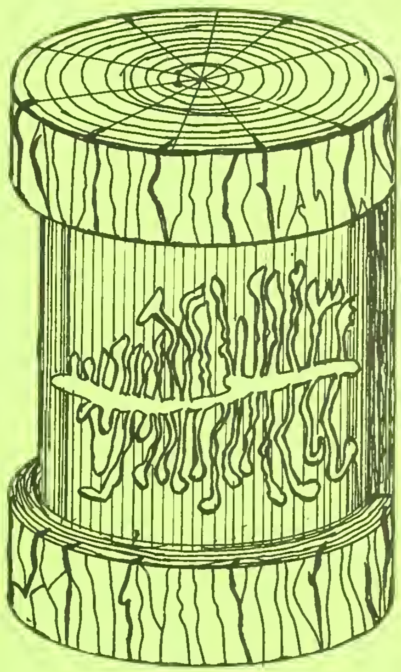
WEATHER, LOGGING, and TREE GROWTH associated with FIR ENGRAVER ATTACK SCARS in WHITE FIR

George T. Ferrell



USDA FOREST SERVICE RESEARCH PAPER PSW- 92 /1973

CONTENTS

THE AUTHOR

GEORGE T. FERRELL, a research entomologist, is studying the biology, ecology, and control of destructive forest insects, with headquarters in Berkeley, Calif. Native of Klamath Falls, Ore., he earned three degrees at the University of California, Berkeley: bachelor's in forestry (1959), master's in zoology (1965), and a doctorate in entomology (1969). Before joining the Station's research staff in 1969, he was a postdoctoral fellow at Simon Fraser University, British Columbia, Canada.

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Bark beetle epidemics in Europe and North America have often been associated with periods of drought, defoliator outbreaks, or stand disturbance, such as logging, windthrow, and ice breakage (Rudinsky 1962). Outbreaks of the fir engraver *(Scolytus ventralis* Lec., Coleoptera: Scolytidae*)*, resulting in severe depletion of stands of true fir *(Abies* spp.*)*, have occurred sporadically in every decade since 1900 in Western North America. Only a few of these epidemics have been studied, however, to determine possible underlying factors, such as drought or host tree defoliation (Stevens 1956; Wickman 1963). Investigations have been hampered by the lack of long-term quantitative estimates of *S. ventralis* populations and the associated fir mortality, as past surveys were largely confined to bark beetles infesting the more commercially valuable tree genera.

Many workers have noted numerous scars, the evidence of past fir engraver attacks, embedded in the stems of living firs (Berryman 1969; Felix, *et al.* 1971; Johnson and Shea 1963; Struble 1957). The beetles bore into the bark and excavate an egg gallery in the cambial zone. If the tree survives the attack, a necrotic lesion is produced which is gradually healed over by the surrounding host tissues. The scar is embedded in the annual ring formed in the year of attack, allowing the attacks to be readily dated. Thus the scars provide a potentially valuable long-term record of past *S. ventralis* activity.

This paper relates temporal fluctuation in abundance of the attack scars in white fir *(Abies concolor* [Gord. & Glend.] Lindl.*)* to trends in host tree growth mortality, weather, and logging operations for the period 1934-69, using multiple regression analysis.

STUDY AREAS

Attack-Scar Plots

Boles of white fir were sampled in 1970 for *S. ventralis* attack scars within two plots on the west slope of Mount Lassen, Shasta County, California. The plots were about 4 miles apart in cutover mixed conifer forest. White fir grew in association with Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco*)*, ponderosa pine *(Pinus ponderosa* Laws.*)*, sugar pine *(Pinus lambertiana* Dougl.*)*, incense cedar *(Libocedrus decurrens* Torr.*)*, and California black oak *(Quercus kelloggii* Newb.*)* in uneven-aged stands. The two plots differed in the proportion of the mature stand removed by past logging operations and in the level of current fir mortality caused by *S. ventralis.* The first cycle of logging on both plots, 1949-57, removed about 50 percent of the timber volume. Portions of both plots were logged again in 1958-70.

The Dersch Meadow plot (2,440 acres at 4,000 ft. elevation) had been heavily logged; only 3 percent of the original volume of mature timber remained in 1970 after the second cycle of logging. The residual stand consisted of scattered clumps of formerly intermediate or suppressed trees interspersed with openings in which shrubs and forbs predominated. Firs recently killed or under current attack by *S. ventralis* were scattered throughout the stand.

The Beal's Place plot (1,280 acres at 4,500 ft. elevation) had not received a second cutting until summer of 1970, the year of this study. Up to that time, the forest cover was more nearly complete than at Dersch Meadow; large (dominant) trees were still present. No firs recently killed by *S. ventralis* were observed in 1970 on this plot.

Fir-Mortality Plots

White fir mortality caused by *S. ventralis* during the period 1939-54 was surveyed on 15 tree-mortality plots (each 20 acres) established within a radius of 30 miles to the northeast of the plots at Dersch Meadow and Beal's Place by entomologists of the Pacific Southwest Forest and Range Experiment Station (Hall 1958). The mortality plots sampled mixed conifer stands varying in logging history (virgin to completely cutover), elevation (4,700 to 6,200 feet), and proportion of white fir. The plots represented a reasonable cross section of stands containing white fir in the region.

Fir engraver populations, as expressed by fir mortality, fluctuated synchronously over the entire region embracing the attack scar and fir mortality plots, at least during certain years within the study period. Forest insect surveys for the region reported that fir engraver damage was generally high in 1939-40 and low in 1948.[1] Thus it seemed likely that trends in fir mortality on the mortality and attack-scar plots would be similar.

In the absence of sound bark beetle population estimates, tree mortality has been commonly used in the past as an index to bark beetle population levels. The present study includes comparison of yearly trends in white fir mortality with those in the abundance of the yearly attack scars to determine whether the scars are a reasonable index to population trends.

SAMPLING AND DATA COLLECTION

Attack Scars

Dersch Meadow—Thirty-two white firs killed by *S. ventralis* in 1969 were selected for their convenient proximity to roads. The trees were felled and tree height and stump diameter were measured. Each tree was cut into 16-foot logs to a minimum diameter of about 4 inches (upper logs were often less than 16 feet long). A 1-inch-thick cross section (disk) was sawn from the lower end of each log, resulting in from three to five sample disks from each tree.

Beal's Place—The sampling procedure was similar to that of Dersch Meadow except that the 41 sample trees had been selected by foresters for felling as being "high-risk" trees likely to succumb to *S. ventralis* attack and were living when felled; also, the butt log was 32 feet in length. A summary of the diameter, height, and age of the sample trees from each plot indicates that Beal's Place trees tended to be larger and older than those from Dersch Meadow *(table 1)*, where most of the large old firs had been removed by past logging.

Table 1—*Diameter, height, and age of white firs sampled for embedded S. ventralis attack scars at two locations, Shasta County, California, 1970*

Items	Dersch Meadow (32 trees)		Beal's Place (41 trees)	
	Mean	Range	Mean	Range
Diameter at stump . . . in.	15.0±2.9	10–20	22.4±4.4	13–35
Height. . . . . ft.	63.1±10.8	43.5–85.8	74.5±18.6	41.2–110.2
Age at stump . . . . yr.	99.5±21.4	61–151	125.5±32.9	85–239

One surface of each disk was sanded with both coarse- and fine-grit papers. *S. ventralis* attack scars were visible in cross section as dark-stained segments of the annual rings *(fig. 1)*. A band saw was used to make radial cuts from the disk exterior to each scar, and the resulting wedge was split out with hammer and chisel to expose the scar. Viewed tangentially, the scars varied from small round niches to elongated egg galleries oriented normal to the wood fibers; surrounding host tissues were impregnated with a dark brown resinous stain *(fig. 2)*.

The year of attack was estimated by subtracting the number of annual rings formed in years subsequent to the attack from the year when the outer annual ring was formed. Also, each scar was examined for the presence or absence of larval mines and pupal chambers as an indication of the reproductive success or failure of the attack.

Tree Growth

Four radial sections, approximately 1/2 inch in width and oriented normally to one another, were cut from each tree's basal disk with a band saw. The presence of decay in some disks made only one to three sections obtainable. The sections were oven-dried (110°C., 6 hr.) to stabilize future shrinkage, and the width of all annual growth rings was measured to 0.01 mm.

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[1]Salman, K. A. *Reconnaissance of west side infestation conditions. Season of 1939.* 8 p. 1939. Engen, E. T. *Forest insect survey. Lassen National Forest and adjacent private lands. Seasons of 1949 and 1950.* 24 p. 1950. (Unpublished reports on file at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California.)

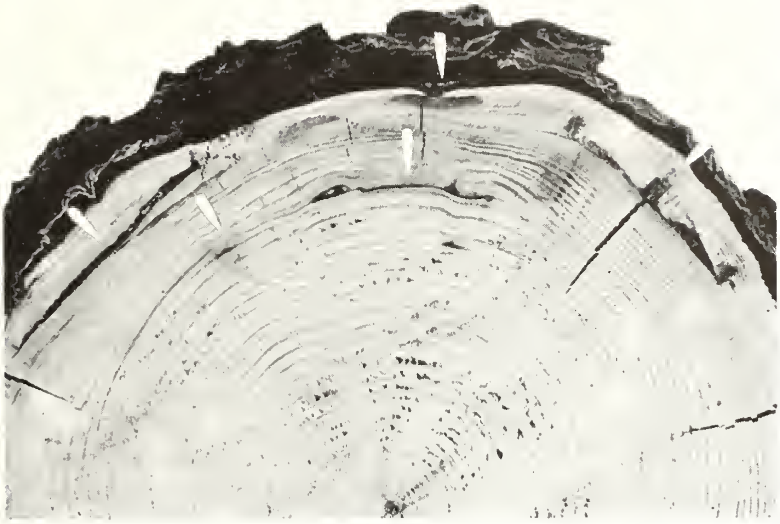


Figure 1—In transverse view, *S. ventralis* attack scars embedded in the annual rings of white fir are visible as dark-stained ring segments (arrows).

Tree Mortality

Yearly tree mortality on the fifteen, 20-acre plots was surveyed from 1939 through 1954 by annual examination of all trees on each plot in late fall or early spring, after trees killed by subcortical insects the preceding summer showed faded foliage (Hall 1958). The species, diameter at breast height (d.b.h.), and height of each faded tree were recorded and the bark was chopped into at breast height to determine the causal insect. Sampling at breast height probably produced a conservative estimate of *Scolytus*-caused mortality; this beetle often kills the upper bole and the lower bole is attacked by the cerambycid, *Tetropium abietis* Fall (Struble 1957). The volume of wood contained in each dead tree was estimated using local volume tables.

Logging

Logging chronologies were constructed for the attack-scar plots from records of the year and approximate boundaries of all known logging operations within the plots and the approximate area of each logged parcel was estimated by superimposing a 40-acre grid, drawn to scale, upon a map.

Weather

Monthly total precipitation (inches) and mean temperature (degrees F.) were obtained from annual summaries of California weather issued by the U.S. Environmental Data Service for the period 1934-69. Shingletown, the weather station nearest the attack-

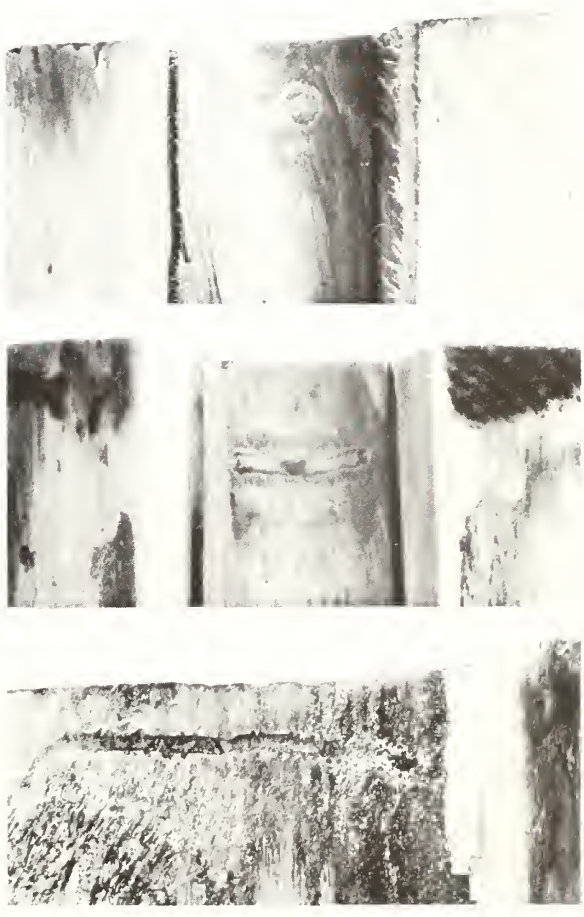


Figure 2—In tangential view, dissected *S. ventralis* attack scars vary in extent of gallery formation from round pockmarks **(top)** to elongated egg galleries oriented perpendicular to the wood fibers **(middle** and **bottom)**. Surrounding host tissues are impregnated with a dark brown, resinous stain.

scar plots, did not record temperature data during the study period, and precipitation data from this station were available only after 1960. Weather data from three other nearby stations (Manzanita Lake, Volta, Mineral) were used to fill these gaps. High correlations of data between the stations (r varied from 0.82 to 0.96) indicated that the weather patterns of the stations were similar. Thus, precipitation records from all four stations, and temperature records from three stations, were used in the regression analysis.

ANALYSIS

Multiple regression analysis was used to relate yearly number of *S. ventralis* attack scars (dependent variable) to weather, growth, logging, and previous abundance of attack scars (independent variables). A linear additive model was used: that is, it was assumed that the relations between the dependent and independent variables were linear and the effects of the latter upon the dependent variable were additive. Because insect populations grow exponentially over time, fluctuations may be large, resulting in a nonlinear relation with other variables. Nonlinearity was at least partially allowed for by introducing the dependent variable as logarithms and including both the independent variables and their squares in the regression.

Regression coefficients and associated statistics were computed by RAFL, a program written by personnel of the Pacific Southwest Forest and Range Experiment Station. The program included a stepping option, by which the variables could be included in the regression model in descending order of their efficiency in explaining attack scar variance (t^2 criterion). Accepted models contained all variables included prior to, and including, the last variable significantly reducing the unexplained variance in attack scars (t^2 probability $\leq .05$).

Typically, in such a ranking process, the addition of the most important variable among a group of highly associated variables leaves little variance in the dependent variable to be accounted for by the remaining variables in the complex, resulting in their exclusion from the model even though they are, in themselves, significant. Frequently, no single variable in the complex is able, by itself, to explain a significant amount of the variance, so that the entire complex is excluded, although as a whole it may be significant.

To circumvent these difficulties, an approach (Hardwick and Lefkovitch 1971) has been used which compares the results obtained from two methods of analysis:

Group Analysis: The variables were combined into four major descriptive groupings: weather, growth, previous *Scolytus* attack scars, and logging. The contribution of each group of variables as a whole, singly, and in combination with each of the other groups, to the explanation of attack variance was examined.

Separate Variable Analysis: The variables were introduced into the regression individually, in descending order of the amount by which they reduced the residual attack scar variance.

Dependent Variable: Attack Scars

For each plot, the yearly number of attack scars observed in all sample trees (1934-69) was obtained by summing over all disks. The yearly numbers of attack scars for the two plots were combined and compared with the annual total volume of white fir timber killed by *S. ventralis* on all mortality plots. The two variables were directly correlated, indicating that scar abundance is a reliable index to past levels of fir mortality from *S. ventralis.* Thus the natural logarithm of the total number of attack scars observed on each plot in the ith year, that is, $\log_e$ Attacks_i, i = 1934 through 1969, was used as the dependent variable (Y) in the regression. The value of 1 was added to each year's attacks so that a definite logarithm could be obtained for years with no observed attacks.

Independent Variables

Many workers have stressed the importance of previous as well as current, environmental conditions upon population fluctuations of insects. Therefore independent variables expressing conditions of years preceding the current (ith) year, as well as those of the year itself, were included in the regression.

Weather—The study plots lie in a region whose climate consists of a distinct wet season (usually October to June). The summers are normally warm and dry with precipitation limited to occasional thundershowers. Sums of monthly total precipitation, and averages of monthly mean temperature, from the previous October through the ith year's September, were considered to represent both the direct and indirect (via host tree) influences of weather upon the beetle population during the ith year ($Precip._i$, $Temp._i$). The year's weather was subdivided by seasons (Win. $Precip._i$, $Temp._i$, October-March; Spr. $Precip._i$, $Temp._i$, April-June; Sum. $Precip._i$, $Temp._i$, July-September) to assess the influences of each, as different developmental stages of the insect occur seasonally. The immature (brood) stages of *S. ventralis* are present subcortically during fall, winter, and spring, whereas emergence, flight, and attack of the adults occur during the summer. Weather during years preceding the ith year was taken into account by averaging precipitation in the ith year with that of up to 4 preceding years ($Precip._{i,j}$, j=1-4).

Growth—Measurements of the radial increment (stump level) of the trees were used to indicate variable host vigor. Tree growth expresses the combined influence of many factors—weather, disease, plant competition, fire, defoliation by insects, etc.—and is thus an indirect measure of many factors for which records were lacking.

The several measurements of the width of each growth-ring, obtained from the sticks from each tree's basal disk, were averaged to obtain the mean width for each ring formed during 1934-70. A yearly mean growth index was calculated from data from each plot by means of the computer program INDXA[2] written by Fritts, *et al.* (1966). The ith year's mean growth index for all sample trees from each plot ($Growth_i$) and averages of the ith year's growth with that of up to 3 previous years ($Growth_{i,j}$, j=1 to 3) were included in the regression.

Logging—Several possible influences of logging activity on *S. ventralis* populations were assessed. Cum. Log_i was the cumulative area logged within each plot (in hundreds of acres) since the beginning of logging operations on that plot through the ith year. It attempted to represent the long-term cumulative effects of stand disturbance by successive logging operations (i.e., increased tree moisture stress resulting from opening the stand, disturbance of root system by logging equipment, entrance to decay organisms through wounds and stumps). The area logged within the plot in the previous year (Log_{i-1}) was considered to be primarily an index to the abundance of recent logging slash as suitable breeding sites as *S. ventralis* readily attacks and reproduces in such host material (Stevens 1956; Struble 1957). However, this variable also expressed stand disturbance caused by logging in the previous year.

Attack Scars in the Preceding Year—As an index of *S. ventralis* abundance, the total number of attack scars observed in all trees from each plot for the preceding year ($Attack_{i-1}$) was included in the regression. Population trends seem to be less predictable for bark beetles than for many other groups of forest insects. For many species of scolytids, however, increased populations (in excess of endemic levels) have often preceded outbreaks (Rudinsky 1962). Like the dependent variable $Attacks_{i-1}$ was transformed to logarithmic scale.

RESULTS AND DISCUSSION

A total of 188 embedded scars in annual rings corresponding to the years 1934-68 was found in the Dersch Meadow trees. An additional 363 attacks were found on the surface of the outer ring—attacks resulting from the mass invasion which killed the trees in 1969. All of the 1969 attacks, but only 3.2 percent of the embedded scars, represented attacks that were reproductively successful. Only 2 percent of the 99 attack scars embedded in Beal's Place trees for the period 1934-69 gave evidence of reproductive success.

The yearly total scars in all trees from both attack-scar plots (pooled) was directly correlated (r=0.72) with the annual volume of white fir killed by *S. ventralis* on the mortality plots between 1939 and 1954. Similarity in the yearly trends of the two variables was evident *(fig. 3)*.

[2]This program fits a negative exponential curve or a straight line with zero, positive, or negative slope to each tree's ring width series by the least squares method, selecting the function which provides the best fit. A growth index is calculated for each year by dividing the observed ring width by the curve value. Growth indexes of unity represent normal, 0-1 subnormal, and greater than one, above normal, growth. Summaries including all trees from a given plot are then computed, yielding yearly mean growth indexes and associated statistics (standard deviation, standard error) for each plot. The curve-fitting and index calculations attempt to eliminate long-term systematic growth patterns such as those associated with tree age, and to isolate for analysis year-to-year fluctuations in growth caused by environmental variables such as weather.

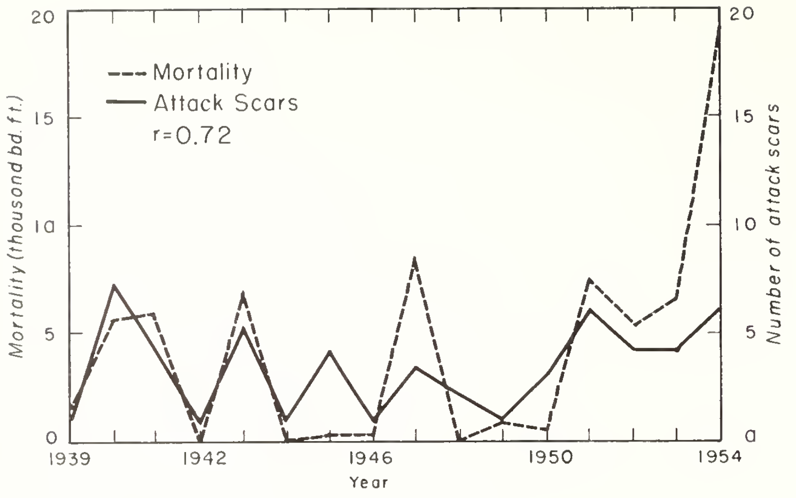


Figure 3—Fluctuation of the yearly total of *S. ventralis* attack scars (73 trees from two plots) was generally synchronous with the annual volume of white fir killed by *S. ventralis* (fifteen 20 acre mortality plots), 1939-54.

Factors Related to Attack Scars

Grouped Factors—The groups of variables representing logging activity and weather were most important in explaining attack scar variance on both plots *(table 2)*. In combination they explained 93.7 and 79.9 percent of the attack scar variance at Dersch Meadow and Beal's Place, respectively. Host tree growth explained an additional 4 percent at Dersch Meadow and 11.5 percent at Beal's Place when added to the model already containing logging and weather. Although scar abundance in the previous year ($Attacks_{i-1}$) by itself explained 57.3 percent and 12.1 percent of the scar variance on the two plots, its addition to the model already containing logging increased the amount of explained variation by only 0.5 and 1.6 percent, respectively. Evidently there was a great deal of overlap in the influence of the previous year's levels of logging and attack scars upon the dependent-variable with logging able to explain a greater amount of the variation.

Separate Factors—Logging was the most important single variable on both plots *(table 3)*. The next most significant variables were current tree growth (Dersch Meadow) and certain precipitation variables on both plots.

The importance of logging and weather in the years preceding the ith year differed between the plots. Variables representing ith year's precipitation and the previous year's logging were more important at Beal's Place, whereas only variables combining ith year conditions with those of at least several previous years were important at Dersch Meadow.

On both plots, precipitation during the entire season (October through September) was more significant than either winter or spring precipitation alone. Mean temperatures had relatively little influence compared to precipitation.

As in the group analysis, the previous year's beetle activity ($Attacks_{i-1}$) did not make a significant contribution in either plot once logging variables had been taken into account.

Table 2—*The contribution of grouped factors, singly and in combination, to the explanation of S. ventralis attack scar variation on two plots, Shasta County, California, 1934-69*

Factor grouping	Cumulative percentage of variation explained ($100R^2$)
Dersch Meadow	
Logging	72.3
Weather	71.0
$Attacks_{i-1}$[1]	57.3
Growth	40.1
Logging + Weather	93.7
Logging + Growth	78.8
Logging + $Attacks_{i-1}$	72.8
Logging + Weather + Growth	97.7
Logging + Weather + Growth + $Attacks_{i-1}$	97.8
Beal's Place	
Weather	56.9
Logging	35.2
Growth	12.8
$Attacks_{i-1}$	12.1
Logging + Weather	79.9
Logging + Growth	42.6
Logging + $Attacks_{i-1}$	36.8
Logging + Weather + Growth	91.4
Logging + Weather + Growth + $Attacks_{i-1}$	98.0

[1]Number of attack scars in the previous (i-1) year.

Table 3–*The contribution of single factors to the explanation of S. ventralis attack scar variation on two plots, Shasta County, California, 1934-69*

Factors, ranked in descending order of efficiency in explaining scar variation[1]	Cumulative percentage of variation explained ($100R^2$)
Dersch Meadow	
Cum. $Log._i^2$ - Cumulative area logged, squared	71.4
$+Growth_i$ - Mean growth index for current year	77.7
$+Precip._{i,2}$ - Mean precipitation for current and two preceding years	79.5
$+Precip._{i,1}^2$ - Mean precipitation for current and preceding year, squared	85.6*
Beal's Place	
$Log._{i-1}$ - Area logged in previous year	13.3
$+Log._{i-1}^2$ - Area logged in previous year, squared	34.6
$+Precip._i$ - Precipitation for current year	38.6
$+Precip._i^2$ - Precipitation for current year, squared	50.9
$+Temp._i$ - Mean temperature for current year	55.3
+Spr. $Precip._i^2$ - Spring precipitation for current year, squared	59.3
+Win. $Precip._i^2$ - Winter precipitation for current year squared	68.0*

t^2 significant at 5 percent level, for all factors listed.
*Significant at 1 percent level (F test).

Of the factors investigated, the first four in the ranking explained 85.6 percent of scar variance at Dersch Meadow. The first five factors (including two variables and their squares) explained 68.0 percent of the scar variation at Beal's Place. The amount or scar variation explained by each model was significant by F test at the 1 percent level.

The results suggest that logging, precipitation, and to a lesser extent tree growth, are important factors influencing year-to-year variation in abundance of fir engraver attack scars. Yearly trends in those factors and the scars are depicted for the plots in *figures 4 and 5* with annual precipitation expressed as the departure from average (44.82 inches) during the study period.

The temporal pattern of the attack scars in the Dersch Meadow trees differed from that at Beal's Place. At Dersch Meadow the scars remained low until 1956, but generally increased each year thereafter until the trees were killed by the beetles in 1969. This increase was related to the incidence of repeated logging operations within the plot in an apparently additive manner (Cum. Log.). The period of greatest increase in the scars (1960-69) coincided with generally subnormal precipitation, continued logging, and in the last years before the trees were killed (1956-69), rapidly declining tree growth. It is possible that the accelerating accumulation of the scars during the period 1965-68 may have in itself contributed to the rapid decline in growth and the death of these trees through interference with the functioning of stem tissues. At Beal's Place, three periods of increased attack scars (1940-43, 1950-53, 1961-65), each followed by return to lower levels, were discernible. The latter two peaks were contemporaneous with periods of logging activity. For all three peaks, the year of initial increase in the scars was preceded by at least 1 year of subnormal precipitation and coincided with years of subnormal or declining growth. Precipitation remained generally subnormal throughout the years when the highest peak occurred (1961-65).

The decline of the attack scars during the interludes between logging operations at Beal's Place suggests that the primary influence of logging on this plot was the temporary provision of logging slash as suitable breeding material for the beetles. Continued increase in scar abundance between logging opera-

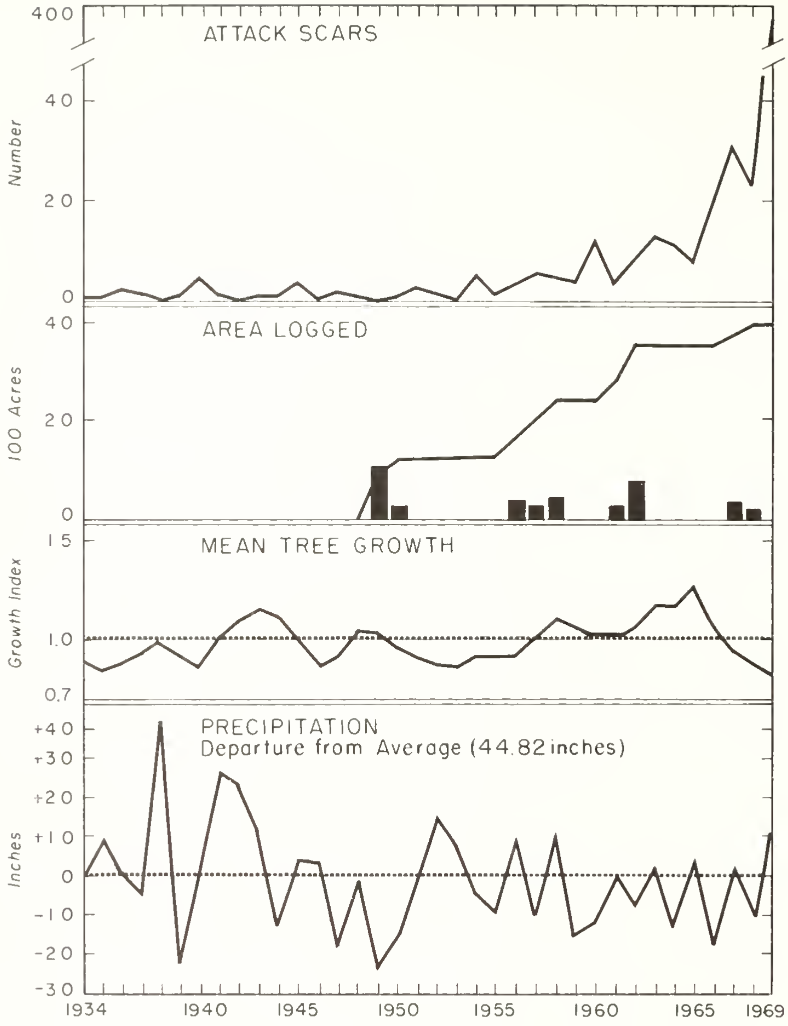


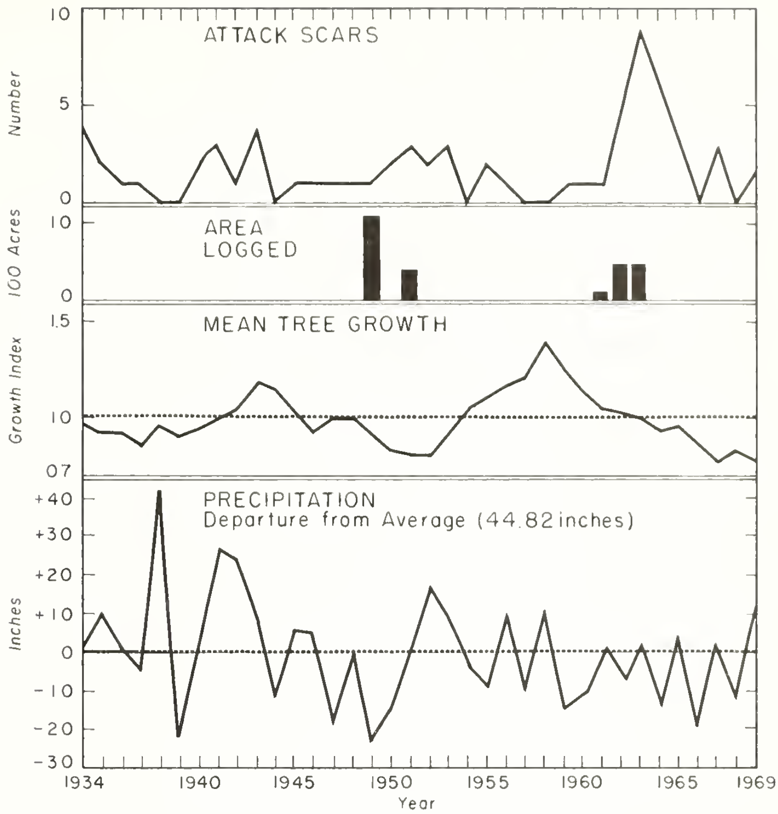
Figure 4—Comparison of trends in factors influencing fluctuation of *S. ventralis* attack scars, 1934-69, Dersch Meadow plot. Both yearly (bars) and cumulative (line) area logged within plot are shown.

tions at Dersch Meadow suggests a longer term influence possibly related to the greater frequency and extent of logging operations on this plot. Logging took place during 9 years at Dersch Meadow, resulting in the removal of 97 percent of the sawtimber volume, compared to Beal's Place, where 5 years' logging removed 50 percent of the volume.

Index to Past Trends

The study results appear to validate the use of attack scars embedded in *Scolytus*-killed and high-risk fir as an index to past trends in fir mortality from *S. ventralis*, even though most of the scars record attacks that were reproductively unsuccessful. Increases in both scar abundance and fir mortality are usually preceded by 1 or more years of subnormal precipitation and coincide with periods of reduced tree growth agreeing with the findings of other investigators. Wickman (1963) found in California that subnormal precipitation preceded outbreaks of tussock moth *(Hemerocampa pseudotsugata* McD.*)* which caused defoliation and reduced growth of white fir. Many of the fir thus weakened were subsequently killed by *S. ventralis*. There was increased incidence of *S. ventralis* attack scars in the tops of white fir infested by true mistletoe, especially following drought (Felix, *et al.* 1971). At Dersch Meadow and Beal's Place, the short- and long-term effects of logging appeared to interact with the effects of drought and subnormal tree growth in a manner similar to that described for outbreaks of *Ips typographus* L. in the spruce forests of Germany (Thalenhorst 1958). Populations of this bark beetle are normally confined (latent phase) to a few fallen trees and dying branches, the scarcity of which acts as the limiting factor. A sudden surplus of nonresistant host material such as logging slash may lead to population increases (extensive phase). The high population produced may then attack living trees (intensive phase), leading to increased tree mor-

Figure 5—Comparison of trends in factors influencing fluctuation of *S. ventralis* attack scars, 1934-69, Beal's Place plot.



tality. This phase may be prolonged by reduced host vigor resulting from drought. Similar mechanisms have been found in North American bark beetles (Hall 1958). Apparently, scar abundance in any year is:(1) directly related to the abundance of attacking beetles as influenced by the availability of nonresistant host material in the preceding years, and (2) inversely related to host resistance as influenced by drought. The paucity of scars in wetter years probably results from many attacks failing to penetrate the cambium and thus failing to form scars recorded in the annual rings. Such attacks, associated with a rapid, resinous response of the phloem, have been reported in fir successfully resisting fir engraver colonization by Berryman (1969) and Struble (1957).

It seems likely that beetle-caused fir mortality in the residual stand following logging could be reduced if logging of stands containing white fir were deferred until periods of drought and subnormal tree growth are ended. Although the data are not yet conclusive, the study results also suggest avoidance of silvicultural systems calling for repeated logging with removal of a high percentage of the mature stand, leaving only the formerly suppressed and intermediate fir. Thorough slash disposal is also indicated.

The investigation gives direction to future studies of the relation between fir silvicultural systems and the fir engraver. It would appear feasible to develop mathematical models for predicting the amount of fir damage by *S. ventralis* if current and previous levels of logging, precipitation, and tree growth are known. The impact of the estimated mortality levels under alternative managerial schemes could then be assessed, and the forest manager could choose the scheme best suited to his needs.

SUMMARY

Ferrell, George T.

1973. **Weather, logging, and tree growth associated with fir engraver attack scars in white fir.** Berkeley, Calif., Pacific Southwest Forest and Range Exp. Stn. 11 p., illus. (USDA Forest Serv. Res. Paper PSW-92)

Oxford: 453–145.7x91.92: 174.7 *Abies* spp. (794): 461[111.781. + 181.65].
Retrieval Terms: Scolytus ventralis; Abies spp.; mortality; drought effects; logging effects; growth vigor; timber management; Shasta County, California.

Attack scars of the fir engraver *(Scolytus ventralis)* were examined in 73 white fir boles from two plots in Shasta County, California, to determine their usefulness in estimating fluctuation of beetle populations, and to explore their relation to trends in weather and other factors. Of these fir, 32 had been killed by *S. ventralis* and 41 were considered "high risk." The two plots differed in the extent of past logging and in the level of mortality from the beetle. A total of 287 scars formed in 1934-69 were found, from 2 to 3 percent showing reproductive success. Attack scars were dated by a count of annual rings, and yearly totals for the two plots were obtained.

Fir mortality over the period 1939-54 was determined from survey of 15 plots in the vicinity of the attack scar plots.

Scar abundance was examined in relation to both previous and current weather, host tree growth, and logging by multiple regression analysis.

Trends in scar abundance were directly correlated with trends in white fir timber volume killed by *S. ventralis* on the mortality plots, indicating the scars were a suitable index to past damage levels. In the regression analysis, accepted models containing logging, precipitation, and tree growth variables explained 85.6 and 68 percent of the attack scar variation on the two plots. Years with increased scar abundance were preceded by at least 1 year of subnormal precipitation and coincided with subnormal or declining tree growth. The highest peaks in scar abundance occurred when these conditions were contemporaneous with logging in the stand.

Differences in logging between the two plots appeared to influence both trends in the scars and levels of fir mortality caused by the beetles. Study results, although not conclusive, suggest that logging of stands containing white fir should avoid removal of all mature trees leaving only formerly suppressed and intermediate fir. Slash disposal should be thorough. If possible, logging should be deferred until periods of severe drought are ended.

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PACIFIC SOUTHWEST Forest and Range Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701

ROAD CONSTRUCTION ON CASPAR CREEK WATERSHEDS. . .
10-year report on impact

J. S. Krammes David M. Burns

USDA FOREST SERVICE RESEARCH PAPER PSW-93 /1973

CONTENTS

Logging and road building affect streamflow, sedimentation, and aquatic habitat in forested watersheds. But how decisive an impact do they have? And for how long must effects be studied to be considered significant? Forest managers would find the answers to these and other questions useful in determining appropriate methods for timber harvesting and for designing logging roads.

To come up with some answers, a number of Federal and State agencies in California began a joint study in 1960 on two Caspar Creek watersheds of the Jackson State Forest, near Fort Bragg, California. The agencies participating are the Pacific Southwest Forest and Range Experiment Station, California Division of Forestry, and California State University, Humboldt. Earlier participants included the California Departments of Fish and Game and of Water Resources.

The study is designed to develop quantitative data on the impact of selection cutting and attendant road systems on streamflow, sediment, and fish habitat. In applying this cutting technique, about two thirds of the timber volume is to be removed. Timber harvesting and road location, design, and construction are all to standards consistent with the intensive management objectives of Forestry. Attention to watershed protection values is kept to within practical limits. The study is not intended to compare differences in types of logging practices or road building methods.

The two experimental watersheds are the North and South Forks of Caspar Creek. They are in the second-growth, redwood–Douglas-fir forest type *(fig. 1)*. The Creek flows into the Pacific Ocean about 6 miles south of Fort Bragg. The South Fork study area consists of about 1,047 acres; the North Fork study area, about 1,255 acres. Both watersheds were clearcut and burned in the late 1800's. In 1961, both supported adequately stocked stands of second-growth Douglas-fir, redwood, hemlock, and grand fir that ranged from 65 to 85 years old. The timber stand in the South Fork averaged 85 years old; the stand in the North Fork, 65 years old. Because of the age difference, the North Fork was selected as the control; and the South Fork as the watershed to be selectively harvested.

This paper reports on streamflow calibrations in the two Caspar Creek watersheds during the first 10 years, and on the effects of road construction during a 4-year period on sediment yield, aquatic habitat, and fish populations. The findings reported may provide useful information for the prudent management of other watersheds, in the north coastal area of California, that have generally similar soils and geology.

SOILS AND GEOLOGY

The geology of the experimental watersheds appears representative of western Mendocino County. Sedimentary rocks of Cretaceous age underlie most of both watersheds. Soils mapped on these rocks are of the Hugo and Mendocino soil series. Rocks underlying the Hugo soils are hard sandstone and shale, moderately weathered, coarse-grained, and deeply shattered. This kind of fractured substratum receives drainage water rapidly, but has only a moderately high water-holding capacity.

In contrast, the sandstone associated with the Mendocino soil is highly weathered—often streaked with lenses of red and white clay. These rocks appear slightly less permeable and were estimated to retain slightly more water than those under the Hugo soils.[1]

Less than 10 percent of the South Fork watershed is underlain with weakly consolidated Pleistocene marine terrace deposits of sand and gravel. The deposits are the parent material for the Caspar and Noyo soils. This substratum is generally firm, moderately permeable, and medium to high in moisture retention—a factor that was considered when the beginning of the logging season was set.

Gladish[1] concluded that the two major soils in the experimental watersheds differed only slightly in surface erodibility. Furthermore, sediment sources would most likely be associated with logging activities adjacent to water courses, and from mass movements, particularly where roads cut through dormant landslides.

[1]Gladish, E. N. *Soils and vegetation of the Caspar Creek watersheds.* 1963. (Unpublished report on file at California Division of Forestry, Sacramento, Calif.)

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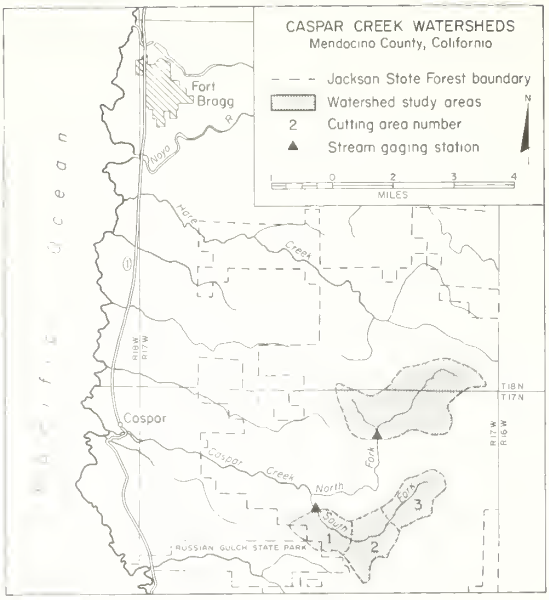

Figure 1—The two experimental watersheds in the Caspar Creek study are the North and South Forks on the Jackson State Forest, in northern California.

TREATMENTS AND MEASUREMENTS

Both watersheds were monitored in an undisturbed condition between 1962 and 1966. A main haul logging road and spurs were built in the summer of 1967 in the South Fork watershed. Effects of the roads were monitored between 1967 and 1971. Timber harvesting started in March 1971 in the South Fork drainage, and the harvesting effects are to be evaluated until about 1977.

A weir was completed in each fork in November 1962. The continuing data collected at each site consists of continuous streamflow measurements, suspended sediment measured at the weirs (stage-triggered and supplemented by hand sampling), measurement of changes in sediment deposition in the debris basins behind the weirs, and rainfall.

Changes in aquatic habitat upstream from the weir were measured periodically at 60 stations in the North Fork and 77 stations in the South Fork watershed. Stations were located at 100-foot intervals upstream from the weirs in each fork.

Two stream channel sections totaling 2,000 feet of the South Fork streambed were mapped in detail. The maps indicate location and extent of pools and riffles, stream width, meander, general nature and extent of bottom materials, prominent landmarks, and location and extent of beds of aquatic vegetation. In addition, sections of the stream, of bottom materials, and of the floral canopy were photographed. The sections have not been re-mapped, as there appear to be little change in them to date.

The last phase of the study—the harvesting and logging operation—began in March 1971. Timber was to be selectively harvested in three consecutive annual sales. Starting at the weir and moving upstream, each sale would be completed in one logging season. Annual sales would remove between 10 and 14 million board feet of timber, averaging about 63 percent of the timber stand volume *(table 1)*. Timber harvested from the 1967 road right-of-way clearing was included to present a total accounting.

The three main considerations which led to the choice of sale areas and scheduling sequence were:

1. Timber volume involved in each of the three sales is consistent with the State Forest timber sale policies. Planned volumes can be removed in one logging season by using available equipment.

2. Ridge-to-ridge sale boundaries provided the most orderly plan for the systematic timber harvest.

3. Starting the first timber sale near the weir, with subsequent sales upstream, should permit better evaluation of sediment source areas without having a

Table 1—*Estimated timber sale volume in the South Fork watershed, Caspar Creek, Jackson State Forest, California*

Sale area	Year	Acres	Harvest	Leave
			– – – – *MM. bd. ft.*	– – – –
Area 1	1971	249	10.3	7.1
Area 2	1972	316	13.6	6.2
Area 3	1973	435	12.1	7.9
Total	–	1,000	36.0	21.2
Right-of-way	1967	47	4.0	–

Figure 2—Typical section of a logging road built in the South Fork drainage of Caspar Creek. The road was completed in September 1967.

cumulative effect as might happen if the sequence of logging were reversed *(fig. 1)*.

Silvicultural Systems

The major second-growth stand is now about 95 years old and consists of redwood *(Sequoia sempervirens)*, Douglas-fir *(Pseudotsuga menziesii)*, grand fir *(Abies grandis)*, hemlock *(Tsuga heterophylla)*, and bishop pine *(Pinus muricata)*. There are also some scattered old-growth trees.

The selection cutting, as being applied, will remove single trees and small groups of trees with the objectives of reserving healthy, fast growing stands of the more desirable species, and of providing openings to encourage regeneration of the same species. Most of the scattered old-growth timber is to be removed. About 50 percent of the young-growth redwood and Douglas-fir, and about 60 percent of the grand fir, trees are to be removed. Hemlock and bishop pine are to be marked heavily to favor the other species.

Near the county roads and the boundary of Russian Gulch State Park, marking is lighter, with special consideration for esthetic values. Some old-growth trees are left. The lighter marking merges in to standard marking at 50 to 200 feet, depending on the local situation. The light marking should also provide a windbreak along the southern perimeter where there are sandy soils and trees are susceptible to windthrow.

Road Construction

Right-of-way clearing for constructing the logging road and main spur roads in the South Fork drainage began at the upper end of the watershed in May 1967. Generally, clearing and road work progressed downstream toward the weir.

All road and bridge construction and all stream cleaning activities were completed by September 12, 1967 *(fig. 2)*. About 4.2 miles of road were built, of which about 3.7 miles were in the aquatic habitat study area. Coarse debris, resulting largely from right-of-way clearing, that was in the stream and along its banks was mostly removed after road construction.

Some of the road-building and bridge construction directly affected the perennial stream, its bed, and its banks. Small trees, many branches and leaves, and considerable quantities of rock and soil slid into, or were deposited at, several locations in the stream. Almost the full length of the aquatic habitat study area was directly affected in one way or another by the road-building activities. About 360 feet of streambed were disturbed by tractor operation directly in the stream. These areas were primarily around bridge crossing locations, landing sites, and in a stretch of stream cleared of debris from right-of-way clearing.

All fill slopes, landings and major areas of soil exposed by the road-building activities were fertilized and seeded with annual ryegrass *(Lolium multiflorum)* in September 1967. The grass was well established before the first rains in November (Jackman and Stoneman 1973).

STREAMFLOW AND SEDIMENTATION

Erosion and Landslides

Winter rains in 1967-68 resulted in some mass movement within road prisms, particularly in the steeper cut slopes and from fill areas next to bridge sites. An estimated 500 cubic yards of soil and rock material from cut banks was deposited on the road in 19 separate slides along 2,000 feet of road. Sixteen slides along the fill slopes contributed an estimated 150 cubic yards directly to stream. No estimate is available for volume of material eroded from areas next to bridge sites or the amount of material that may have spilled into the stream during road maintenance.

A splash dam had been constructed on the South Fork during the first timber harvest in the 1880's for transporting logs downstream. This dam, about 10,800 feet upstream from the South Fork weir, failed in December 1967. The road crossed the South Fork at a point 300 feet above the old splash dam, on the upper end of the estimated 5,600 cubic yards of sediment that had been trapped behind the dam. Considerable debris was removed from the channel between the dam and the road crossing. These construction activities may have hastened the dam failure. In any case, an estimated 925 cubic yards of sediment entered the stream as it cut a new channel through the trapped sediment, to be added to material coming directly from road-building activities. Most sediment from both sources entered the channel during the winter of 1967-68, and it is not possible to say how much of the subsequently measured downstream sedimentation originated from each.

Peak flow periods during the first winter were not of sufficient length or magnitude to transport bed material for long distances; hence an unusual amount of sediment did not accumulate in the sedimentation basin during the 1967-68 measurement.

By June 1968, the streambed generally did not appear much different from the way it looked before the roads were built. This lack of visible streambed change was due to the distribution and the leveling of sediment all along the stream.

Stream Turbidity

Road building and associated activities caused some turbidity, as was expected.

Trees felled into the stream, and its tributaries tended to increase stream turbidity only slightly (p.p.m. concentrations established from turbidometer instrument calibration curve). For example, a summer falling operation 4,700 feet upstream from the weir and on a tributary 4,450 feet above the weir yielded a concentration of 11 p.p.m. About 1,000 feet downstream the concentration dropped to 2 p.p.m. These concentrations were from samples taken during the time of clearing.

Construction of a bridge 6,700 feet upstream from the weir resulted in high turbidity for about 1,000 feet downstream from the construction site, but it apparently had little effect on the concentration beyond a mile downstream. Maximum observed turbidity during the summer low flow period was about 4,000 p.p.m., caused by a tractor preparing bridge footings. The next day, the observed maximum at the bridge site was 18 p.p.m.; 700 feet downstream from the bridge site, the concentration had returned to the observed preconstruction level of around 1 p.p.m.

The presence of the new road, plus the failure of the splash dam, must be held responsible for peak increases in turbidity in the South Fork during the winter of 1967-68. During a period of moderate rainfall in mid-January 1968 turbidities were as high as 3,000 p.p.m. in the South Fork study area, at least as far upstream as 4,600 feet from the weir. Because samples were taken only during visits to the study area, they may not represent maximum concentrations.

Turbidity values greater than the preconstruction level were not measured during summer low flow periods subsequent to the 1967 road building season.

Suspended Sediment

Suspended sediment is the parameter most often used as an index to estimate erosion from a watershed. Since sediment concentrations under undisturbed conditions vary widely, isolated samples do not directly represent watershed conditions. Long-term relationships between suspended load and stream discharge must be developed before suspended sediment concentrations can be used to evaluate treatment effects.

Anderson (1971) uses weighted sediment concentrations to assess land use changes. His method, related measured suspended sediment concentrations to measured streamflow at time of sediment sampling. Comparisons are made by applying the sediment streamflow relations to normalized streamflow expectancy. Annual suspended sediment yields for normalized expectancy of streamflow and existing watershed conditions were estimated for both Caspar Creek drainages *(table 2)*, very few high flows were sampled during the 1962-63 hydrologic year, so that estimates are probably not determinable.

Suspended sediment concentrations during an early December, 1967, storm reached 4,036 p.p.m. at the South Fork weir sampling location. This runoff event transported a sizable portion of the readily available fine sediment. A storm in mid-January 1968 with about the same peak streamflow yielded sediment concentrations of 1,292 p.p.m. The last sizable storm during that hydrologic year had a peak flow twice that of the earlier storms but produced maximum concentrations of 2,609 p.p.m.

Table 2–*Estimated suspended sediment discharge for normalized expectancy of streamflow North and South Forks, Caspar Creek, Jackson State Forest, California*[1]

Hydrologic Year (Oct. 1–Sept. 30)	Caspar Creek South Fork	Caspar Creek North Fork
	– – – – *Tons/sq. mile*	– – – –
Calibration period:		
1962-1963	[2] 61	[2] 130
1963-1964	160	135
1964-1965	133	188
1965-1966	196	193
1966-1967	221	125
Road calibration period:		
1967-1968	742	151
1968-1969	215	120
1969-1970	166	99
1970-1971	233	109

[1]Based on method outlined by Anderson (1971). These are not estimates of actual discharges for the year, but are normalized to a standard streamflow expectancy.

[2]Few high flows sampled, so estimates probably not determinable.

Table 3–*Measured deposition in the Caspar Creek Basin, Jackson State Forest, California*

Hydrologic year (Oct. 1–Sept. 30)	Caspar Creek South Fork	Caspar Creek North Fork
	– – – – *Cu. yd./sq. mile*	– – –
Calibration period:		
1962-1963	87	64
1963-1964	45	69
1964-1965	224	686
1965-1966	193	793
1966-1967	109	60
Road calibration period:		
1967-1968	134	53
1968-1969	231	391
1969-1970	147	227
1970-1971	655	334

The great suspended sediment increase during the first year after construction is notable *(table 2)*. Two of the remaining 3 years during the road calibration period had suspended sediment loads somewhat in excess of the mean value estimated for the calibration period. Since the estimation procedure normalizes suspended sediment discharges for average flow conditions among watersheds, we would conclude that the road-building activity and splash dam failure did increase suspended sediment discharges markedly during the first year after construction, and may have caused a small increase in the 3 subsequent years.

Debris Basin Deposit

The large increase in sediment deposition in the North and South Fork basins in 1964-65, prior to road construction, is associated with high flows of the December 1964 flood *(table 3)*.

There was a small increase in weir-basin deposition in the South Fork watershed during the first three winters after the road building activities ceased, and a major increase in the fourth winter, relative to deposition in the North Fork basin. Material side-cast into the stream channel during construction, during road maintenance, from several small landslides, and from splash dam failure moved only during high runoff periods, but may have moved only relatively short distances during each period.

It is interesting to note that the South Fork basin deposition peaked in the fourth season, whereas the suspended sediment peaked in the first. A possible–though speculative–explanation is that it took the additional 3 years for a major part of the sediment from the splash dam failure to be transported 10,800 feet down the channel to the weir basin.

There is little doubt however, that the sediment potential of the South Fork was increased because of slope failures in road fills and of erosion around bridge sites.

AQUATIC HABITAT CHANGES

Temperature and Radiation

Most of the physical, chemical and biological properties of an aquatic system are affected by temperature. Opening of the canopy for road construction increased summer water temperatures in the South Fork. Most observed summer maximums in both forks before road building were below 60°F., in the South Fork. The maximum temperature observed in the South Fork was 78°F. Water temperatures in the undisturbed North Fork remained unchanged.

Constant exposure to water temperatures higher than 78°F. can injure anadromous fish populations. Inland streams where late summer and fall seasons are usually hot and dry often have maximum temperatures in excess of 78° F. Short coastal streams, such as Caspar Creek, actually benefit through a slight increase in insolation by stimulating a favorable production in the food chain. Optimum temperatures for basic habitat requirements are in the range of observed temperatures in the South Fork drainage.

Daytime surface water temperatures in the South Fork tended to increase between points 11,100 feet and 4,700 feet above the weir—the part opened to insolation as a result of road building. Warming was partially offset by inflow of cold water from springs and tributaries. Highest summer water temperatures in the South Fork tend to occur between 6,500 and 3,500 feet upstream from the weir. This trend is consistent with the greatest increase in radiation exchange occurring in the same stream reach as a result of exposure by road building. About 1.4 miles of the total 4.2 road miles impinge directly on the stream channel. Solar radiation data collected over several years provide a basic index on the effects of canopy removal. A general cooling occurs beginning about 3,500 feet and continues downstream to the lower end of the study area because much of the original shade still remains in this lower reach of the stream.

Other factors which might be altered by increased insolation, in addition to stream temperatures, are aquatic plant growth and oxygen production and use.

Dissolved Oxygen

Generally, dissolved oxygen concentrations should not be below 6 p.p.m. for growth and well-being of anadromous fish and their associated biota. Concentrations should never drop below 4 p.p.m. at any time or place; they may range between 5 and 6 p.p.m. for short periods provided the water quality is favorable in other respects (Federal Water Pollution Control Administration 1968).

During the road construction period of 1967, dissolved oxygen concentrations as low as 5 p.p.m. were measured in the South Fork near construction activities and in some isolated pools holding decaying slash. The blocking of the streambed, at a location 1,100 feet upstream from the weir, produced a small reservoir in which oxygen concentrations in flowing water areas were from about 7 to 9 p.p.m. The following year (1968), the lowest recorded concentration in the flowing stream was 7 p.p.m. on June 25—a level not far below that of air-saturation under the prevailing conditions. Dissolved oxygen concentrations were not materially affected by the construction activities or by removal of some stream-side vegetative cover.

Food Production

On the South Fork of Caspar Creek, the numbers of insects falling into the stream were greatly increased after the logging road was built.[2] A twofold increase in number and weight of insects occurred over the entire stream. In "disturbed" areas, where the road paralleled the stream, drop insects increased three and one-half times by number and one and one-half times by weight over the "control" area. In the "highly disturbed" areas, where the road crossed the stream, insect numbers increased by five and one-half times, and a threefold increase by weight over the "control" areas was noted.

A more than proportionate amount of the increase occurred in those adult insects having aquatic immature states. One such family, Chironomidae, had a greater occurrence after road construction than the other 11 families combined had before construction. This family showed the most significant increase in numbers of all the families studied and provided an increased food supply.

Although the road building activity destroyed some of the aquatic invertebrates, other orders of insects offset the losses. Rapid recolonization took place in the South Fork. And within 2 years benthos increased 370 percent over its biomass prior to road construction. During the same period, the North Fork benthos increased only 64 percent (Burns 1972).

FISH POPULATIONS

One of the most important variables in determining production of anadromous fish species in tributary streams is the amount of available living space. Young steelhead trout *(Salmo gairdnerii gairdnerii)* and salmon *(Oncorhynchus kirutch)* are territorial fish (Chapman 1966). Emerging fish establish their territories during late spring while water levels are still quite high. As the flow diminishes in the summer, fish with territories at the stream edges are forced to become nomads and to seek new territories. Mortality is higher among the displaced fish than among those with stable home territories.

On small streams, the volume of streamflow directly affects living space. Our streamflow records show quite a range in summer season runoff. In the South Fork, for example, measured streamflow for June 1967 was more than double the June 1968 run-

[2] Hess, L. J. *The effects of logging road construction on insect drop into a small coastal stream.* 1968. (Unpublished master's thesis on file at California State College–Humboldt, Arcata, Calif.)

off volume and more than three times the 1964 runoff. Higher runoff in late spring contributes to and influences population densities in the summer months. While studying the carrying capacity of seven northern California streams Burns (1971) found streamflow volume to be significantly related to salmonid biomass.

In the South Fork watershed, road construction did not significantly effect the volume of living space for the fish population.

Yields of juvenile steelhead trout and salmon emigrants were counted in the South Fork before and after construction of the logging road. Graves and Burns[3] compared the numbers, length, and age-class structures. They found more steelhead smolts (age class: 1+ years and having characteristic silvery appearance that develops before emigration) and fewer salmon smolt migrants in 1968 than in 1964 *(table 4)*. The combined migrant populations of steelhead and salmon smolts decreased 20 percent, but this combined decrease was estimated to be within the range of natural fluctuation reported from other northern California streams (Graves and Burns 1970).

Steelhead and salmon fry (age class: 0- to 3-month newly hatched fish) downstream migrants were more numerous in 1968 than in 1964. No steelhead fry were trapped in 1964; 72 percent of the migrants in 1968 were fry. Age composition of the salmon also shifted markedly from 1964; fry comprised 5 percent of the total in 1964, and 81 percent in 1968.

Population Densities

Population densities *(table 5)* in the South Fork decreased immediately after road construction (Burns 1972). Population estimates for the North Fork fluctuated *(table 6)*. Recovery in the South Fork began the following year and by the second spring the salmonid biomass returned to within 9 percent of the

[3]Graves, David S., and James W. Burns. *Comparison of the yields of downstream migrant salmonids before and after logging road construction on the South Fork Caspar Creek, Mendocino County*. 1970. (Unpublished, Inland Fish. Admin. Rep. 70-3, on file at California Dep. Fish and Game, Sacramento, Calif.)

Table 4–*Downstream counts of migrants, South Fork, Caspar Creek, Jackson State Forest, California, by population*

Population and year (March 13-July 1)	Steelhead trout	Coho salmon	Total
Smolts:			
1964	79	581	660
1968	187	341	528
Fry:			
1964	0	32	32
1968	488	1,429	1,917
Total:			
1964	79	613	692
1968	675	1,770	2,445

Source: Graves and Burns 1970.

Table 5–*Population densities and numbers of salmonids in South Fork Caspar Creek, Jackson State Forest, California*

Survey date	Steelhead Trout				Coho Salmon	
	Young of year		Yearling or older			
	No. per sq. mile	No.	No. per sq. mile	No.	No. per sq. mile	No.
June 1967	1.69	10,183	0.11	673	1.00	6,001
Oct. 1967	.29	1,436	.02	106	.21	1,038
June 1968	1.32	6,580	.04	176	.50	2,510
Oct. 1968	.58	2,365	.01	51	.32	1,283
June 1969	1.45	9,512	.06	407	.77	5,036
Oct. 1969	.81	3,224	.04	141	.48	1,885

Source: Burns 1972.

Table 6–*Population densities and number of salmonids in North Fork of Caspar Creek, Jackson State Forest, California*

Survey Date	Steelhead Trout				Coho Salmon	
	Young of year		Yearling or older			
	No. per sq. mile	No.	No. per sq. mile	No.	No. per sq. mile	No.
June 1967	1.37	6,558	0.02	93	0.07	313
Oct. 1967	.52	2,015	.02	69	.03	122
June 1968	1.61	5,801	.02	82	.10	359
Oct. 1968	.57	1,172	.03	77	.08	194
June 1969	.81	4,005	.04	211	.55	2,724
Oct. 1969	.47	1,151	.03	71	.45	1,105

Source: Burns 1972.

Table 7—*Composition of streambed materials, North and South Forks, Caspar Creek, Jackson State Forest, California*

Survey Date	South Fork			North Fork		
	<0.8 mm.	<3.3 mm.	<26.7 mm.	<0.8 mm.	<3.3 mm.	<27.6 mm.
	– – *Mean pct. of sample vol.* – –					
June 1967	20.6	36.4	73.3	18.4	32.0	72.0
Oct. 1967	34.2	47.8	77.8	17.5	33.5	79.5
June 1968	17.9	37.2	84.4	18.2	34.6	78.0
Oct. 1968	19.0	37.1	74.8	18.0	35.5	75.7
Aug. 1969	28.5	44.2	75.0	23.2	40.5	80.4

Source: Burns 1970.

predisturbed biomass. All age groups of salmonids had greater mean lengths after the road construction. Comparison of steelhead smolt lengths was difficult because of the emigration of more than one age class.

The two large weir ponds, and a fish ladder upstream from the emigrant traps, obscured the impact of stream habitat alteration by providing refuge for fish during road construction and right-of-way logging. Some of the population decrease in the South Fork in 1967 may have resulted from migration of some large steelhead trout from the study area to the pools formed behind the streamflow gaging and fish trapping facility. The ponds made up about 20 percent of the total salmonid habitat. In all probability, then, not all the decrease in 1967 population densities can be considered mortality *(table 5)*.

Streambed Composition

Streambed conditions can affect fish habitat. Compacted streambeds prevent digging of redds, reduce supply of oxygen to the eggs, and prevent emergence of fry. Large proportions of fine sediment may fill the voids to reduce fry emergence and intergravel oxygen flow.

As a measure of salmon and trout production, streambed conditions were evaluated in both watersheds. During three consecutive seasons, the California Department of Fish and Game collected quantitative data on the changes of sediment sizes within the streambed (Burns 1970) *(table 7)*. In the South Fork watershed, the volume of fine sand and smaller size particles increased immediately after road construction, but were about the same the summer after the first runoff season. Survey data collected about 2 years after road construction show an increase in the smaller size fractions. A similar trend was found in the North Fork watershed.

Streambed gravel conditions are most critical during the winter runoff period when eggs are deposited and in the spring when fry emerge. Within that same period, the streambed was undergoing constant change owing to peak runoff events. Even though there was a change in the composition of the streambed particle size, it did not materially affect fish populations.

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1973. **Road construction on Caspar Creek watersheds . . . 10-year report on impact.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 10 p., illus. (USDA Forest Serv. Res. Paper PSW-93)

A long-term study of the effects of logging and road building on streamflow, sedimentation, and fish habitat on two watersheds of Caspar Creek, in northern California, was started in 1960. After 10 years, the study has progressed through a period of stream flow calibration. And during a 4-year period, effects of road construction were studied. In 3 of the 4 years, the impact of timber removal for road construction and of road and bridge building was reflected in above-normal yields of sediment. But the impact on fish habitat and fish populations appears to have been minimal.

Oxford: 383:116.38:(794).
Retrieval Terms: bridge building; road construction; logging operations; environmental impact; streamflow; sedimentation; fish habitat; Caspar Creek; California.

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PACIFIC SOUTHWEST Forest and Range Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701

FIRE PREVENTION FILM SPOTS FOR TELEVISION. . . narrator influence on knowledge and attitude changes

Gene C. Bernardi

USDA FOREST SERVICE RESEARCH PAPER PSW-94 /1973

ERRATUM

"Fire Prevention Film Spots for Television...narrator influence on knowledge and attitude changes," by Gene C. Bernardi (USDA Forest Service Research Paper PSW-94, 1973)

Page 1, 4th paragraph of text, line 4 as reads:

"KIEM, Yreka, California..."

Should read:

"KIEM, Eureka, California..."

CONTENTS

THE AUTHOR

GENE C. BERNARDI, a research sociologist with the Station at Berkeley, conducts studies in the prevention of man-caused forest fires. She holds a bachelor's degree (1951) in psychology and a master's degree (1964) in sociology from the University of California at Berkeley. She joined the Station staff in 1968 after working for the City of Oakland as a research associate (1964-1967).

ACKNOWLEDGMENTS

The experiment involving California high school students was done with the cooperation of Dr. Richard S. Boyd, superintendent, Oroville Union High School District; principals of the Oroville, Prospect, and Las Plumas High Schools; and the teachers and students who participated. John McCloud produced the film spots. Richard L. Aronoff, University of California, Berkeley, wrote the computer programs used in analyzing the data.

The experiment in which film spots were televised on commercial channels in California and Oregon was done with the cooperation of Newton L. Steward, vice president, KIEM-TV3, Eureka, California; Russ Jamison, director of programing, KMED-TV, Medford, Oregon; and Richard Ernest, fire prevention officer, California Division of Forestry. Marilyn Wilkes, University of California, Berkeley, wrote the computer programs used in analyzing the data.

SUMMARY

Bernardi, Gene C.

1973. **Fire prevention film spots for television . . . narrator influence on knowledge and attitude change.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 14 p. (USDA Forest Serv. Res. Paper PSW-94)

Oxford: 432.13:U659.148.

Retrieval Terms: fire prevention education; television research; attitude change; behavior change.

Three 60-second fire prevention television spots designed to reach high fire risk persons in the young adult population were evaluated by two experiments. The films differ only in the character of the narrator: Smokey in one, a Youth in a second, and a Ranger in a third. The hypothesis being tested was: learning and positive attitude change are more likely to occur among young people following a message communicated by a peer group member or idol than following one by an enforcement authority figure (Ranger) or a symbolic figure (Smokey Bear).

The films were more effective in the captive audience situation of Experiment 1 conducted with 170 Northern California high school students than under normal television viewing conditions in Experiment 2. In the classroom experiment, all three of the films were effective in teaching proper fire use practices.

The success, in Experiment 1, of *all* three films in teaching proper fire use practices, although not a confirmation of the study's hypothesis, justified conducting Experiment 2 as a test of the hypothesis under normal television usage.

Experiment 2 retested the Smokey and Youth versions under conditions of normal exposure by commercial TV channels. The Smokey film was shown by KIEM, Yreka, California, and the Youth version by KMED, Medford, Oregon. Interviews were conducted before and after the showings, in Arcata, California, which received only the Smokey film, in Yreka, which received only the Youth film, and in Red Bluff, California, the control community, where neither of the films could be viewed.

The Youth film, under conditions of normal television viewing, was more effective than the Smokey film. In Yreka, after the Youth film was seen, people felt more strongly that "Fire prevention rules and regulations should be more strictly enforced." In the Arcata area where the Smokey film was viewed, the reverse occurred: people felt less strongly about the enforcement of fire regulations. In the normal television viewing situation there were no other statistically significant changes in answers to the remaining attitude statements nor to the knowledge questions on how to prevent forest fires. However, in the communities where the experimental films were shown there was more change (although not statistically significant) to correct answers following the film showings than in the control community.

Because the films were specifically designed to reach the high fire risk segment of the population under 25 years of age, the effectiveness of the films with different age groups was compared. Age was found to have no significant relationship to the effectiveness of the films. The relationship of other characteristics of the viewing populations–relevance of fire prevention, income, sex, marital status, employment status–was also investigated to determine whether either film was significantly more effective with some groups than others. The Youth film was found to be more effective than the Smokey film in eliciting a stronger position on fire law enforcement among those who had had recent forest and wildland experience. Neither film was consistently more effective than the other with any other subgroup.

Results of the two experiments suggest that these TV spots, with young people portrayed, were more effective in teaching proper fire use practices in a clasroom situation than they were in the normal viewing situation for which they were intended. And the Youth film was more effective under normal viewing conditions, than the Smokey film, in making the population studied more concerned about the enforcement of fire regulations.

A combination of techniques for effective fire prevention is suggested by the findings: Education in captive audience situations where high fire risk persons may be found, such as offices or factories, and attitude change through the use of mass media personages with whom members of the target audience can more readily identify than they do with Smokey.

The development of guidelines for effective fire prevention films for television has been a continuing research effort by the U.S. Forest Service. An earlier experiment (Bernardi 1970) compared the attitude-changing effectiveness of three films varying in "threat" content. For the survey sample as a whole, one film was no more effective than another in changing attitudes, but for that one-third of the subjects who had recently lived or worked in the wildlands, the "mild-threat" film was significantly more effective.

No human beings were portrayed in these first experimental films. This suggested an explanation for the failure of any of the films to affect significantly the attitudes of the majority who had not recently lived or worked in wildland areas: members of the audience had no one with whom they could identify.

The need for television spots effective with wildland visitors as well as wildland residents and workers, and the assumption that audience identification with human models would lead to attitude change and learning, inspired three new experimental fire prevention films. In these, the persons portrayed were intended to appeal to members of a particular target audience—those high fire risk persons identified as such in a survey of residents of Butte County, California (Folkman 1965). High wildland activity, together with poor fire prevention knowledge and attitude scores were the indicators for the target group. Members tended to be unmarried persons under 25 years of age with a limited amount of schooling for their age and a total family income in the low-to-medium range. They appeared to spend less time than average listening to the radio, but their TV watching was higher than average.

The three films showed a group of young people in a wildland recreation activity, and varied only in the person narrating. In one film this was a Forest Ranger; in the second, Smokey Bear; and in the third, a moderately "hip" youth, one with medium-length hair.

To reach the target audience with the films developed for this study, two approaches were used. In the first experiment, conducted in December 1970, a group of high school students viewed the three films as a school activity; before-and-after questionnaires were used to test their knowledge and attitude change and their reactions to the character of the narrator. In the second experiment, two of the three films were shown on two commercial TV channels, each having separate viewer coverage. Before and after the TV showings, in home interviews, community members were interviewed with questionnaires similar to those used with the students.

This paper reports on the relative effectiveness of the films in teaching fire prevention. The specific objective of the study was to test this hypothesis: Learning and positive attitude change (fire prevention knowledge and fire caution) are more likely to occur among young people of the lower socioeconomic group (undereducated lower-income youth) following a message communicated by a peer group member or idol (the Youth) than following one by an enforcement authority figure (Forest Ranger) or a symbolic figure (Smokey Bear). The hypothesis implies two agents of possible change—the message itself (constant) and the credibility of the message source, or narrator (varying). It was recognized that other elements in the films or in the viewing situation might need to be explored if the results showed positive knowledge or attitude changes not related to greater source credibility.

METHODS

To test the hypothesis, procedures in three areas had to be devised. It was necessary first to develop films that might appeal to the assumed audience; second, to choose the subjects and testing plan; and third, to devise the questionnaires.

Experimental Films

Development of three new 1-minute color television films to appeal to the target audience required some assumptions. For some of these, I drew upon a number of published studies of appeal elements in mass-media materials. The assumption that the use of persons with whom the audience can presumably identify is valuable was borne out in a study by Blomgren and Scheuneman (1961). In illustrated leaflets featuring endorsement by a professional racing driver versus a "scare" approach, the former was significantly more effective. Mehling (1959) found that a photograph of a prestigious person accompanying a news story increased attitude change. Identification of viewers with like-sexed characters in films was explored by Maccoby and Wilson (1957), who found that boy viewers remember aggressive content, with the boy hero as agent, better than girls, whereas girls remember interactive content better than boys. Viewer identification with members of a social class aspired to was also noted. The importance of the way students perceive the prestige of the communicator was reported by Greenhill (1967); and Berscheid[1] found that lack of identification with the communicator's value system in a particular area resulted in change of opinions to a position opposing the communicator's. Kishler (1950), exploring audience attitudes toward the main character in a film, found positive changes occurred, but most differences were not statistically significant.

In establishing a basis of interests for the target audience, I assumed they shared the generally widespread taste of young people for rock music and the dress and hair styles generally associated with "hip" culture. A study of 16- and 17-year-old students explored differences between smokers and nonsmokers (Salber and Rochman 1964). Sixty percent of high school smokers were found to be low achievers, and two-thirds of the low achievers were smokers. Although we do not know the smoking habits of our high fire risk group, we do know that many are high-school dropouts. We may assume, therefore, that the personality differences of smokers are relevant to our target group. The study found that smokers, more than nonsmokers, own cars and go to dances. Cars and rock music were assumed to be useful elements for inclusion in the films. Poor adjustment in family relationships and with authority in general was also noted in boys who smoked. The investigators suggest that boys, at least, would not be likely to identify with a film personality representing a parental or authority figure.

[1]Berscheid, Ellen. *The effects of communicator-communicatee value similarity and dissimilarity upon opinion change.* 1965. (Unpublished Ph.D. thesis on file at Univ. of Minnesota, Minneapolis.).

Besides the lack of opportunity for viewer identification, an apparent weakness of our earlier set of experimental film spots was that they merely admonished the viewer to be careful with fire, but did not explain how. Therefore I decided that the new spots should inform their viewers of the proper way to build and put out a campfire and how to smoke safely while in the woods.

The three new television films devised differ only in the character of the narrator who advises the viewers on proper fire use practices. The film opens with young people arriving by sports car and motorcycle in a wooded area. Background rock music grows louder as the young people hike to a campsite. Scenes follow showing the young people and rock musicians assembled at the site. Then a closeup of the "narrator" who gives the fire prevention advice appears. As the narrator describes a proper fire use practice, a scene of the young people demonstrating the proper method is shown. The "Ranger" and "Smokey" narrations are identical, but the "Youth" narration incorporates the hip idiom in the first and last two paragraphs.

Ranger and Smokey Narration

Forests are for all of us to enjoy
And all of us can help protect them
By being *extra* careful.

Before you build a fire
Clear off a circle that's ten feet across
Right down to bare earth.

Make a ring of rocks
Or dig a hole at the center,
And then build a small fire inside.

If you have to smoke,
Sit down and do it in a cleared area,
And be sure all matches and cigarettes are dead out.

Before you leave, douse your fire
And stir the ashes until they are cold.

If we protect our forests now,
We can still enjoy them in the future.

Youth Narration

Yeah, people,
The woods are good for your head,
But be cool,
Do your thing the right way.

. . .

Before you split,
Douse your fire
And stir the ashes until they are cold.

The nature scene is far out—
Let's keep it that way for future trips.

Test Subjects and Film Showing

Experiment 1

The first phase of the testing was conducted with captive audiences: 170 high school students in Oroville, Butte County, California. Four treatment groups were set up, one to view each of the experimental films and a control group which viewed only an unrelated film. To secure an adequate number of subjects, the experiment was conducted four times, utilizing 12 different teachers' students at the several schools making up the Oroville Union High School District—Oroville, Prospect Continuation, and Las Plumas—providing a total of 170 students. Students in each classroom at a participating school were randomly assigned to four treatment groups. Later, for purposes of analysis, scores of all students who had viewed a particular film were grouped together, regardless of the school and day of their participation.

To simulate normal TV viewing conditions, each 1-minute fire prevention spot was spliced as a rider onto an 11-minute color film, "Life in the Sea," produced by Encyclopedia Britannica Films, Inc. The control group saw only this film.

Every effort was made to test the effectiveness of the films with the target audience for which they were designed: the high fire risk group identified in the Butte County survey (Folkman 1965). As described earlier, this group consisted largely of high school dropouts from lower or lower-middle income families. Those employed had only part time or intermittent jobs. They were mainly city or open-country nonfarm residents, and most had formerly lived in small towns.

To reach potential high school dropouts, the test group included as many Title I Classes (disadvantaged students qualified for special funding under the Elementary Secondary Education Act) as possible, and both the morning and afternoon sessions at the continuation high school. Our experimental audience closely resembled the high fire risk target group identified by the Butte County survey. Ninety-three percent of the students were single and had never been married. They were young, 97 percent being between 14 and 20 years of age. Of those who considered themselves in the labor force during the past year, 34 percent were employed just part time or part of the year, and another 14 percent were unemployed. Most of the students were from the small town of Oroville, and the next largest group were open country nonfarm residents. Three-fifths formerly lived in either a city or a small town.

Equal numbers of each sex made up the group identified by the Butte County survey as high fire risk. Three-fifths of the Oroville High School experimental group were boys, however.

Experiment 2

Significant results with the captive audience of students justified us in repeating the experiment under conditions of normal exposure from commercial TV channels. Two of the three films were retested in the fall of 1971 through stations KIEM-TV3 in Eureka, California, and KMED-TV in Medford, Oregon. Budget restrictions limited us to two of the original three films, and we chose the films using Smokey and the Youth.

To control as many variables as possible, it was necessary to choose test communities which not only do not receive each other's television signals, but also have fairly similar population characteristics. The three communities which came closest to meeting these two criteria were Arcata, Yreka, and Red Bluff. Each is a small northern California city of under 10,000 population: Arcata, 8,985; Yreka, 5,461; Red Bluff, 7,653 (U.S. Bureau of Census 1972). Each of these communities are in counties with a small minority group population: Arcata, Humboldt County, Negro 0.3 percent, Spanish surname 2.2 percent, Indian 2.5 percent; Yreka, Siskiyou County, Negro 2.2 percent, Spanish surname 4.1 percent, Indian 1.8 percent; Red Bluff, Tehama County, Negro 0.2 percent, Spanish surname 3.7 percent, Indian 0.7 percent (California Division of Fair Employment Practices 1964, 1965; California Division of Labor Statistics and Research 1965).

Income characteristics of the three communities are similar. In Arcata and Yreka, median income is about $10,000; in Red Bluff it is closer to $9,500. The proportions of the population with income below the poverty level in the three towns are 9.5, 7.1, and 8.2 percent, respectively.

Of course, no two communities are exactly alike, and there are some important differences here. Arcata is on the coast and adjacent to the relatively large city of Eureka, whereas Yreka and Red Bluff are inland and somewhat isolated from other towns. Also, Arcata has a college whereas the other towns do not.

The test community of Arcata received only the experimental Smokey film from KIEM, and Yreka received only the Youth film from KMED. Red Bluff, the third distinct viewing area, which receives neither of these channels, served as a control community.

Interviews preceded and followed a 1-week period (September 20-27, 1971) during which each spot was shown several times daily. In an effort to reach a group comparable to the high fire risk group of the Butte County survey, the interviews were confined to a representative sample of households in districts having a relatively high proportion of low-rent and low-assessed housing according to the U.S. Census Bureau. (These criteria were used because the 1970 census income information had not yet been released.) A higher sampling rate was applied in districts with the greatest concentration of low-income housing. One or two sampling units in each community were urban and the remainder were rural or semirural.

We oversampled the youth-young adults; that is, if a household member was 14-24 years of age, we chose that person for interviews, rather than using the random selection method to determine the respondent, as we did in other households.

The sample consisted of 378 potential respondents; 123 in Arcata, 136 in Yreka, and 119 in Red Bluff. From this sample, interviews were conducted, before the film showings, with 82 percent, or 308 of the total potential respondents. Following the film showing, we interviewed 90 percent or 277, of those with whom we had a "before" interview.

The percentage of youth in our samples' low-income districts was low in Yreka and Red Bluff, 17 and 18 percent respectively, but almost one-third (32 percent) in Arcata,[2] apparently because of the college population there. Our special sampling techniques gave us a higher-than-random proportion of youth in our samples: in Yreka 39 percent of our initial interviews were with persons under 25; in Red Bluff, 35 percent, and in Arcata, 45 percent.

In other characteristics of the high fire risk group, the youth in this study's three samples combined tended to be similar: 77 percent were unmarried; 52 percent had not finished high school; of the 46 percent not in the labor market most were students; another 39 percent were employed part time or part of the past year and 14 percent full time. Only 2 percent reported unemployment for the entire past year. Almost half of these youth reported their occupation in the household and service worker or laboring group. Another 7 percent were operatives, 12 percent clerical, and 23 percent, most of whom were students, either had never been employed or had had no steady or substantial job experience. Sixty-five percent had yearly family incomes under $10,000 per year. There were almost equal numbers of each sex (51 percent females). Most considered themselves city or small-town residents. Their TV-watching behavior and radio-listening behavior were similar to that of the total sample, with 48 percent watching TV 2 or more hours per day and 23 percent listening to radio 2 or more hours per day.

The total sample differed from the youth portion of it as follows: the proportions of single persons, students and persons employed only part time were smaller. Although the proportion reporting their occupation as household and service worker or laborer was smaller, over 70 percent of the total sample had incomes under $10,000 per year. In the total sample, there were more females than males, particularly in Red Bluff. Most of the total sample also considered themselves city or small town residents.

On some of the above characteristics, youth in the three study communities differed considerably. Partly because Arcata is a college town, there were more subjects with some college there than in Yreka and Red Bluff, where the majority had only some high school or less. Similarly, a greater proportion of the youth sampled in Yreka and Red Bluff were concentrated in the 14-20 age group; in Arcata they were 21-24. The proportion of those reporting their status as employed rather than student is also apparently related to age, more in Arcata having been employed part time or full time during the past year. In yearly family income, the Arcata sample's youth had the largest proportion with under $6,000 per year, Yreka the largest with over $10,000 per year, and Red Bluff a greater concentration in the income range between. Almost three-fifths of the youth were females in Arcata and Red Bluff, but 56 percent in Yreka were males. In Red Bluff, the control community, we found the most TV-prone youth, 71 percent watching 2 or more hours per day. In Arcata, only 30 percent watched that much, and 25 percent watched not at all or only once or twice per week. In Yreka, TV habits were similar to those of the total combined sample, with 49 percent watching 2 or more hours per day.

Questionnaires and Interviews

Experiment 1

In conducting the experiment special measures were taken to control the nonexperimental variables, such as preexisting differences between the participating classes. One possible difference may have been the influence of the teachers who read aloud the preliminary attitude-knowledge questionnaires to their intact classes. Any differences from this procedure were distributed, along with other differences, by the

[2]Data from Census Services Facility, University of California, Berkeley.

random assignment of students to the next day's four film groups, where the second questionnaire was given following the film showing. Theoretically, each of these four groups included equal numbers of students from each class.

Four assistants were used. Because the experiment was conducted four times, once at Oroville High, twice at Prospect (morning and afternoon), and once at Las Plumas, it was posssible to assign each assistant to a different film treatment each time, thus neutralizing any special influence of the assistant on the results of the second questionnaire. This influence could have been considerable in that it was necessary, because of the low reading level of the students, for the assistant to read the standardized instructions, questions, and attitude statements aloud to the students as they completed the questionnaires.

The first, or preliminary, questionnaire measured attitude and knowledge, and identified demographic characteristics. The second, or final, questionnaire explored the viewer's recall and reactions to the fire prevention film, and repeated the attitude and knowledge items of the first questionnaire.

The preliminary questionnaire was designed to determine existing attitudes toward fire prevention and knowledge of proper fire practices, as demonstrated in the fire prevention spots. In Questionnaire I, Part I, Education, Community, and Environment 11 of the 53 items, pertained to fire prevention attitudes, and three to fire prevention knowledge; Part II, Background Information, contained seven items on demographic characteristics of respondents. The remaining items in Part I were intended to disguise the purpose of the questionnaire, and to interfere with recall of specific answers given to the fire prevention questions which were repeated in the second questionnaire.

A set of attitude statements in which there are five possible responses (strongly agree, agree, undecided, disagree, and strongly disagree) was used (Likert 1967). To avoid response set—a tendency to select the same response for all statements—about half of the fire prevention attitude statements were worded so that agreement denoted a favorable attitude, and the remainder so that disagreement denoted a favorable attitude. (The response most favorable to fire prevention was scored 5, and that least favorable was scored 1.)

Six of the 11 attitude statements were selected from the Butte County study (Folkman 1965, p. 30-32). The six questions chosen were among those that were differentiating; that is, participants in the Butte County study did not all respond to these questions in the same way. The wording was slightly altered in two of the six questions to avoid response set. Analysis of results of a pilot test (Bernardi 1970, p. 4) showed the following three attitude statements best differentiated between students with the most favorable "before" attitude and those with the least favorable "before" attitudes. These statements were in order of discriminating ability...

1. Fire prevention literature is a waste of taxpayer's money.
2. People should be required to obtain fire permits much on the same basis as driver's licenses.
3. Schools should not be permitted to use school time for instruction in forest fire prevention.

Questionnaire II consisted of three parts. In Part I, five questions covered recall of the fire prevention spot seen, and reactions to it, if any. Part II consisted of 29 scales evaluating the acceptability of message sources. Each scale consisted of a pair of adjectives judged to be antonyms, one at each end of a seven-point rating scale. Respondents were asked to rate the narrator (Smokey, Ranger, or Youth) in the fire prevention film viewed, on each scale. The dimensions probed by the scales were safety-qualification-dynamism, an index to source credibility (Berlo, Lemert, and Mertz 1969-70), and sociability and attraction. A receiver may be said to find a source credible if the receiver perceives the source as trustworthy (safety), expert (qualification), and bold (dynamism). Part III contained 21 questions on the respondent's wildland experience; these included a repeat of the 11 attitude and three knowledge questions in the preliminary questionnaire.

Experiment 2

The showing of film spots during the week of September 20, 1971, was preceded and followed by interviews with the population sample chosen. In order to control other potentially influencing variables, ideally, the two TV spots shown during the one-week period should each have been shown adjacent to the same programs and at the same time of day. This ideal could not be perfectly achieved, because the two cooperating stations are not on the same national network and because the spots were treated as public service announcements and were therefore in competition with paid commercials. Nevertheless, the two stations came close to meeting the ideal schedule which I suggested: Playing the spot three times daily, at noon, 3:00 p.m. and 8:00 p.m. Station KIEM varied slightly from this schedule for the Smokey spot on only three occasions in the entire week of showings; KMED played the Youth spot around noon and 3:00 p.m. almost every day, but could not sacrifice the 8:00 p.m. prime time and instead played the spot between 10:00 and 11:15 p.m. The showings of our experimental spots were in addition to the regular fire prevention programing.

In each of the three communities a team of five interviewers and an interviewer-supervisor were hired. I trained the interviewing teams during the week of August 30, 1971. Interviewing began shortly thereafter with Schedule I, the preliminary interview, and was concluded on Sunday, September 19, the day before the film spot showings began. No interviews were conducted during the week the spots were shown. Interviewing with Schedule II, the final interview, began on Monday, September 27, and was concluded by October 7.

Schedule I was essentially the same as Questionnaire I except that four filler items were eliminated. Also, the background information section was redesigned for interviewing and included more demographic information, such as occupation and income.

Schedule II, Part I, determined a respondent's wildland experience. Part II repeated the attitude and knowledge questions of Schedule I. Part III was considerably changed from Questionnaire I to fit the second experiment. It probed, first through recall-type questions, and then recognition-type questions, whether a respondent saw, or remembered seeing, the experimental spot. Part III also included both subjective and objective measures of response to the narrator, Smokey Bear in Arcata, and the Youth in Yreka. The objective measure was a much shortened and simplified version, better adapted to interviewing, of Part II, Questionnaire II. Fifteen adjectival pairs of antonyms made up a two-point scale; either the adjective or its antonym could be chosen to describe the narrator, but nothing in between. Part III also included questions on the TV-watching, radio-listening, and organizational behavior of the subject.

Interpretation of Scores

To test the hypotheses in both experiments as to attitude and knowledge changes and narrator effectiveness, scores on the relevant items as described above were compared.

Changes were studied on an individual-item basis. Whether a respondent underwent a positive attitude change toward fire prevention, or learned something about proper fire practices, was measured by determining the difference between his "before" and "after" scores on each item. Changes were also measured as differences between total attitude and between total knowledge scores and differences between summed scores on three differentiating attitude statements. Where scores on knowledge questions were compared the differences are called knowledge change scores and where scores on attitude statements were compared the differences are called attitude change scores.

The operational indicator of narrator credibility was the scoring of the antonyms bounding a seven-point scale in the first experiment, and making up a two-point scale in the second experiment. An average score of all the scores on the adjectival pair scales was used, but scores were also computed on a particular dimension such as credibility, attraction or sociability, using the applicable groups of adjectival pairs.

Scores were evaluated for statistical significance by the Kruskal-Wallis one-way analysis of variance test (Siegel 1956, p. 184-94). The Mann-Whitney U test for comparison of individual pairs of treatments was also used.

RESULTS

Knowledge and Attitude Change

Experiment 1

Significant gains in fire prevention knowledge were made by those students viewing any one of the three experimental fire prevention films. The gain was particularly noticeable in a comparison of the total knowledge scores on the three fire prevention practices questions *(table 1)*. Almost all in the control group chose the same answers after seeing the unrelated film as they had before. The statistically significant difference in knowledge change scores ($P < 0.001$) occurred in completion of these statements: "The surest way to put out a campfire, assuming all these methods are available, is to . . ." and "When building a campfire it is safest to . . . " The difference in change scores in completion of the statement "It is safest to smoke in the woods while . . . " was significant ($0.02 < P < 0.05$), but the probability of this difference occurring by chance was greater than that for the differences in scores on the other two statements.

Sizable percentages of each student group changed to the correct answers after they saw the film spot. In

Table 1–*Total knowledge change on three questions on fire prevention practices, among California high school students who viewed one of three experimental fire prevention films* [1]

Direction of change		Youth (n=40)	Smokey (n=48)	Ranger (n=46)	Control (n=36)
		Percent [2,3]			
	+3	7	21	2	0
To correct:	+2	28	19	24	0
	+1	35	33	37	22
No change	0	28	27	30	75
To incorrect	-1	3	0	7	3

[1] A total knowledge change score is the difference between the total scores received, before and after seeing a film, on the three questions testing knowledge of fire prevention practices.
[2] Differences between treatments and control were significant by Kruskal-Wallis test on ungrouped scores: This yielded an $H = 29.34$, which with $df = 3$ shows $P < 0.00001$.
[3] Columns may not add to 100 percent because of rounding.

the Youth, Smokey, and Ranger viewing groups, 53, 48, and 39 percent respectively changed their answers to the correct one on the surest way to put out a campfire. On the safest way to build a campfire, 28, 45, and 41 percent respectively changed to the correct answer. On both these questions, 92 percent of the control group chose the same answer, correct or incorrect, they had chosen before seeing the unrelated film. Comparing the total knowledge scores, we find that 70, 73, and 63 percent respectively of the Youth, Smokey, and Ranger groups changed from one to three of their answers to correct ones following the film. In the control group the total knowledge score changed in a positive direction for only 22 percent of the students, and then by only one point.

Comparison of the experimental fire prevention film groups by pairs showed no one film to be significantly more effective than either of the others in teaching these proper campfire practices.

In attitude items, no statistically significant differences in change scores occurred among the four film groups, as shown in scores on single attitude statements, total scores on all 11 statements, or a summed score of the three differentiating statements. The tendency in all four groups, however, was for the total fire prevention attitude change score to shift to a weaker or less favorable position *(table 2)*. This effect may have been due to the testing situation or instrument itself. A probable explanation is that the respondents did not react as strongly to an attitude statement when confronted with it for a second time. This tendency was slightly reversed, except in the control group, for the summed change scores on the three discriminating attitude statements.

Experiment 2

The significant fire prevention knowledge gains by the students justified the effort to determine whether the experimental film spots would retain their effectiveness under conditions of normal use.

Sample projections indicate that close to one-third of the Yreka population studied, and more than one-fourth of the Arcata population studied, saw the film. In Arcata, 20 percent definitely recalled seeing or recognized a description of the Smokey spot; 8 percent were not sure whether or not they had seen it. In Yreka, 24 percent definitely saw the Youth spot, 8 percent were not sure.

Regardless of whether or not they recalled seeing the film spots, those in the communities where the films were shown had a greater tendency to change to the correct answers on the fire use practices questions than did those in the control community *(table 3)*. The differences, however, were not statistically significant.

The Smokey and Youth films significantly differed in their effectiveness in changing attitude on only one out of 11 attitude statements: "Fire prevention rules and regulations should be more strictly enforced." The Kruskal-Wallis test showed $0.001 < P < 0.003$. (Where there are 11 items the probability of a chance difference this large is less than 0.033.) This significant difference in the effectiveness of the two films holds, even when those who recalled seeing a spot and those who did not are considered separately. In the Yreka area, where the Youth film was shown, attitudes became more positive toward this statement after the showings. In the Arcata area where the Smokey film was shown, the opposite occurred; after

Table 2–*Total attitude change on eleven attitude statements, among California high school students who viewed one of three experimental fire prevention films*

Direction of attitude change	Youth (n=40)	Smokey (n=48)	Ranger (n=46)	Control (n=36)
	Percent [1]			
Stronger	32	37	39	36
No change	13	8	4	8
Weaker	53	52	52	50
No answer	3	2	4	6

[1] Columns may not add to 100 percent because of rounding.

Table 3—*Total knowledge change score on three questions on fire prevention practices, among respondents in three California communities who viewed one of three televised film spots*[1]

Direction of change	Yreka (Youth) n=114	Arcata (Smokey) n=97	Red Bluff (Control) n=97
	Percent[2,3]		
To correct	31	28	21
No change	49	51	59
To incorrect	20	22	21

[1] A total knowledge change score is the differences between the total scores received, before and after seeing a film, on the three questions testing knowledge of fire prevention practices.

[2] Differences between treatments and control were not significant by Kruskal-Wallis test on ungrouped scores. This yielded an $H = 2.23$ which with $df = 2$ shows $0.30 < P < 0.50$.

[3] Columns may not add to 100 percent because of rounding.

the showing, people were inclined to feel less strongly than they had previously about the enforcement of fire prevention regulations.[3] The differences from the control results in Red Bluff[4] where over two thirds of the respondents showed no attitude change in the Schedule II interview, were significant. The percentages, for those who recalled seeing the spot, were Youth: stronger 28 percent, weaker 7 percent; Smokey: stronger 9 percent, weaker 27 percent. For those who did not recall seeing the spot, percentages were Youth: 22 and 19 percent, Smokey: 8 and 31 percent. The control group as a whole showed changes to stronger, 8 percent and to weaker, 15 percent. Thus, of those control subjects who did change, most moved to a more negative position, but this tendency was not as great as in the Arcata (Smokey) area. No statistically significant differences in attitude change occurred on 10 other attitude statements, when compared singly, or when summed scores on all 11 attitude statements, or on the three discriminating statements were compared.

Because the films were designed to reach the high fire risk segment of the population under 25 years of age, the effectiveness of the films with different age groups was compared. Age was found to have no significant relation to the effectiveness of the films.

[3] The Mann Whitney U test showed for Smokey vs. Youth, $U = 5503$ or $z = 3.26$ and P of $z \geqslant 3.26 < 0.0007$.

[4] The Mann-Whitney U test showed for Smokey vs. Control, $U = 4288$, $z = 2.03$, P of $z \geqslant 2.03 = 0.02$; Youth vs. Control, $U = 3889$, $z = 1.61$, P of $z \geqslant 1.61 = 0.05$.

Comparisons were made for 19 other characteristics, including 12 that were socio-economic, five that indicated relevance of fire prevention to respondents, and two that described the respondents' residential environment. Preliminary tests (Kruskal-Wallis) showed that the attitude changes from the three experimental treatments differed significantly according to subgroups determined by marital status, family size, current employment status, and relevance of fire prevention. When individual pairs of film treatments are compared, (Mann-Whitney U test) for such differences, however, the pattern of response is inconsistent. (For example, the Smokey film may be more effective with married persons than with the widowed, divorced, and separated in changing an attitude in a positive direction on one statement, and the Youth film more effective with the married in improving their attitude on another statement.) For only a few subgroups did attitudes improve after the Smokey film was shown; in most, attitudes were weakened. Grouping according to the relevance of forest fire prevention produced some interesting results, however.

Criteria used to determine whether or not forest fire prevention was relevant to viewers were these questions: Did they visit forest or wildlands in the past year? Or work or visit there in the past 3 weeks? Did they live or work in forest or wildlands, or visit there 11 or more times in the last year? The Youth film was more effective than the Smokey film *(table 4)* in changing the attitude of those who had had recent forest and wildland experience, by all four criteria, to a stronger position on the statement "Fire prevention rules and regulations should be more strictly enforced." With several criteria, however, the effect of the Youth film was not significantly different from that in the control community. That is, the significant difference between the Smokey and Youth film was, with these criteria, due to the extent of the negative effect of the Smokey film rather than to the positive effect of the Youth film.

The Youth film was also effective with those to whom forest fire prevention is less relevant because of their lack of recent wildland experience. But the Youth film's effectiveness did not hold for all criteria of nonrelevance, sometimes changing a subject's opinion in a positive direction on one attitude statement, sometimes on another, and sometimes not at all. In fact, the Smokey film's attitude-changing capacity was greater with this group to whom forest fire prevention is not relevant, because they do not go to the wildlands, than it was with any other subgroup.

Opinion of Narrator

Experiment 1

On only one of the dimensions for evaluating message sources—attractiveness—was there a statistically significant difference in the opinion scores of the high school students viewing the fire prevention spots *(table 5)*. The adjectival pairs making up this dimension were: attractive—repulsive, one of us—one of them, stuffed shirt—regular guy, and plastic—real. Whereas the Youth and the Ranger were rated high on the attractiveness dimension (average scores 4-6) by 45 and 50 percent, respectively, of their viewers, Smokey was rated low on this dimension (average scores 0-3) by 63 percent of his viewers. There were no statistically significant differences on the sociability dimension; nor were there on the source credibility dimension or on a total opinion score figured on all 29 scales.

Results on the subjective reaction items showed that most respondents in each of the groups which viewed a film spot (73 percent—Youth, 85 percent—Smokey, 87 percent—Ranger) thought it was somewhat interesting or very interesting. Most also thought that the scenes portrayed were generally pleasant or very pleasant (93 percent—Youth, 87 percent—Smokey, 85 percent—Ranger).

Forty-eight percent of both the Youth and Smokey film viewers, and 43 percent of the Ranger film viewers, reported they were either informed or fascinated, or both. The balance were indifferent, annoyed, or confused.

A majority (54 percent—Ranger, 56 percent—Smokey, 58 percent—Youth) when asked what they thought the main point of the film was, answered, "to show how to prevent forest fires." Another 35 to 37 percent either did not know the main point or replied that it was "outdoor recreation." The rest either did not remember, did not answer, or said the main point was to advertise "cigarettes," "soft drinks," or "motorcycles."

Table 4—*Change in attitude shown toward enforcement of fire prevention regulations among respondents in three California communities after seeing one of three televised film spots, by type of narrator and relevancy of films to respondents' experience* [1]

Narrator in film viewed, and relevancy[2]	Change in respondent's attitude after seeing fire prevention film		
	Stronger	No change	Weaker
	Percent		
Youth:			
Relevant (n=41)	32	51	17
Not relevant (n=61)	18	67	15
Smokey:			
Relevant (n=52)	6	65	29
Not relevant (n=34)	12	53	35
Control:			
Relevant (n=28)	11	71	18
Not relevant (n=58)	9	78	14

[1] Mann-Whitney U test calculated with ungrouped scores showed:

Relevant

Youth vs. Smokey: U = 754, z = 2.60, P of $z \geqslant 2.60 = .005$

Youth vs. Control: U = 483, z = 1.25, P of $z \geqslant 1.25 = .106$

Smokey vs. Control: U = 620, z = 1.17, P of $z \geqslant 1.17 = .121$

Not relevant

Youth vs. Smokey: U = 796, z = 2.16, P of $z \geqslant 2.16 = .015$

Youth vs. Control: U = 1632, z = .92, P of $z \geqslant .92 = .179$

Smokey vs. Control: U = 817, z = 1.66, P of $z \geqslant 1.66 = .049$

[2] Relevancy determined by answer to question: Have you worked in or visited in any forest or other wildland areas in the past three weeks?

Table 5—*Scores on attractiveness of message narrator in television film spots viewed by California high school students who viewed one of three experimental fire prevention films*[1]

Attractiveness score[2]	Youth (n=40)	Smokey (n=48)	Ranger (n=46)
	Percent[3]		
Positive (4-6)	45	15	50
Intermediate (3.1-3.9)	25	19	15
Negative (0-3)	25	63	28
No answer	5	4	7

[1] Differences between treatments were significant by Kruskal-Wallis test on ungrouped scores: This yielded an H = 13.69 which with df = 2 shows $0.001 < P < 0.01$.

[2] Based on ratings of adjectival pairs: attractive—repulsive; one of us—one of them; stuffed shirt—regular guy; plastic—real.

[3] Columns may not add to 100 percent because of rounding.

Experiment 2

No significant difference between the two viewing communities was noted in the respondents' opinions of the narrator. This was true of opinion scores based on the complete set of adjective scales as well as on either of the two single dimensions, attractiveness and credibility. The latter dimension, in this experiment, was composed of 14 of the adjective scales recommended by Berlo, Lemert, and Mertz (1969-70, p. 574) and the former only on the one scale, attractive—repulsive.

The absolute numbers in the samples of those who recalled seeing the spots are too small to make subgroup comparisons of credibility or opinion of narrator meaningful.

According to subjective reactions of those who saw a film, the Youth film was somewhat more impressive than the Smokey film. In Yreka 88½ percent said the Youth film was very interesting or somewhat interesting, and the rest said it was not very interesting. In Arcata 57 percent said the Smokey film was very or somewhat interesting and 43 percent said it was not very or not at all interesting.

Ninety-six percent of the Youth film viewers found the scenes portrayed pleasant and 4 percent found them very unpleasant. Eighty-nine percent of the Smokey film viewers found the scenes portrayed pleasant or very pleasant and 11 percent found them unpleasant.

Of the Youth film viewers 83 percent found the Youth agreeable and the balance found him *very* agreeable. All the Smokey film viewers found him only agreeable.

DISCUSSION

The 60-second fire prevention television spots tested in this study were designed for use on commercial channels, where they would be received by the public at their discretion, ordinarily in the home. The captive audience evaluation with students was merely a stepping stone to the field evaluation of these fire prevention spots.

The spots were more effective in teaching proper fire use practices when shown to the captive audience. None of the films improved attitudes in this use, but the Youth film did, apparently, have a limited effect on attitude when shown to the public.

In the showings to students, Experiment 1, no one of the fire prevention films was significantly more effective than another, but all three were significantly effective in teaching the viewers how to build and how to put out a campfire. These results, and the absence of significant differences between viewers' evaluations of the narrator, except as to attractiveness, suggest that the narrator did not affect the reception of the total film. This conclusion is borne out by the viewers' subjective reactions, which vary little from film to film.

The important thing we found in the first experiment was that youngsters in a classroom situation did *learn* proper fire use practices from the explicit directions and demonstrations in these films. But this did not happen for the reason hypothesized: that the identification potential of the Youth film would render it more effective with "undereducated" young people than the Smokey or Ranger film. The findings of the first experiment did not show that the improved learning was from identification with, greater credibility of, or even greater attractiveness of a peer group member rather than an authority figure or symbolic figure.

The hypothesis being disproved, we can only guess at the reasons for all three films' success in the classroom experiment. For example, identification with the young people arriving by car and motorcycle and interest in the rock music and general party atmosphere portrayed in each of the films may have overwhelmed the change in only one variable, the character of the narrator. On the basis of Experiment 2, however, carried out under conditions of normal television viewing, this conjecture does not hold up. Here no teaching effect was observed, but the Youth film was effective, though to a limited extent, in changing attitude in a positive direction, whereas the Smokey film weakened attitudes. Again, we must guess at the reasons for the significantly greater attitude-change effectiveness of the Youth film, for there were no significant differences between the two films on the hypothesized factor, credibility or opinion of narrator.

If we look for an explanation in environmental factors in the communities, two of the most obvious relevant variables are forest fires and the effect of other fire prevention programing during the test period.

According to the National Forest offices, a major forest fire, or one reported as major, took place in the surrounding area of each of the communities during the study.

On September 18, 1971, just as the Schedule 1 interviews were being completed and 2 days before the spot showings began, a major fire, the "Red Fir Fire," started in the Klamath National Forest near Yreka. This fire was contained on September 19. Also on September 18, the "Lamb" fire started in the Six Rivers National Forest near Arcata. Because of its potential this fire was reported in the news as a major fire. Under aggressive air attack, however, it was contained the same day at 241 acres. The largest fire occurred in the Mendocino National Forest near Paskenta outside Red Bluff, our control community. This fire started on September 13, about midway in the interview period preceding the spot showings and was not contained until September 18. It burned 1,500 acres.

Thus, the fire situations in the test communities of Yreka and Arcata were very similar during the study period and are not likely to explain any differential effect in attitude change. If the fire situation was influential, the expected improvement would have been not in Yreka, but in Red Bluff, where the fire was largest and of greatest duration.

Other fire prevention programing, as indicated by the schedules of other fire prevention spots played during the test week, was apparently not a factor. Station KIEM, which played the Smokey Spot, had a much heavier schedule of regular fire prevention spots, especially the first part of the week, than did KMED. This is probably a fairly good indication of the fire prevention spot dosage in these communities because only a few channels are received in each. Since TV coverage of fire prevention seemed to be heavier in the Eureka–Arcata area than in Yreka, assuming a positive correlation between dosage and improved attitude, we would expect the reverse of the effects that actually occurred. Therefore, we cannot attribute the improved attitude in the Yreka area to the amount of TV spot fire prevention coverage.

Although our hypothesis that the Youth film would be more effective was confirmed in the second experiment, this was not because it was more effective with the youth under 25 years of age for which it was designed. It was just as effective with one age group as another in changing attitude toward a stronger interest in the enforcement of fire regulations.

The Youth film, irrespective of the wildland experience criterion used, was more effective than the Smokey film in changing the attitude of those who had had recent forest and wildland experience to a stronger position on the statement, "Fire prevention rules and regulations should be more strictly enforced." With several criteria, however, this effectiveness is only apparent; the changes did not differ significantly from the changes that occurred in the control community. In other words, the significant difference between the Youth and Smokey films was due more to the latter "turning off" those with wildland experience, than to the former "turning them on." By the relevance-of-fire-prevention criterion, the Smokey film was effective in changing attitudes in a positive direction, in a few instances, but only with those who had *not* had wildland experience, that is, only with those to whom fire prevention had least relevance.

Perhaps the most important group to reach with our fire prevention messages is those who visit, live, or work in the wildlands. In the experiment using films with varying degrees of threat (Bernardi 1970), we found that the "mild threat" film was especially effective with those who had lived or worked in wildlands in the past year. Although the field experiment reported here has ruled out Smokey as an effective message source in the normal viewing situation for *both* this group and visitors to wildlands, it has added very little to our knowledge about what *will* reach those to whom fire prevention is relevant.

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The relative effectiveness of 60-second films on fire prevention, with different narrators, was tested among high school students and by exposure on commercial television channels. The narrators were Smokey Bear, a Youth, and a Ranger. All three films were effective in teaching proper fire use practices to the high school classroom audience. In commercial TV showings, fire use practices were not learned, but the Youth film was more effective than the Smokey Bear film in making the sample population interviewed more concerned about fire law enforcement.

Oxford: 432.13:U659.148.
Retrieval Terms: fire prevention education; television research; attitude change; behavior change.

PACIFIC SOUTHWEST Forest and Range Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701

Released advance reproduction of white and red fir. . . growth, damage, mortality

Donald T. Gordon

USDA FOREST SERVICE RESEARCH PAPER PSW-95 /1973

CONTENTS

The Author

DONALD T. GORDON is doing research on the silviculture of Sierra Nevada forest types, with headquarters at Redding, Calif. Native of Oxnard, Calif., he was educated at the University of California, Berkeley (B.S. in forestry, 1939), and joined the U.S. Forest Service in 1940. He became a member of the Station's staff in 1946.

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David C. Maul, formerly with the California (now Pacific Southwest) Forest and Range Experiment Station and now retired, was responsible for the early design and installation of the milacre sampling system from which much of the data reported in this paper was derived.

SUMMARY

Gordon, Donald T.

1973. **Released advance reproduction of white and red fir . . . growth, damage, mortality.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 12 p., illus. (USDA Forest Serv. Res. Paper PSW-95)

Oxford: 243:231.1:181.65 [+ 174.7 *Abies concolor* + 174.7 *Abies magnifica*].

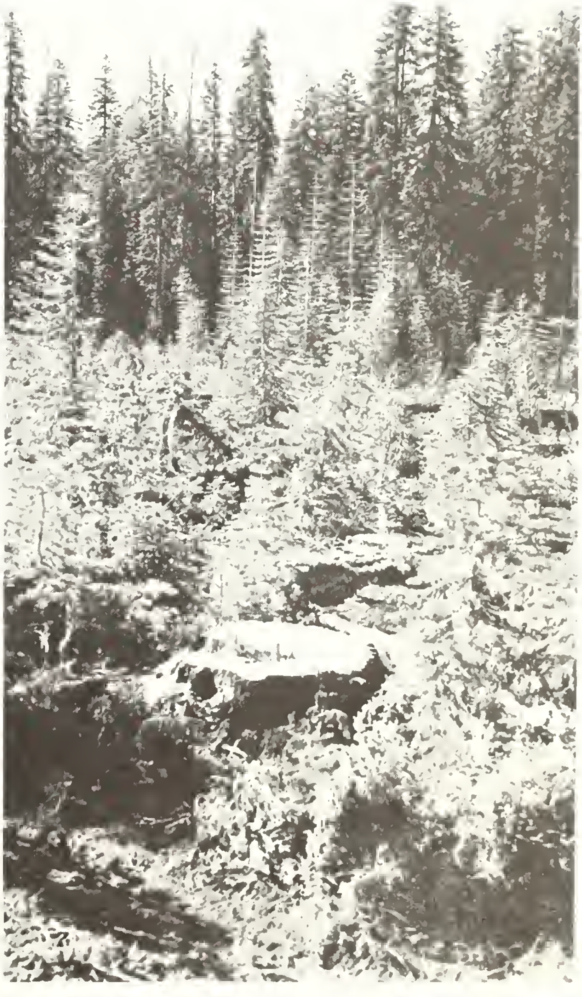
Retrieval Terms: Abies concolor: Abies magnifica; advance growth; liberation cutting; growth response; Swain Mountain Experimental Forest.

The scant early literature mentioning small white and red fir trees indicated without qualification that slow growth could be expected for the first 30 or 40 years. Such a characteristic would seriously lengthen rotations of these important conifers. At the Swain Mountain Experimental Forest, in northern California, the response of advance reproduction of both species to complete removal of a scattered overmature overstory was measured for several years.

A good general response in height growth rate was not apparent until the fifth year after release. Then, both white and red fir advance reproduction responded well. Dominant trees of the advance reproduction retained their relative crown positions. Some trees which initially had been less than 4.5 feet tall increased their annual height growth from 0.1 or 0.2 foot to about 1 foot. A few trees that had been 4 to 8 inches d.b.h. at time of release were consistently adding growth rings 3/8- to ½-inch wide at stump height.

Damage to the young trees was caused principally by logging, with snow and ice ranking next in importance. Logging damage, however, caused only 18 percent of mortality. Obvious or suspected effects of drought and competition accounted for most recorded mortality, and this occurred mostly among the smallest trees. On a 17-acre release cutting, advance reproduction stocking was entirely adequate at the end of the study.

The results of this study should generally have wide application in the management of true firs in the Sierra Nevada and southern Cascade Range.



Since 1958, the Pacific Southwest Forest and Range Experiment Station has been investigating the silvicultural management of true firs at its Swain Mountain Experimental Forest, in northeastern California. A number of experimental cuttings were made on the Forest. The research included studies of released white fir *(Abies concolor* [Gord. & Glend.] Lindl.*)* and red fir *(A. magnifica* A. Murray*)* understory, and of natural regeneration after logging. In an earlier report, I described several factors that affected natural regeneration (Gordon 1970). A later report deals with wind damage in stands of overmature white fir and red fir bordering clearcuttings (Gordon 1973).

The Swain Mountain Experimental Forest is about 10 miles north of Lake Almanor, at the southern limit of the Cascade Range. Elevations range from 5,700 to 7,054 feet. The forest cover is essentially pure fir, with white fir predominating at low elevations, red fir appearing almost exclusively at high elevations. Scattered sparingly over the Forest are small patches of lodgepole pine *(Pinus contorta* Dougl.*)*. These apparently became established after lightning fires. A fir understory often is present beneath this pine, or fir already has overtopped and is eliminating the pine.

Soil is derived from vesicular andesite and is 3 to 8 feet deep over most of the area. Rocks vary in size and abundance.

Precipitation falls mainly as snow during winter. Since 1957-58, a water equivalent of 40 to 50 inches a year usually has been recorded. Monthly surveys during four winters showed that maximum snow depth ranges between 8 and 10 feet. Study areas are in Site Class II (Dunning 1942), with dominant trees averaging 150 feet high at 300 years or 65 feet at 50 years. Site on the Experimental Forest is unusually uniform.

Stand structure varies widely. Gross volume of 147,000 board feet (Scribner) per acre has been recorded for commonly occurring dense old-growth stands. Until they begin to deteriorate, such stands prevent establishment of understory. Volumes of 60,000 to 80,000 board feet per acre are more usual in stands with some crown and age differentiation. All areas where only scattered old trees remain are covered with abundant advance reproduction *(fig. 1)*.

This paper reports a 7-year study of growth, damage, and mortality in released advance reproduction of white and red fir at the Experimental Forest. The cutting areas from which basic data were derived are few and on slopes of a single mountain. And they sample only a small range of possible residual conditions. Therefore, some results should be considered as examples or trends, rather than as average or typical. Other results, however—particularly those of physiological response—should have wide application in the management of true firs in the Sierra Nevada and southern Cascade Range.

METHODS

Early interest at Swain Mountain was centered on post-logging natural regeneration. Consequently, most data reported here on advance reproduction were gathered concurrently with those on new natural seedlings. Study areas were prepared by tractor logging all merchantable trees from (a) 3- and 5-chain wide strips in areas of dense old-growth and (b) irregularly shaped blocks conforming to areas supporting less dense old-growth with abundant understory. Size of the understory release blocks ranged from about 8 to 40 acres. Only one block was sampled, while three strips were studied.

Most data (76 percent) for this study were derived from a 17-chain long strip of square milacres running from edge to edge of an irregularly shaped block cut to release advance reproduction. The transect was installed nearly perpendicular to most skid trails. An average of 28 trees and 55,480 board feet (gross) per acre had been harvested from the block. Logging was supervised closely to insure minimum damage to advance reproduction.

The northwest-southeast oriented clearcut strips were prepared principally for observing factors influencing establishment of natural regeneration. One

Figure 1—Advance reproduction of white fir and red fir was released by experimental cuttings at the Swain Mountain Experimental Forest, northeastern California.

3-chain and two 5-chain wide strips contributed a small amount of data to this study. Strips were sampled by three milacre transects located within areas prepared to represent three different slash treatments. Because of original condition and disturbance by logging and slash treatments, only a few small groups and isolated trees of advance reproduction remained on the strips.

Data for the main body of study of regeneration and of release were gathered from a permanent system of continuous transects of square milacre plots. Transects ran across strips rather than parallel to cutting edges. All transects were oriented northeast-southwest, and on strips had limited random starts within slash treatment areas.

Initial observations on transects were recorded early in the two summers of installation (1959, 1960). These followed cutting by nearly a year. All areas were reexamined in fall 1960 and annually—except in 1962—through 1965.

Slopes recorded on study areas were 10 percent or less. All aspects were northeast. These two site factors were not included in any analyses.

For each milacre, these observations, as pertinent, for advance reproduction were recorded:

1. Species.
2. Number of stems.
3. Height class, by 1-foot intervals up to 10 feet.
4. Diameter for trees over 10 feet high, by 1-inch classes to 12 inches, and by 2-inch classes for larger trees.
5. Damage.
    a. Logging damage (15 specific types).
    b. Dwarf mistletoe (presence in bole or branches or both).
    c. Disease, excluding dwarf mistletoe ("snow fungus," etc.).
    d. Insects.
    e. Weather (sun, snow or ice, temperature, etc.).
    f. All other (defective form, browsing, bark damage by animals, etc.).
6. Cause of death, primary and secondary, by classes a-f above, and "unknown."

In the first examination only trees having some live needles were tallied. The few trees already dead could only be categorized with trees torn out during logging, and of course there was no record of the latter.

Diameter and height were not measured each year. Instead, trees were carried in their original size classes until the last remeasurement in 1965. Annual mortality or damage during the period of observation was assigned to the original size classes.

For another part of the study, age and annual height and diameter growth rates of a few small trees were recorded in 1969. Only 56 trees were included in the sample; half were white fir, and half red fir. Individual trees were selected for measurement within some 1958-60 cutting units not otherwise sampled. Selection was based on (a) density of seedling- or sapling-size advance reproduction around a chosen tree, and on (b) presence or absence of nearby poles or slightly larger trees (to about 16 inches d.b.h.) which might function as a competitive "overstory." Stem density ratings around sample trees were subjective. They were based on (a) previously observed growth reactions along some of the milacre transects, and (b) on professional judgment formed from observations within the Experimental Forest. No estimate of number of stems or of basal area per acre can be given. For the sample trees, total heights to branch whorls were measured in feet and tenths. Then, since most trees had been less than 4½ feet high at time of release, all were cut at ground level and a ½-inch-thick disk was cut from the severed end of each stem to determine total age and radial growth rate.

RESULTS

Stem Frequencies

Small released trees were not expected to die in vast numbers, and they did not. But we were concerned about another possibility: Would these true fir stands respond significantly to release?

For 4 years after release few trees in this study showed appreciable increase in annual height growth. In the fifth year after release, however, most trees began to grow faster than before. An important effect of release had become apparent—trees with dominant crown positions continued to retain their relative dominance. The results suggest that young fir trees on good sites only need growing space for relatively rapid growth; they require freedom from competing trees of larger size class.

Initially 827 trees classed as advance reproduction were found on sample milacres: 351 white firs, 452 red firs, and 24 lodgepole pines. Stem frequency per unit of area followed the usual pattern of decreasing numbers as sizes increased.

The relative number of stems by size classes was not significantly different statistically for white and red fir at the beginning of the study—except for the height class "less than 1 foot." Red fir had a greater initial relative frequency in that smallest class. During the study, however, mortality was proportionately greater there than for white fir, and proportionately more red fir grew into the 2-foot (and probably taller) height class. Seven years after release, differences in size class frequencies of the two fir species *(fig. 2)* still were statistically not significant.

Many tree stems within the 1-foot height class were spindly and bore few needles—especially those in heavily shaded locations. All trees were several years old. And 61 percent of all red fir mortality and 44 percent of white fir mortality occurred in this size class.

Net change in stem count, by size classes, was affected both by mortality and growth during the study. Fewer trees died than moved into larger size classes. The net effect was to increase frequencies in several classes, but not the smallest *(figs. 2, 3)*.

Stocking

Trees on the most densely stocked milacres would be expected to have the lowest survival rate because of competition for moisture, nutrients, and light. Results in this study show that this was not completely true *(fig. 4)*.

On the irregularly shaped block, the most densely stocked milacres had high survival rates *(fig. 5)*. Part of the reason for this anomaly is the nearly flat soil moisture drainage area crossing the transect from the 10- to 12-chain point to the 17-chain point. In most years shaded soil surface there appears damp until midgrowing season.

Availability of soil moisture also explains the persistence of post-logging seedlings on the densely stocked areas during the study period. However, mortality rates for smallest trees indicate that most of these new seedlings will eventually die from competition—just as they do beneath densely stocked mature stands.

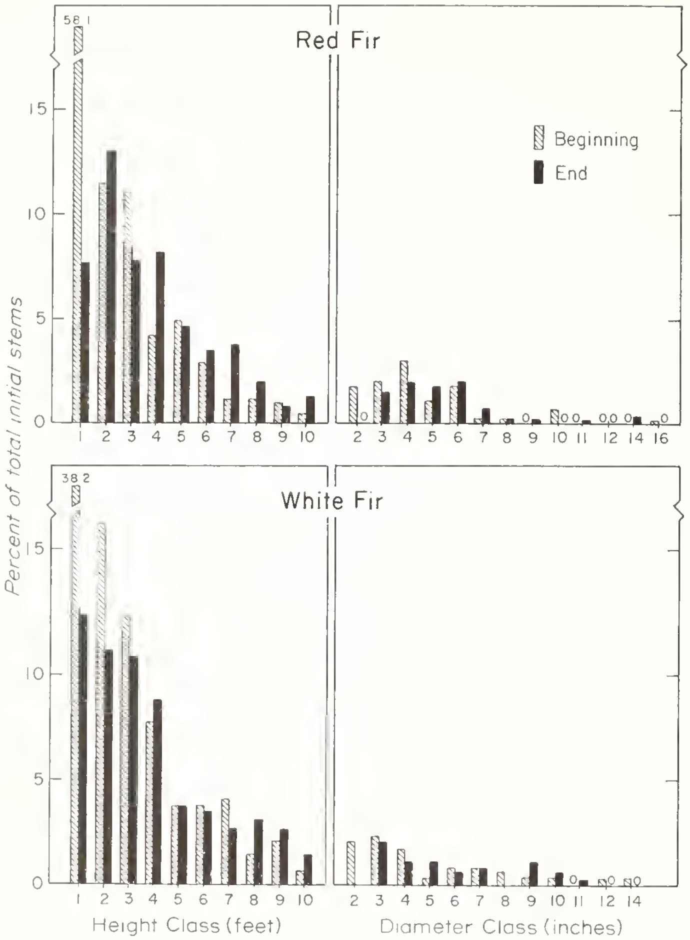


Figure 2—Size class frequencies of white and red fir during the 7 years of study at Swain Mountain Experimental Forest were essentially similar.

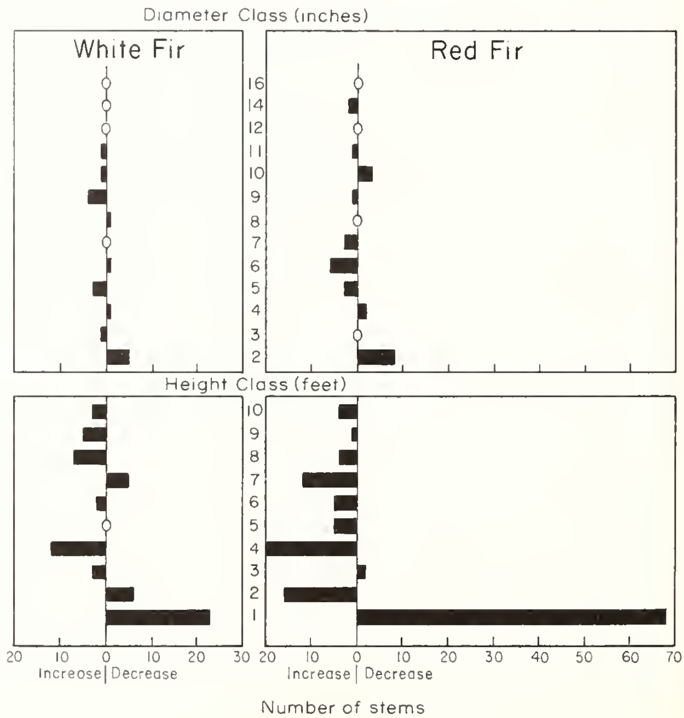


Figure 3—Net changes in size class frequencies clearly show that mortality and growth effects were concentrated in smallest trees during a 7-year study at Swain Mountain Experimental Forest.

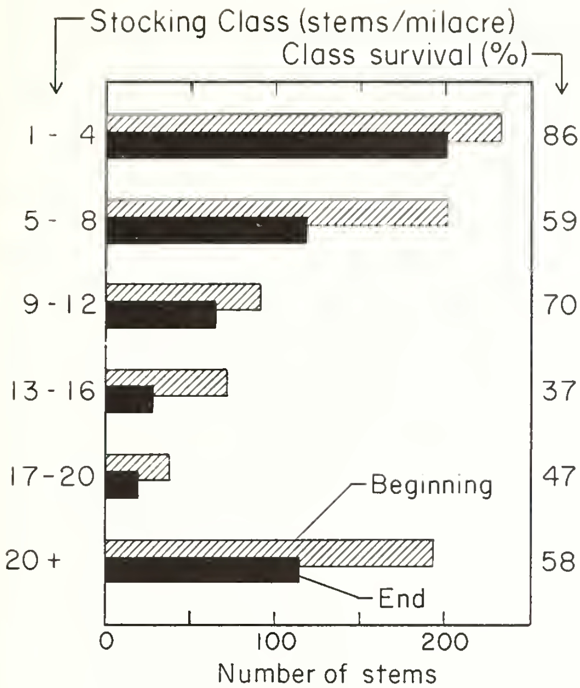


Figure 4—Survival of released advance reproduction followed no consistent pattern governed by density of stocking during the 7-year study period at Swain Mountain Experimental Forest.

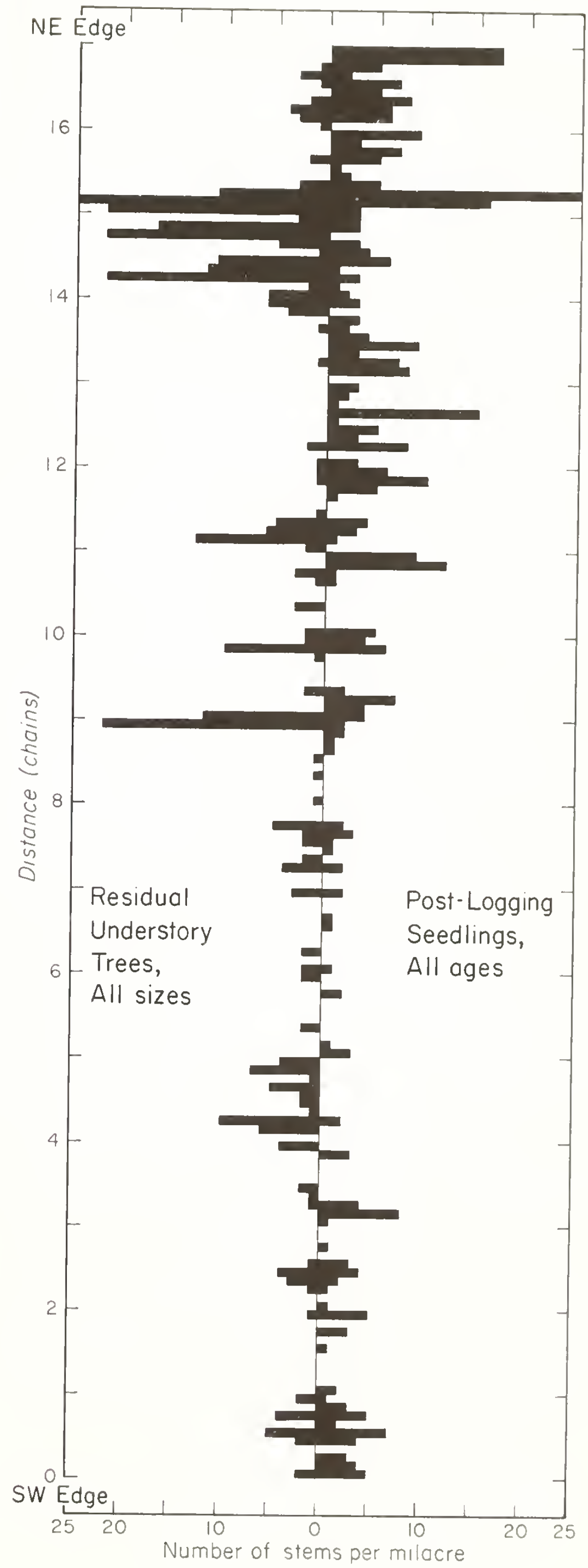


Figure 5—On a 17-chain long transect, milacres with densest stocking of residual understory trees also had most post logging seedlings 7 years after logging. A few large pole-size trees near the transect produced the seeds which generated new seedlings shown on the lower left part of the illustration.

Table 1–*Sources and kinds of damage and mortality*[1] *of affected trees, all study areas, by number of observations and of trees, Swain Mountain Experimental Forest, California*

Sources and kinds of damage	Observations[2] First	Observations[2] Final	Trees that died
	No.		
Logging:			
Bole scar,[3] on lower one-third	49	21	10
Bole scar, on upper two-thirds	5	1	1
Bole scar, on lower one-third and upper two-thirds	23	5	11
Bole scar, on lower one-third, and less than 40 percent crown destroyed	4	1	1
Bole scar, on upper two-thirds, and less than 40 percent crown destroyed	2	1	0
Bole scar, on lower one-third and upper two-thirds, and less than 40 percent crown destroyed	5	1	3
Bole scar, on lower one-third, and more than 40 percent crown destroyed	2	0	1
Bole scar, on upper two-thirds, and more than 40 percent crown destroyed	1	0	1
Bole scar, on lower one-third and upper two-thirds, and more than 40 percent crown destroyed	3	0	3
Crown, less than 40 percent destroyed	4	2	2
Crown, more than 40 percent destroyed	1	0	1
Bent or leaning	5	18	2
Bent or leaning, with any kind of scar	2	13	0
Prostrate	29	13	21
Prostrate, with any kind of scar	15	7	13
	150	83	70
Weather:			
Snow or ice	49	35	4
Wind	0	2	0
Sunscald	3	0	0
	52	37	4
Dwarf mistletoe (*Arceuthobium* sp.):			
In bole	2	1	1
In bole and branches	3	5	0
In branches	9	9	0
	14	15	1
Disease (excluding dwarf mistletoe):			
Brown felt blight ("snow mould") (*Herpotrichia nigra* Hartig)	4	14	0
Unknown	3	0	0
	7	14	0
All others:			
Defective form (severe crook, sweep)	23	28	2
Fire	1	1	0
Animals (browsing)	0	13	0
Animals (rodents)	0	1	0
Unknown	19	3	0
	43	46	2
Total	266	195	77
Total trees affected[4]	240	167	77

[1] "Mortality" indicates only that trees of certain originally rated damage classes died, not necessarily that they died because of the specific damage or defect listed.

[2] A single tree could be observed to have more than one kind of damage.

[3] Size not specified.

[4] Number of trees may not equal number of observations because damage increased during study.

At the end of the study, milacre stocking along this transect was:

	Milacre stocking (percent)
Unstocked	24
Stocked	76
With advance reproduction only	15
With advance reproduction and new seedlings	33
With new seedlings only	28

Causes of Damage

Logging caused more damage to small trees than did any other agent *(table 1)*. Bole scars were the most frequent form of logging damage. However, many bole scars healed completely—at least externally—during the short span of this study. Some trees categorized as bent, leaning or prostrate in the final observation may have been mistallied under "logging" as the cause. Since plots were disturbed only by the original logging, some of the "final" observations in bent, leaning, or prostrate categories probably should have been listed under snow or ice damage.

"Snow or ice" was the second most damaging agent encountered. Dwarf mistletoe *(Arceuthobium* sp.*)* infections, the third most damaging agent, were relatively light throughout the study areas, and neither they nor other pathogens caused any notable mortality.

Effects of Damage on Mortality

Of the original 240 trees with damage, 77 (32 percent) died *(table 1)*. Eighteen more trees were damaged and died during the study period. Still another 22 surviving trees sustained damage after initial observation.

The relationship of initial damage classification to mortality of small white and red firs was affected particularly by the higher relative rate of mortality of red firs less than 1 foot tall, and more specifically, the undamaged trees in that size class *(table 2)*. Trees taller than 6 feet of any species died only if they had been damaged.

Primary Causes of Mortality

Primary and secondary causes of death of trees were recorded as "best estimate" at each annual examination. Logging damage caused only 18 percent of mortality. Effects of competition, and some instances of "shock," probably account for much mortality indicated as "other" and "unknown."

	No. of trees
Logging damage	53
Pathological (but not dwarf mistletoe)	1
Insects	7
Weather	8
Other	93
Unknown	125
Total	287

Some of the records listing greater detail with "other" and "unknown" categories have been misplaced. In both classes, effects of competition and drought were either obvious or suspected in many instances. Cause of death could not be positively identified in the 44 percent of mortality assigned to the "unknown" category. In the end, record of secondary causes showed nothing significant.

Mortality with Time

Because plots were installed in different years and because no records were obtained in fall 1962, mortality during years 1 and 2 and years 4 and 5 were

Table 2—*Trees with and without initial damage, and subsequent mortality within those classes, Swain Mountain Experimental Forest, California*

Species	Trees	Initial damage class		Mortality of trees initially classed as		Total mortality
		Undamaged	Damaged	Damaged	Undamaged	
	No.	*Percent*				
Lodgepole pine	24	67	33	19	0	12
White fir	351	73	27	29	40	32
Red fir	452	69	31	41	30	38
Total	827	–	–	–	–	35

grouped. Mortality during the first 3 years after cutting made up about three-fourths of the 7-year total:

	White fir	*Red fir*
	(percent)	
Years after cutting:		
1,2	53	60
3	17	15
4,5	22	19
6	4	5
7	4	1

Growth

In 1969, I examined growth on the 1958-69 release-cut areas from which all merchantable trees had been removed. Before release most seedlings and saplings had grown only 0.1 or 0.2 foot in height per year *(fig. 6)*. In 1968 and 1969, a few of these trees with the greatest amount of growing space already were increasing their height by 0.9 to 1.1 foot per year. On the average, rate of height growth of the trees receiving most release was increased about four times. Increased height growth rate was not generally noticeable until the fifth year after release. But I have seen a stand in the Sierra Nevada where height growth response of red fir was noticeable in the third year after release. Consequently, no common release-response pattern is apparent from this study.

Diameter growth response to release was evident within 1 to 2 years for both firs. Piths were off-center in nearly all disks cut from stems at ground level. Most of these young trees had stem crooks near the ground from snow bend. After release, stems buttressed rapidly to counteract bending forces. Buttressing gives a somewhat exaggerated indication of diameter growth rate at ground level, where disks were cut. Ground level was chosen as a common height at which to determine total age and diameter growth rate, since many trees were less than 4.5 feet tall when released.

Before trees were released, their radial growth was 70 to 100 rings per inch *(fig. 6)*. After release, those having moderate to good growing space averaged 7 to 12 rings per inch. Some of the largest trees were adding ¼- to ½-inch-wide rings each year.

Tree ages at time of release ranged from 39 to 45 years. At those ages total height was only 2.2 to 5 feet, and diameter inside bark at ground level was 0.7 to 1.2 inches. The suppressive effect of larger overstory trees is obvious.

Additional observations of rapid growth rates of both white and red fir became possible when some

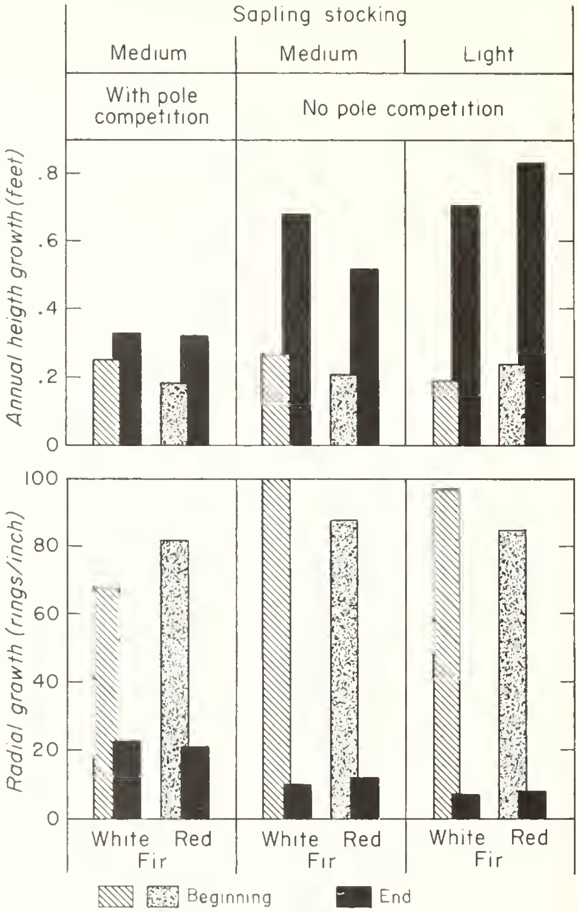


Figure 6—After overmature overstory was removed, height growth of red fir and white fir saplings increased, and the number of annual growth rings per inch decreased in a study on the Swain Mountain Experimental Forest.

young former understory trees remaining on the 1958-60 clearcut strips were cut for a special project in summer 1972. Most had been small poles (4 to 8 inches d.b.h.) when the overstory was removed. Those with most growing space had been consistently adding 3/8-inch to 1/2-inch radial growth per year at stump height. Only those which had been situated in a few relatively crowded groups were adding as little as 1/4-inch radial growth per year. Furthermore, dominant trees of post-logging red fir reproduction originating on clearcuttings in 1961 had grown by 1972 to heights of 5 to 6 feet and more. These seedlings grew slowly for the first 3 to 4 years, then began to grow more rapidly in height.

DISCUSSION

Forestry literature is replete with statements that white fir and red fir grow slowly for the first 30 years or more. What has emerged is a sort of folklore about the growth habits of these two species. Occasionally, there has been some slight modification of the statements—an allusion to several factors affecting growth other than release. One of the earliest references I know of about the effect of cutting on fir advance reproduction is found in Dunning's (1923) report, which includes a photograph titled "Heavy cutting. . . on Site I, effective in releasing the abundant advance growth of sugar pine and white fir . . . ." It illustrates lengthening internodes near the tops of fir saplings, but provides no supporting data in the text. At the time, cutting results were reported primarily as they affected mature and overmature residual trees—but not the understory.

Papers on the silvical characteristics of white and red firs by Fowells (1965), Hallin (1957), and Maul (1958) are often cited as sources. They include references to others' observations that early growth of the two species is slow. Such observations were probably made in uncut forests. And in that context, the conclusions drawn are certainly true. Maul (1958), for example, found repeated references in the literature that, in essence, claim that white fir grows "very slowly for the first 30 (or 40) years." He traced the statement as far back as the early 1900's (Kerr 1913). My point here is to refute such statements in the literature that the early growth rate of fir is, without qualification, slow.

Studies at the Swain Mountain Experimental Forest have shown that small fir trees, some of which grew slowly in an understory for more than 40 years, will develop rapidly after release from overstory. Furthermore, rapid growth rates of newly established natural regeneration in clearcuttings have been reported here. I hope that these findings will put to rest a troublesome ghost in the literature.

Behavior of white and red fir advance reproduction after release does not differ significantly from that of some other fir species. European silver fir *(Abies alba* Mill.*)* adapts itself to release in 2 years and increases height growth in the third year (Bellon and Kowalski 1968)—somewhat more rapidly than white and red fir. Hatcher (1960, 1964) found that small balsam firs *(A. balsamea* L. [Mill.]*)* increased in height growth rate within 3 years after release. Also, within a given height or age class, height growth after release was directly related to vigor at time of release.

Snow damage exceeded all other kinds of natural damage, but did not appear to create a serious obstacle to survival of adequate numbers of red and white fir seedlings and saplings. Some groups of large poles on the cutting areas had a few trees damaged by snow during the 2-year period following cutting, but these were outside measured plots. This kind of damage also has been seen in unreleased groups, so it may be a natural "thinning" process.

The effect of logging and other damage on future heart rot should be investigated. Aho (1960) found this hazard to be low in Pacific silver fir *(A. amabilis* [Dougl.] Forbes*)* reproduction in the Wind River area of Washington. I found that logging-caused bole scars on many small white and red fir trees healed externally within 7 years.

The extremely slow growth of abundant fir saplings beneath scattered old trees indicated that uneven-aged culture will be inferior to even-aged culture if rapid tree growth is desired.

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1973. **Released advance reproduction of white and red fir . . . growth, damage, mortality.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 12 p., illus. (USDA Forest Serv. Res. Paper PSW-95)

Advance reproduction of white fir and red fir released by cutting overmature overstory was studied at the Swain Mountain Experimental Forest in northern California, at 6,300 feet elevation. Seedling and sapling height growth before logging was only 0.1-0.2 foot per year. Five years after cutting, seedling and sapling height growth had accelerated to about 0.5 to 0.8 foot annually, with better trees growing 0.9-1.1 foot. Radial growth rate at ground level increased from 70 to 100 rings per inch to 7 to 12 rings; some trees grew 2 to 4 rings. Damage to advance reproduction was caused by logging, snow or ice, and several miscellaneous agents. Mortality after cutting was attributable mostly to logging damage and to effects of competition and drought. Vigor of dominant released trees increased greatly after cutting, with milacre stocking about 50 percent.

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Oxford: 243:231.1:181.65 [+ 174.7 *Abies concolor* + 174.7 *Abies magnifica*].
Retrieval Terms: Abies concolor; Abies magnifica; advance growth; liberation cutting; growth response; Swain Mountain Experimental Forest.

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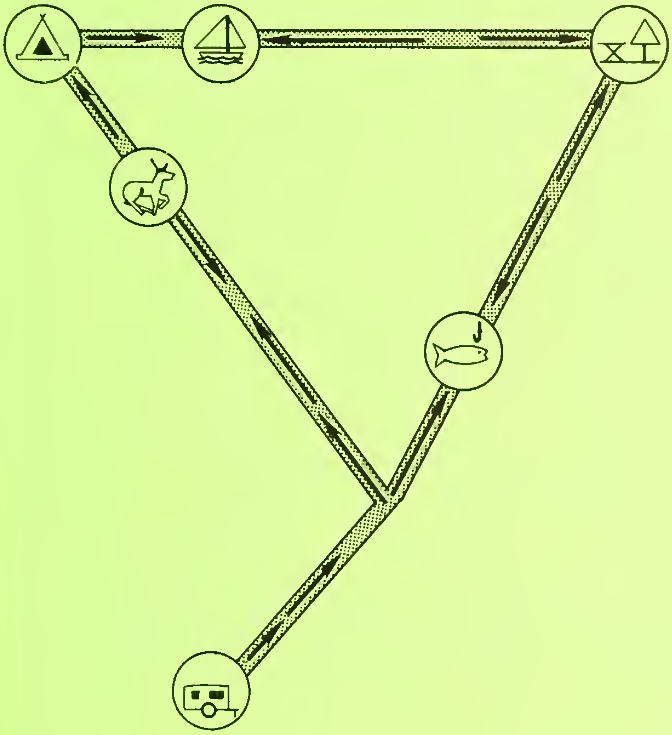
PACIFIC SOUTHWEST
Forest and Range
Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701



PREDICTING TRAFFIC LOAD IMPACT OF ALTERNATIVE RECREATION DEVELOPMENTS

Gary H. Elsner   Ronald A. Oliveira

USDA FOREST SERVICE RESEARCH PAPER PSW- 96 /1973

CONTENTS

The Authors

are assigned to the Station's forest recreation and landscape management research unit, with headquarters in Berkeley, California. **GARY H. ELSNER**, in charge of the unit, received a B.S. degree (1962) in Agricultural Economics at the University of Arkansas, and an M.S. (1964) and a Ph.D. (1966) at the University of California, Berkeley. He joined the Forest Service in 1966. **RONALD A. OLIVEIRA**, an economist, earned degrees in agricultural economics at the University of California at Berkeley (B.S., 1968) and at Davis (M.S., 1969; Ph.D., 1973). Before joining the Station staff in 1972, he was assigned to the Forest Service's Rocky Mountain Region, Denver, Colorado.

ACKNOWLEDGMENTS

Discussions with George W. Tourtillott of the Rocky Mountain Region, U.S. Forest Service, Denver, Colorado, and Roy W. Feuchter, now with the U.S. Forest Service Division of Recreation, Washington, D. C., resulted in the definition of the research objective. Giuseppe Rensi, University of California, Berkeley, aided in the development of the simulation technique and specifically suggested the method used to calculate the p_{ij} values. Jerry Schneider of the University of Washington, Seattle; and Michael R. Travis and Peter Wong of the U.S. Forest Service, Berkeley, California, made helpful review comments and suggested attractive and useful display formats. Kenneth C. Scholz and Charles C. Hathaway, both of the Black Hills National Forest, Custer, South Dakota, provided the necessary coordination and working conditions for estimating and testing the method.

SUMMARY

Elsner, Gary H., and Ronald A. Oliveira
1973. **Predicting traffic load impact of alternative recreation developments.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 12 p., illus. (USDA Forest Serv. Res. Paper PSW-96)

Oxford: 907.2.
Retrieval Terms: recreation areas; automobiles; traffic load; road systems; simulation techniques; Harney Peak area; South Dakota.

Creation of a new recreation facility has a necessary impact on the local traffic load. Planners need to be able to predict the magnitude of such an impact.

To analyze the impact of an additional recreational development in the Harney Peak–Sylvan Lake area in South Dakota, a method was devised which could consider several alternative options. This report describes the method in general and in algebraic terms, and its application to the Harney Peak area.

In the approach used here, the spatial points between which travel occurs are called *nodes,* and are classified as recreation attractions, overnight accommodations, or in- or out-terminals. Travel types are defined as internal in the recreation system, inflowing, outflowing, or both. Routes, composed of road links, connect the nodes. Information on the facilities available at each node is used to compute a rank for each node to indicate its drawing power. Rank, combined with proportions (probabilities) of cars estimated to be traveling for the four travel types, and total number of cars in the system, gives values for the number of cars traveling between any two nodes. The load on each link of the selected route is calculated as a summation of all cars traveling on that link to reach any node.

To simulate a change in the system, it is necessary only to recompute the ranking information, the probability and number of cars traveling between the nodes, and the link loads, according to the modification. Expected percentage change in loads can then be obtained.

The computer operation, as illustrated in a simple example, converts raw data to a normalized ranking for the nodes, and allows calculation of t_{ij}, the total number of cars going between node i and node j during a given unit of time. Calculation of the traffic load on each link of the system is possible by using a routing matrix of o's and 1's which define which links are included in each route. All the values for the links in the appropriate rows of the routing matrix are multiplied by the corresponding t_{ij}, and the columns of the matrix are then summed.

The Harney Peak area involved 12 nodes and 25 links. The percent changes resulting from each of six alternative development options, as shown in the summary table, give a usable prediction of the effects of these plans on recreation traffic loads. Although the estimates are theoretical, and unconstrained, they are based on data that are often available.

The simulation technique is particularly useful in evaluating alternatives. The effect of changes in recreation facilities and attractions may be simulated before final plans for land use are drawn up. The results of this study were a significant input to a meeting on May 12, 1970, held by the U.S. Forest Service and open to the public, to discuss land-use planning in the Harney Peak area.

Creation of a new recreation facility will usually result in impacts on the local recreation system. If the change attracts more visitors, there will be an increased traffic load on the existing highway system. This additional load may be of little consequence if the system is underutilized, but if it is already heavily used, bottlenecks and other traffic disorders may result. Careful calculation of the expected impact under alternative land-use plans will simplify planning and future management. The recreational planner must not only measure future demand levels, but also determine their spatial distribution. Changes proposed for a recreational system will distort a spatial pattern that is the result of complex interactions. Planners need to "be able to determine in advance, what shape such distortions are likely to have, what magnitudes they might be, and to evaluate whether the distortions are beneficial or not."[1]

This paper describes the results of an attempt to estimate the impact of an additional recreation complex on an existing scenic highway system in the Harney Peak–Sylvan Lake area in South Dakota, which includes Mount Rushmore. The system is heavily used during the summer months, mainly by persons seeking outdoor recreation. In addition to analyzing the impact of a new development in the Sylvan Lake area, this study also considered several alternative additional development options, including increases in parking facilities at Mount Rushmore and in campsites at Horse Thief Lake.

Most earlier studies attempting transportation system simulation have dealt with larger networks than the one considered here, and distance (usually measured in travel time) has largely determined the selection of destinations and routes. In smaller networks it may be possible to travel from any point to any other point in much less than half a day. Thus distance need not determine recreation destinations in a small network, but may influence the selection of routes.

This observation required the development of a new simulation technique, which is described in both general and algebraic terms. When this technique was applied to the problem of planning for the Harney Peak area, the traffic impact of proposed developments became evident. The impact takes the form of a difference between the computed present two-way traffic load on each link of the highway system and the estimated load under each of the alternative recreation development plans. The computed percent change can be given for each link.

METHOD

Theory and Definitions

To calculate the traffic loads on a highway system, the probability of travel of various types between any two spatial points must be estimated. In the approach used here, the spatial points between which travel occurs are designated as *nodes* and are classified by location and function. A node may be within the system or a connection of the system with the rest of the world. Nodes within the system may be further classified by function as overnight accommodation areas (takeoff bases) or tourist attractions (visiting points). Some nodes may of course combine these functions.

Nodes on the outside or boundary of the system may be further classified as entrance or exit terminals (in-terminals or out-terminals), or both at the same time, which is usual. It is also reasonable for a node to be a "rest of the world" terminal and yet provide overnight accommodations to the system.

Travel types are defined as follows:

1. *Travel within the system,* consisting exclusively of routes from an overnight accommodation to an attraction to the same overnight accommodation (two ways).
2. *Inflowing travel,* consisting exclusively of routes from an in-terminal to an overnight accommodation (one way).
3. *Outflowing travel,* consisting exclusively of routes from an overnight accommodation to an out-terminal (one way).
4. *Inflowing-outflowing travel,* in the same given unit of time, consisting exclusively of routes from an in-terminal to an attraction to an out-terminal (two ways).

[1]Ellis, Jack B., and Carlton S. Van Doren. *A comparative evaluation of gravity and system theory models for statewide recreational traffic flows.* J. Reg. Sci. 6(2): 57-70.

A *route* is defined as that portion of the highway system that is used in travel from one node to another. A *circuit* is the route from one node to another plus the return route, which may be different. A *link* is a segment of the major road system that connects either two nodes or a node and a highway intersection or two intersections.

Information on the facilities available at each node in the system serves as raw data input for the computation of a ranking value in percent for each node, as an indicator of its drawing power; that is, the probability of travel of one or more of the specified types to that node. Additional computer inputs are the total number of cars in the system, and the proportions of cars estimated to be traveling for each of the four travel types. By combining these data with the node ranking, the computer produces values for the number of cars traveling between any two nodes.

To obtain the traffic load on a specific highway link, a route, consisting of selected links between nodes, must be designated. The selection of links comprising each route is considered in this study as basic data input. Selection may be based on historical observations, travel time on each link, scenic and recreation attractions along each link, or other reasons. The load on each link is calculated as a summation of all cars traveling on that link to reach any node.

To simulate a change in the system, it is necessary only to recompute the ranking information, the probability and number of cars traveling between the nodes, and the link loads, according to the modification. The new link loads may then be compared with the base loads as originally calculated, to find the expected percentage change resulting from the change in the system.

The procedure just described is based on the assumption that if, at any given time, there are a given number of cars in a system, for a given travel type, their allocation will be proportional to the ranking of the nodes appropriate to that travel type.

The method of computation in algebraic terms is illustrated in the next section by a simple example. The more complex Harney Peak area analysis, as presented here, may be understood, however, without reference to the algebraic illustration.

Computation Method

The computer uses as data input the number and kind of nodes, the travel types, and the number of cars in the system, as described above. To explain the procedure, we will use a miniature hypothetical recreation travel system *(fig. 1)* composed of four nodes and four highway links.

First, each node i is ranked according to its over-all attractiveness (tourist drawing power), a_i; overnight (bedroom) preference, b_i; entrance preference, e_i; and exit preference, x_i. A zero is assigned to each rank if it is not applicable, that is, $a_j = 0$ if node j is exclusively an overnight accommodation or terminal and has no tourist attractions. Each rank must be greater than or equal to 0 and less than or equal to 1. In addition, the ranks in each category must sum to 1. Summarized, the node rankings are

$$a_1, a_2, \ldots, a_n$$
$$b_1, b_2, \ldots, b_n$$
$$e_1, e_2, \ldots, e_n$$
$$x_1, x_2, \ldots, x_n$$

in which

$$\sum_i a_i = \sum_i b_i = \sum_i e_i = \sum_i x_i = 1, \quad i = 1, 2, \ldots, n,$$

and

$$0 \leqslant a_i, b_i, e_i, x_i \leqslant 1.$$

Historical data obtained on the system in our illustration indicate that node 1 has recreation attractions receiving 5,000 visits a year, overnight accommodations (camping) for 30 people, and no direct inflow and outflow from nodes outside this system. Therefore, since node 1 is used as neither an entrance nor an exit, e_1 and x_1 will both be 0. Node 2 has a major recreation attraction receiving 45,000 visits a year.

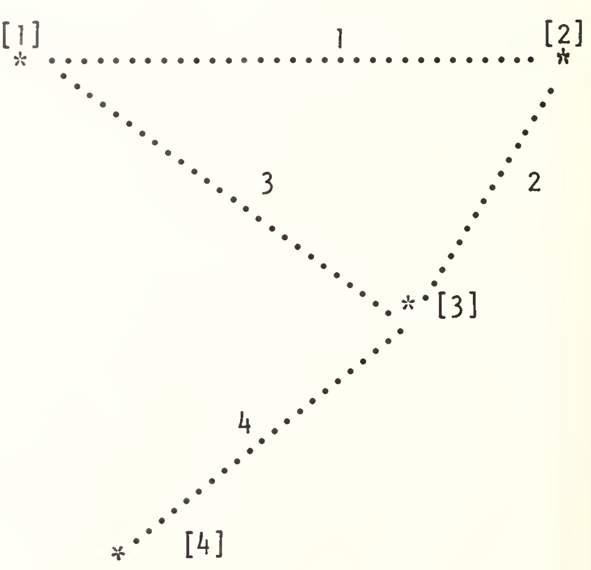


Figure 1—A simple recreation travel system, consisting of four nodes (*) joined by four highway links.

Node 3 has neither a recreation attraction nor any overnight accommodations but is a node connecting this system with the outside world. It averages 40 cars in and 40 cars out per day. Node 4 has only overnight accommodations for 30 people.

Next, we consider the cars in the system and the known proportions for each travel type:

T = total number of cars in the system

T_1 = number of cars driving for travel type 1 (internal)

T_2 = number of cars driving for travel type 2 (inflow)

T_3 = number of cars driving for travel type 3 (outflow)

T_4 = number of cars driving for travel type 4 (in-out)

where

$$T = T_1 + T_2 + T_3 + T_4$$

The proportion of cars in the system traveling for travel type i is P_i, in which

$$P_i = \frac{T_i}{T} \qquad i = 1, 2, 3, 4.$$

The example input data indicate that there are an estimated 100 cars in the system (T) and that 80 percent of these stay in the system for this time period (PINTRN or P_1), 5 percent enter the system (PINFLO or P_2), and 5 percent leave the system (POUTFL or P_3), and 10 percent both enter and leave the system (PINOUT or P_4). Thus $P_1 = 0.80$, $P_2 = 0.05$, $P_3 = 0.05$, and $P_4 = 0.10$.

The input data as they appear on the computer printout are given in *figure 2.* Columns 1 through 4 of the "Unnormalized Ranking Information" summarize the input data on recreation use (number of visits), overnight accommodations, traffic inflow, and traffic outflow, respectively. The ranks, a_i, b_i, e_i, and x_i, obtained from this raw data are given in columns 1 through 4 of the "Normalized Ranking Information," a matrix obtained by dividing each element of the "Unnormalized" matrix by its column sum. For example,

$$a_2 = \frac{45{,}000}{5{,}000 + 45{,}000} = 0.9$$

The rankings are used with the P_i's defined earlier to compute P_{ij}, the proportion of the cars in the system going from node i to node j during a representative unit of time. (The number p_{ij} may also be viewed as the probability of a car within the system going from node i to node j during a representative unit of time.) This may be visualized as the summation of the proportions of each of the four types of travel occurring between node i and node j multiplied times the number of cars in the system. The proportions or probabilities, p_{ij}, are calculated according to the following formula:

$$\begin{aligned} P_{ij} = {} & P_1 \cdot (b_i \cdot a_j) \cdot (0.5) \\ & + P_1 \cdot (a_i \cdot b_j) \cdot (0.5) \\ & + P_2 \cdot (e_i \cdot b_j) \\ & + P_3 \cdot (b_i \cdot x_j) \\ & + P_4 \cdot (e_i \cdot a_j) \cdot (0.5) \\ & + P_4 \cdot (a_i \cdot e_j) \cdot (0.5) \end{aligned}$$

in which

$(P_1 \cdot b_i \cdot a_j)$ = proportion of cars in the system that are of travel type 1 originating at bedroom i and allocated at attraction j;

$(P_1 \cdot a_i \cdot b_j)$ = proportion of cars in the system that are of travel type 1 originating (on the way back) at attraction i and allocated at bedroom j.

$(P_2 \cdot e_i \cdot b_j)$ = proportion of cars in the system that are of travel type 2 originating at in-terminal i and allocated at bedroom j;

$(P_3 \cdot b_i \cdot x_j)$ = proportion of cars in the system that are of travel type 3 originating at bedroom i and allocated at out-terminal j;

$(P_4 \cdot e_i \cdot a_j)$ = proportion of cars in the system that are of travel type 4 originating at in-terminal i and allocated to attraction j;

$(P_4 \cdot a_i \cdot x_j)$ = proportion of cars in the system that are of travel type 4 originating at in-terminal i and allocated to out-terminal j.

Since travel type 1 involves a complete circuit (i.e., from i to j to i or vice versa), P_1 occurs twice in the formula for p_{ij} and is given a weight of 0.5 each time. The same reasoning is applied to P_4. The computational formula for p_{ij} may be clarified by viewing the various ranks as probabilities. For example, the probability of travel type 3 originating at bedroom i and allocated at out-terminal j is the joint probability of three independent events: (1) the probability of travel type 3 occurring, (2) the probability of bedroom i being selected or used, and (3) the probability of out-terminal j being selected.

For the illustration, the probabilities or proportions of cars going from any node i to any node j (p_{ij}'s) have been calculated *(fig. 2).* The printout shows that the highest probability of travel is from node 4 to and from 2 (p_{24} and p_{42}) and from node 1

```
TEST SET OF DATA ...... ''ORIGINAL'' SET.

NUMBER OF LINKS =              4  NUMBER OF NODES =          4
TOTAL CARS IN SYSTEM =          100.

PINTRN =  .800 PINFLO =  .050 POUTFL =  .050 PINOUT =  .100

UNNORMALIZED RANKING INFORMATION
*NODE ONE*                 5000.        30.         0.         0.
*NODE TWO*                45000.         0.         0.         0.
*NODE THREE*                  0.         0.        40.        40.
*NODE FOUR*                   0.        30.         0.         0.

NORMALIZED RANKING INFORMATION
*NODE ONE*              .100000    .500000    .000000    .000000
*NODE TWO*              .900000    .000000    .000000    .000000
*NODE THREE*            .000000    .000000   1.000000   1.000000
*NODE FOUR*             .000000    .500000    .000000    .000000

PROBABILITY OF TRAVEL BETWEEN NODES
                     *NODE      *NODE      *NODE      *NODE
                      ONE*       TWO*     THREE*      FOUR*

*NODE ONE*           .0400      .1800      .0300      .0200       1
*NODE TWO*           .1800      .0000      .0450      .1800       2
*NODE THREE*         .0300      .0450      .0000      .0250       3
*NODE FOUR*          .0200      .1800      .0250      .0000       4

                        1          2          3          4

TRAVEL BETWEEN NODES
                     *NODE      *NODE      *NODE      *NODE
                      ONE*       TWO*     THREE*      FOUR*

*NODE ONE*          4.0000    18.0000     3.0000     2.0000       1
*NODE TWO*         18.0000      .0000     4.5000    18.0000       2
*NODE THREE*        3.0000     4.5000      .0000     2.5000       3
*NODE FOUR*         2.0000    18.0000     2.5000      .0000       4

                        1          2          3          4
```

Figure 2—Computer printouts show input data for the system in *figure 1,* leading to normalized ranking and estimates of travel between nodes.

to and from node 2 (p_{12} and p_{21}). This is as expected, as nodes 1 and 4 have only overnight accommodations (both having a capacity of 30) and node 2 has the largest recreation attraction in the system. It should be noted that the probability p_{11} is greater than zero, indicating that the "travel" of some of the people staying overnight at node 1 will in fact be use of the recreation area at this node.

The total number of cars going between node i and node j is estimated as

$$t_{ij} = T \cdot p_{ij}$$

The t_{ij} values for the illustration are also shown in the printout *(fig. 2)*.[2]

As noted earlier, the above computational procedure assumes that if there are T_k cars in the system during any given time period for travel type k, their allocation between nodes, that is, the t_{ij}'s, is proportional to the ranks of these nodes for those categories relevant to travel type k. For example, the number of cars of travel type 3 (outflowing) originating at bedroom i and allocated at out-terminal j is a function of the importance or ranking of node i as a bedroom (b_i), the ranking of node j as an out-terminal (x_j), the number of cars of travel type 3 (P_3), and the total number of cars in the system (T).[2]

Calculation of the traffic load on each link of the system requires a routing matrix composed of 0's and 1's to indicate whether a highway link is excluded or included in a route from node i to node j. (The route from j to i is not necessarily the same as that from i to j.) The routing, which is basic data input, is influenced by the character of nodes and links. Thus, for the illustration *(fig. 3)* the route (b_3) between node 1, a recreation attraction, and node 3, an in-out terminal, in the recreation attraction node 2, although the distance covered on links 1 and 2 is somewhat greater than that on link 3, the direct route.

To calculate the traffic load on each link, all the values for the links in the appropriate rows of the routing matrix *(fig. 3)* are multiplied by the corresponding t_{ij}, and the columns of the matrix are then summed.

Using the calculated estimations as the base for comparison, alternative plans may be simulated. For this illustration, simulation I examines the effect of building a larger recreation attraction at node 1 (with the same number of cars in the system). Node 1 now attracts 30,000 visits a year instead of 5,000. The

[2]The number of trips for each of the four types between nodes i and j can also be computed

Type	Number of trips =
1	$P_1 \cdot [b_1 \cdot a_j + a_i \cdot b_j] \cdot T \cdot (0.5)$
2	$P_2 \cdot [e_i \cdot b_j] \cdot T$
3	$P_3 \cdot [b_i \cdot x_j] \cdot T$
4	$P_4 \cdot [e_i \cdot a_j + a_i \cdot e_j] \cdot T \cdot (0.5)$

This elaboration of the computational procedure, suggested by Peter Wong, U.S. Forest Service, Berkeley, California is not included, however, in the computerized model.

ROUTING MATRIX

	LINKS			
ROUTE :	1	2	3	4
(1, 2) :	1	0	0	0
(2, 1) :	1	0	0	0
(1, 3) :	1	1	0	0
(3, 1) :	1	1	0	0
(1, 4) :	0	0	1	1
(4, 1) :	0	0	1	1
(2, 3) :	0	1	0	0
(3, 2) :	0	1	0	0
(2, 4) :	0	1	0	1
(4, 2) :	0	1	0	1
(3, 4) :	0	0	0	1
(4, 3) :	0	0	0	1

Figure 3—Computer printout of routing matrix for the system in *figure 1*.

printouts *(figs. 4, 5)* show the results of this simulation. On the diagramatic map *(fig. 5)* the link traffic loads for the original data and the simulation data are shown next to the corresponding links. For example, for link 2 the estimated load from the original data (as given in *figs. 2* and *3*) is 51, whereas the estimated load for link 2 in simulation I is 30. The percent change in traffic load on each link is included in the printout.

As might be expected, because node 3 provides the inflow and outflow from the outside world, there is an increase in the proportion of travel from node 3 to node 1 and a decrease in the proportion of travel from node 3 to node 2, although the latter is still the larger value. This may not be a reasonable simulation, however, if the visitors at node 2 are not expected to decrease because of the development at node 1. If 30 additional cars are attracted to the system (T = 130), the highway traffic in the area of node 2 (links 1 and 2) will be equal to that originally estimated. The results of simulating this increase of cars in the system plus the development of additional recreation attractions at node 1 are shown in *figures 6* and *7*. The estimated link loads from simulation II, (lower number) are compared with those from the original data (upper number) as given in *figures 2* and *3*.

The results *(fig. 7)* show a 420 percent increase in the traffic on link 3 and a 30 percent increase in the traffic on link 4 (with insignificant changes on links 1 and 2). These results provide quantitative estimates of

```
TEST SET OF DATA.........''SIMULATION'' SET I.

NUMBER OF LINKS =            4  NUMBER OF NODES =          4
TOTAL CARS IN SYSTEM =        100.

PINTRN =  .800 PINFLO =  .050 POUTFL =  .050 PINOUT =  .100

UNNORMALIZED RANKING INFORMATION
*NODE ONE*               30000.        30.         0.         0.
*NODE TWO*               45000.         0.         0.         0.
*NODE THREE*                 0.         0.        40.        40.
*NODE FOUR*                  0.        30.         0.         0.

NORMALIZED RANKING INFORMATION
*NODE ONE*              .400000    .500000    .000000    .000000
*NODE TWO*              .600000    .000000    .000000    .000000
*NODE THREE*            .000000    .000000   1.000000   1.000000
*NODE FOUR*             .000000    .500000    .000000    .000000

PROBABILITY OF TRAVEL BETWEEN NODES

                  *NODE      *NODE       *NODE      *NODE
                   ONE*       TWO*      THREE*      FOUR*

*NODE ONE*        .1600      .1200       .0450      .0800     1
*NODE TWO*        .1200      .0000       .0300      .1200     2
*NODE THREE*      .0450      .0300       .0000      .0250     3
*NODE FOUR*       .0800      .1200       .0250      .0000     4

                    1          2           3          4

TRAVEL BETWEEN NODES

                  *NODE      *NODE       *NODE      *NODE
                   ONE*       TWO*      THREE*      FOUR*

*NODE ONE*      16.0000    12.0000      4.5000     8.0000     1
*NODE TWO*      12.0000      .0000      3.0000    12.0000     2
*NODE THREE*     4.5000     3.0000       .0000     2.5000     3
*NODE FOUR*      8.0000    12.0000      2.5000      .0000     4

                    1          2           3          4
```

Figure 4—Computer printout of computation of travel between nodes, for the system shown in *figure 1,* under simulation I calling for a larger recreation attraction at node 1.

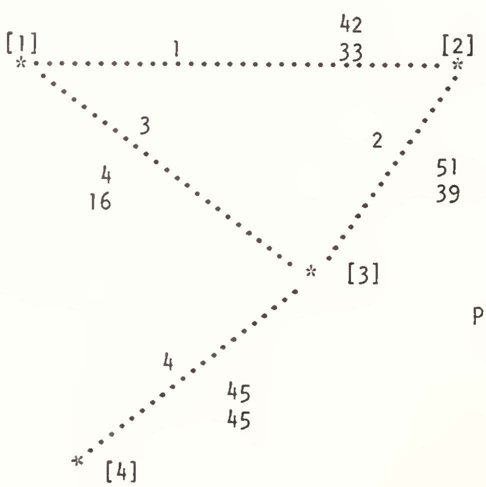


Figure 5—Results of simulation I showing changes in traffic loads. Upper number is original base data, lower number simulation data.

PERCENT CHANGE IN LOAD ON EACH LINK

```
 -21.4286  LINK   1
 -23.5294  LINK   2

 300.0000  LINK   3
    .0000  LINK   4
```

TEST SET OF DATA.........''SIMULATION'' SET II.

NUMBER OF LINKS = 4 NUMBER OF NODES = 4
TOTAL CARS IN SYSTEM = 130.

PINTRN = .800 PINFLO = .050 POUTFL = .050 PINOUT = .100

UNNORMALIZED RANKING INFORMATION

NODE ONE	30000.	30.	0.	0.
NODE TWO	45000.	0.	0.	0.
NODE THREE	0.	0.	40.	40.
NODE FOUR	0.	30.	0.	0.

NORMALIZED RANKING INFORMATION

NODE ONE	.400000	.500000	.000000	.000000
NODE TWO	.600000	.000000	.000000	.000000
NODE THREE	.000000	.000000	1.000000	1.000000
NODE FOUR	.000000	.500000	.000000	.000000

PROBABILITY OF TRAVEL BETWEEN NODES

	NODE ONE	*NODE TWO*	*NODE THREE*	*NODE FOUR*	
NODE ONE	.1600	.1200	.0450	.0800	1
NODE TWO	.1200	.0000	.0300	.1200	2
NODE THREE	.0450	.0300	.0000	.0250	3
NODE FOUR	.0800	.1200	.0250	.0000	4
	1	2	3	4	

TRAVEL BETWEEN NODES

	NODE ONE	*NODE TWO*	*NODE THREE*	*NODE FOUR*	
NODE ONE,	20.8000	15.6000	5.8500	10.4000	1
NODE TWO	15.6000	.0000	3.9000	15.6000	2
NODE THREE	5.8500	3.9000	.0000	3.2500	3
NODE FOUR	10.4000	15.6000	3.2500	.0000	4
	1	2	3	4	

Figure 6—Computer printout of computation of travel between nodes for the system in *figure 1* under simulation II, calling for a larger recreation attraction at node 1 with the addition of cars to the system.

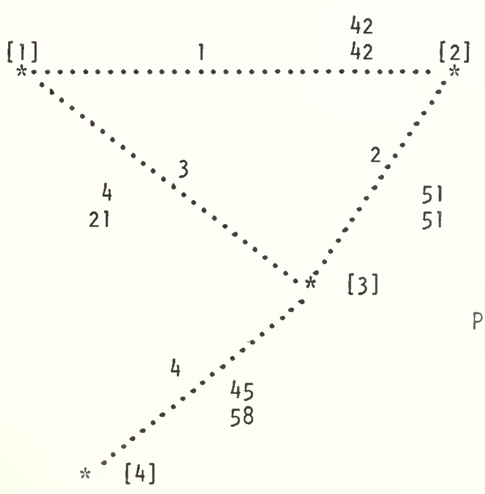


Figure 7—Results of simulation II showing changes in traffic loads. Upper number is original base data, lower number simulation data.

PERCENT CHANGE IN LOAD ON EACH LINK

2,1429	LINK	1
-,5882	LINK	2
420,0000	LINK	3
30,0000	LINK	4

the expected effects on link loads of increased recreation attractions and cars in the system.

Although the computations for this small system may seem simple, for systems of a more realistic size the computations are complex, as illustrated in the Harney Peak analysis which follows.

HARNEY PEAK AREA ANALYSIS

This analysis examines proposed developments in the Harney Peak and Sylvan Lake area. For the study, system boundaries were defined as Sheridan Lake to the north, Wind Cave to the south, Jewel Cave to the west and Rapid City to the northeast.

Nodes and Highway Links

Recreation facilities such as campgrounds exist throughout the area, but the facilities and attractions are largely concentrated at 12 sites, or nodes *(fig. 8)*:

1. Rapid City
2. Recreation complex, on highway 16 south of Rapid City
3. Sheridan Lake
4. Hill City
5. Mount Rushmore
6. Horse Thief Lake
7. Sylvan Lake
8. Custer
9. Stockade Lake
10. Custer State Park
11. Jewel Cave
12. Wind Cave

Four of these nodes, Rapid City, Sheridan Lake, Jewel Cave, and Wind Cave, were considered to provide significant amounts of highway traffic inflows and outflows for the system. Except for Rapid City, these nodes also provide significant recreation attractions; all four provide overnight accommodations as well.

Twenty-five highway links were defined and routes were selected for travel between each of the 12 nodes. As noted earlier, the method allows for the specification of a different route for the return journey (i.e., node j to i different from node i to j). Thus, 132 possible routes could be defined if the "routes" from node i to node i were not included.

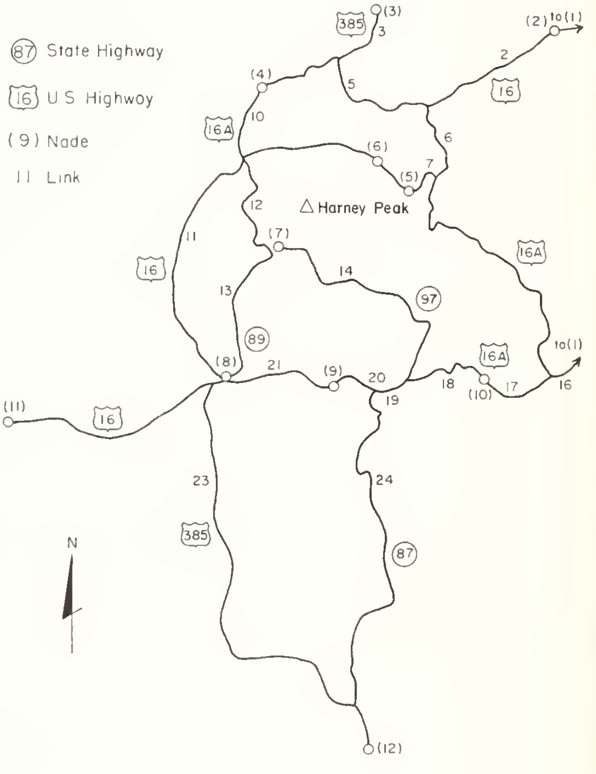


Figure 8—Map of recreation travel network near Harney Peak (triangular symbol), South Dakota. The system includes 12 nodes and 25 highway links.

Ranking Input Data

The raw data input for computation of the ranking value for recreation attraction was the total number of recorded visits at each recreation point in the node area. For several nodes this included visits to a major attraction as well as to several picnic grounds. For the overnight accommodation rating, it was an estimate of the number of people who could stay overnight in the node area. This typically included the capacity of several campgrounds and possibly some motels or a hotel (as at Sylvan Lake). The other nodes, such as Rapid City, provided motel accommodations primarily.

For inflow and outflow rankings, input consisted of estimates of inflows and outflows of vehicles into the system. These estimates and one for total cars in the system (T = 27,872) were based on an average July day; July is the peak travel month for this system.[3]

Reliability of Estimates

To evaluate the success of the method of analysis described here in predicting traffic load on the scenic highway system, we compared the predicted values with observed values. The most recent complete set of traffic data available at the time of the analysis was used to supply these observed values: the data were collected in 1968.[4] The link traffic load estimates were generally close to the observed values, but in some instances a significant difference may indicate the need for better input data.

Simulation Results

Once the model is estimated and calibrated, input changes can be easily introduced and their effect on the predictions can be examined. The effect is measured as percent change in load on each link. Six types of simulations were computed, analyzing possible recreation developments in the Harney Peak-Sylvan Lake area *(table 1)*. In each analysis, the percentage effect upon the load of each link in the system was higher for the three links connecting the Sylvan Lake node to the rest of the system. These links are numbered 12, 13, and 14, and are (highway 89-87 to the north, highway 89 to the southwest, and the Needles highway, 87, to the southeast).

The simulations are based on information specifying two levels for the proposed recreation developments in the Harney Peak-Sylvan Lake area. One level of development was designed for 200,000 visits per year and the other level for 500,000 visits per year. The first three simulations assume annual visits of 200,000 people.

The first of this group assumes that only the recreation complex is developed and no other changes are made in the system. That is, no additional cars are attracted into the system and other major developments do not occur. With an increased recreation attraction at Sylvan Lake and the same cars in the system, we might expect a heavier load on the links around Sylvan Lake and possibly lighter loads elsewhere. This is generally borne out in the results.

Table 1—*Estimated percent increase in traffic load on links adjacent to Sylvan Lake, Harney Peak area, South Dakota, as a result of simulated changes in recreation system*

Simulated changes in the recreation system	Increase on links . . .		
	12	13	14
	--- *Percent* ---		
Harney Peak Development—200,000 visits a year	12	30	13
Harney Peak Development—200,000 visits a year; 28,272 cars	14	32	15
Harney Peak Development—200,000 visits a year; 30,659 cars; Mount Rushmore Parking Expansion—2,116,800 visits; Horse Thief Lake Development—4,000 visits, 260 overnight accommodations	28	40	26
Harney Peak Development—500,000 visits a year	29	73	33
Harney Peak Development—500,000 visits a year; 29,072 cars	35	80	39
Harney Peak Development—500,000 visits a year; 30,659 cars; Mount Rushmore Parking Expansion—2,116,800 visits; Horse Thief Lake Development—4,000 visits, 200 overnight accommodations	46	84	46

The second simulation for this level of development assumes that Sylvan Lake is developed and there is an increase of cars in the system. The link loads in the vicinity of Mount Rushmore National Memorial are assumed to be about equal to their original estimates.

The third simulation assumes not only that the Sylvan Lake area is developed (with the expected visits of 200,000) but also that an increase in parking at Mount Rushmore National Memorial results in a 20 percent increase in visits to 2,116,800, and that Horse Thief Recreation area has additional picnic facilities (receiving 4,000 visits) and more overnight accommodations (260). In addition to these changes it is assumed that 10 percent more cars (from 27,872 to 30,659) are in the system.

The last three simulations examine the same changes, with the expected level of use at Sylvan Lake set at 500,000, visits, however.

The following appendixes showing printouts of the computational results for the basic model estimation and of each of the six computer simulations are available upon request to: Director, Pacific Southwest

[3]South Dakota Department of Highways. *Automatic traffic research data—a comparison of the average daily traffic volumes for each month of 1968 and 1969.* (Form DHRP 327, revised 1968)

[4]South Dakota Department of Highways, Research and Planning Division. *Diagrammatic rural traffic flow map—showing annual 24-hour average traffic, 1968.* 1968.

Forest and Range Experiment Station, P. O. Box 245, Berkeley, California 94701, Attention: Computer Services Librarian:

Appendix	*Description*
A	Listing of computation results for basic model estimation
B	Simulating development in Harney Peak area receiving 200,000 visits
C	Simulating development in Harney Peak area receiving 200,000 visits and cars increasing to 28,272
D	Simulating development in Harney Peak area receiving 200,000 visits; Mount Rushmore, 2,116,800 visits; Horse Thief Lake, 4,000 visits, Horse Thief Lake, 260 accommodations; and cars increasing by 10 percent
E	Simulating development in Harney Peak area receiving 500,000 visits
F	Simulating development in Harney Peak area receiving 500,000 visits and cars increasing to 29,072
G	Simulating development in Harney Peak receiving 500,000 visits; Mount Rushmore, 2,116,800 visits; Horse Thief Lake, 4,000 visits, Horse Thief Lake, 260 accommodations, and cars increasing by 10 percent.

The approach developed is conceptually simple and requires data that are frequently available. The analysis covers the effect of recreation developments on only one variable, however—recreation traffic load. Also, the estimates are of course theoretical. In the real world, unaccounted-for changes in the system may occur. Further, estimates are interpreted as unconstrained use increases in link loads. Capacity limits on certain links may result in an unexpected increase on other links. Nevertheless, the method described allows useful predictions of the effects of alternative sets of recreation developments on highway traffic.

The effect of changes in recreation attractions, and facilities, including roads, campgrounds, picnic areas, and lodging, may be simulated before final plans on land-use are drawn up. The technique is particularly useful in evaluating alternatives and in providing information on alternatives to land managers and others. The results of this study were a significant input to a meeting held on May 12, 1970, by the U.S. Forest Service and open to the public to discuss land-use planning in the Harney Peak area.

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Elsner, Gary H., and Ronald A. Oliveira

1973. **Predicting traffic load impact of alternative recreation developments.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 12 p., illus. (USDA Forest Serv. Res. Paper PSW-96)

Traffic load changes as a result of expansion of recreation facilities may be predicted through computations based on estimates of (a) drawing power of the recreation attractions, overnight accommodations, and in- or out-terminals; (b) probable types of travel; (c) probable routes of travel; and (d) total number of cars in the recreation system. Once the basic model has been established, development alternatives may be simulated to provide percent change estimates of probable traffic load effects on each link of the road system. Illustrative estimates are made for six alternatives for the Harney Peak area of South Dakota.

Oxford: 907.2

Retrieval Terms: recreation areas; automobiles; traffic load; road systems; simulation techniques; Harney Peak area; South Dakota.

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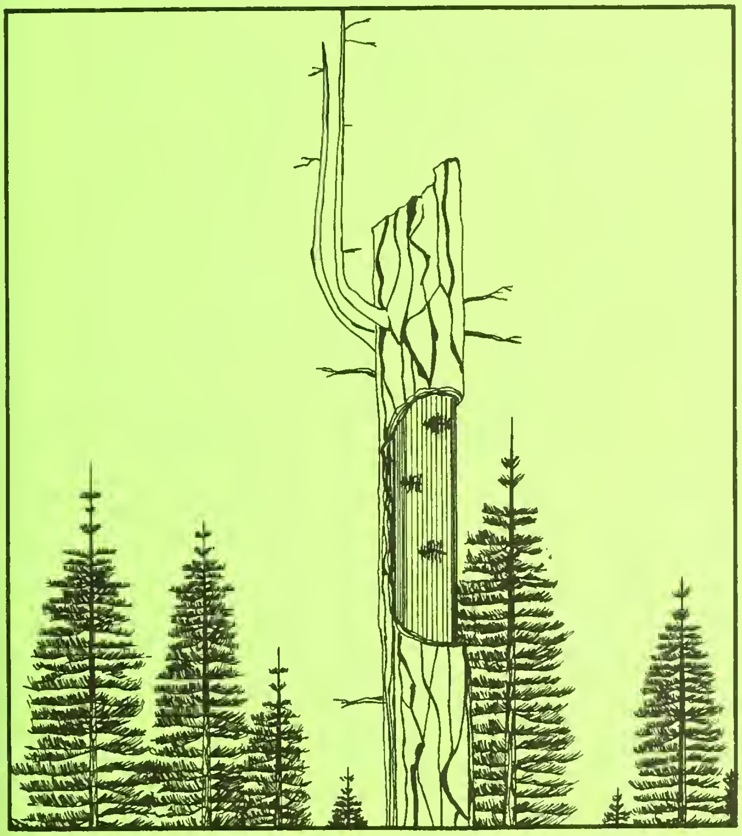


Stand and Tree Characteristics Influencing Density of Fir Engraver Beetle Attack Scars in White Fir

George T. Ferrell

USDA FOREST SERVICE RESEARCH PAPER PSW-97 /1973

CONTENTS

The Author

GEORGE T. FERRELL, a research entomologist, is studying the biology, ecology, and control of destructive forest insects, with headquarters in Berkeley, Calif. Native of Klamath Falls, Ore., he earned three degrees at the University of California, Berkeley: bachelor's in forestry (1959), master's in zoology (1965), and a doctorate in entomology (1969). Before joining the Station's research staff in 1969, he was a postdoctoral fellow at Simon Fraser University, British Columbia, Canada.

ACKNOWLEDGMENTS

I am indebted to the late Willis W. Wagener, Pacific Southwest Forest and Range Experiment Station, for permission to analyze data collected by him and his associates, and to William Beatty Associates, Consulting Foresters, Redding, California, for logging and site information on the study plots.

SUMMARY

Ferrell, George T.

1973. **Stand and tree characteristics influencing density of fir engraver attack scars in white fir.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 00 p., illus. (USDA Forest Serv. Res. Paper PSW-97)

Oxford: 453–145.7x19.92: 174.7 *Abies concolor.*
Retrieval Terms: Abies concolor; Scolytus ventralis; predator-host relations; damage indexes; attack scars; tree vigor; host resistance; host tree mortality; risk rating; lumber defects.

A total of 530 living white fir was felled along transects through two virgin, old-growth stands in central California, and stem cross-sections were examined for embedded scars resulting from past fir engraver *(Scolytus ventralis)* attacks. An additional 41 living "high-risk" fir, and 32 fir recently killed by the fir engraver were similarly examined within two cutover stands in northern California.

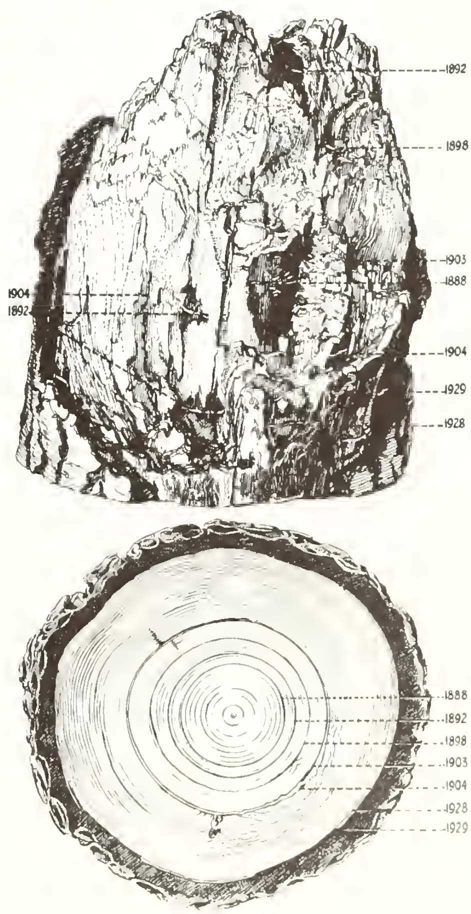
The mean density of scars formed per 10 cu. ft. per decade was obtained by dividing the number of scars found in each cross-section by its volume and age. Mean scar densities were compared in fir according to crown class, whether trees were living or killed by fir engravers, quality of growing site (site class), and percentage of the stand removed by past logging.

Mean scar densities were found to be directly related to percentage of mature stand removed by logging. An inverse relationship was found between scar density and site quality.

Mean scar densities were higher in suppressed and intermediate trees compared to dominant trees, so that inverse relationships with the following characteristics associated with crown class were evident: diameter, height, age, volume, and mean growth rate.

The highest scar densities were found in intermediate and suppressed fir recently killed by the fir engraver in a heavily cutover stand growing on the lowest quality site studied (Site II-III). High density of the scars was interpreted to be primarily an indication of decreased resistance to fir engraver attack in the past.

It appears possible to develop a risk rating system for identifying white fir with decreased resistance to fir engraver attack, based on tree and stand characteristics such as growth rate, crown class, site class and logging history. Such a system would allow selective removal of high risk fir, thus reducing future mortality from fir engraver attacks. Another possible use might be the identification of fir with large amounts of lumber defects caused by high scar density.



The fir engraver *(Scolytus ventralis* Lec.*)* attacks the main stems of true fir *(Abies* spp.*)* in western North America. This bark beetle mines and oviposits in the cambial zone of standing trees and in recently cut logging slash. Heavily attacked trees usually die, but often only the top, or strips and patches of the bole, are killed. If the tree survives the attack, the invasion of the insect and associated microorganisms results in a necrotic lesion that is healed over by the surrounding living tissues. The attack scar is visible in stem cross sections as a darkly stained segment of the annual ring, so that the year of attack is readily determinable. The embedded attack scars provide a long-term record of fir engraver attack activity, as the scars are often numerous in individual fir, indicating that the tree has been repeatedly attacked over many years of its life *(fig. 1)*.

Analysis of the scars embedded in living and recently killed fir indicated that fluctuations in scar abundance were directly correlated with trends in the volume of fir timber killed by the fir engraver over a 15-year period. This suggested that the scars could be used as an index to past levels of fir damage and fir engraver populations where such data are lacking (Ferrell 1973). The analysis also provided insight into the causes of fir engraver outbreaks. The scars were more abundant in years of drought when fir growth rates were below normal or declining, especially when the stands were being logged under these conditions. Also, the scars in the dead trees rapidly increased in frequency in the narrow annual rings formed in the last few years before the fir were killed by the insect. These results agreed with those of Felix *et al.* 1971, who found that the embedded attack scars were more abundant in tops of fir heavily infected by true mistletoe, especially during drought years, than in uninfected fir. These observations support the conclusion that the scars provide a long-term record of the interaction between the beetles and their host.

In addition to providing information on past levels of host resistance, beetle populations, and host tree mortality, the old fir engraver attack scars cause lumber defects such as stain, ring-shake, and decay (Johnson and Shea 1963; Struble 1957). Knowledge of the scar distribution promises to be useful in predicting the amount of these defects to be expected from various trees and stands.

Both Struble (1957) and Stevens (1971) suggested that silvicultural methods of controlling the fir engraver seemed most promising, but indicated that this is presently impractical because it is difficult to identify those fir most vulnerable to the beetles before they are killed.

This paper reports the distribution of fir engraver attack scars in relation to stand and tree characteristics of white fir in California. The purpose of the study was to develop methods of identifying fir particularly vulnerable to fir engraver attack and the resulting stem defects.

STUDY SITES

Four plots, differing in site quality, in the extent of past logging activity, and in the criteria used for selecting sample trees, were established in uneven-aged mixed conifer stands, with white fir *(Abies concolor* [Gord. and Glen.] Lindl.*)* as a major component.

Old-Growth Plots

Two sites were sampled more than 50 years ago by pathologists of the California (now Pacific Southwest) Forest and Range Experiment Station, who were investigating stem defects in white fir on the west slope of the Sierra Nevada. The two plots were located near Shaver Lake, Fresno County, California at elevations of 5,200 to 6,600 feet (Wagener 1970). The plots at Madson Mill (90 acres) and Ellis Meadow (120 acres) were virgin when sampled (1921 and 1917, respectively). All age and size classes were represented, with large, mature trees predominating. Comparison of the height-age relationships of the dominant white fir on these plots, with site classifi-

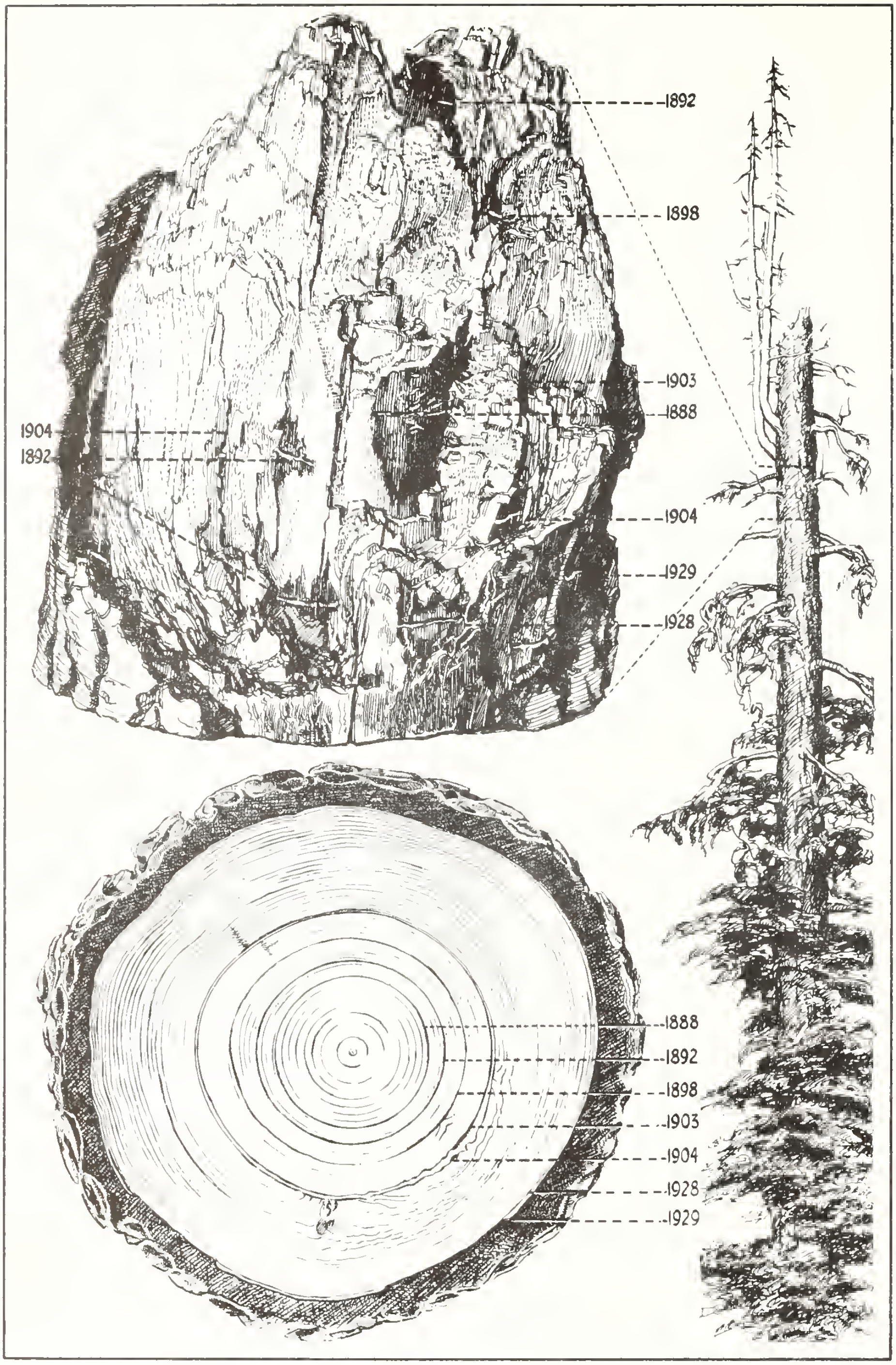


Figure 1—Scars embedded in the stem of a living white fir resulted from periodic *Scolytus ventralis* attacks during the years 1888-1929.

cation curves for white fir in Sierra Nevada mixed conifer forest (Maul 1958), indicated that both Madson Mill (Site I), and Ellis Meadow (Site II), were good growing sites for white fir. In addition to white fir, varying proportions of ponderosa pine *(Pinus ponderosa* Laws*)*, sugar pine *(P. lambertiana* Dougl.*)*, Jeffrey pine *(P. jeffreyi* Grev. and Balf.*)*, incense-cedar *(Libocedrus decurrens* Torr.*)*, and California black oak *(Quercus kelloggii* Newb.*)* were present. Levels of fir engraver activity on these plots were not estimated during sampling, as this was outside the scope of the defect study.

Cutover Plots

Two plots, differing in proportion of mature stand removed by past logging, and in current levels of fir engraver activity, were sampled 4 miles apart at Dersch Meadow and Beal's Place on the west slope of Mount Lassen in Northern California in 1970. The associated tree species were the same as on the old-growth plots except, that Jeffrey pine was absent and Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco*)* was present. The first cycle of logging on both plots (1949-1957) had removed approximately 50 percent of the volume of mature sawtimber. An additional 47 percent of the original sawtimber volume was removed during the years 1958-1968 on the Dersch Meadow plot (4,000 feet elevation, 1,440 acres), leaving scattered clumps of young or formerly suppressed and intermediate trees interspersed with openings in which shrubs and forbs predominated. Firs recently killed by the fir engraver were scattered throughout this plot in 1970. The forest cover was more complete on the Beal's Place plot (4,500 feet elevation, 1,280 acres) before the second cycle of logging in 1970. No recent fir mortality attributable to the insect was observed on this plot in 1970. Beal's Place was a good growing site for white fir (Site II), while Dersch Meadow was somewhat poorer (Sites II and III).

COLLECTION AND MEASUREMENT OF SAMPLES

Old-Growth Plots

A total of 530 living white fir were felled along meander-line transects through the old-growth plots. The pathologists conducting the defect study attempted to include a representative sample of all age and size classes present. Only the lower 50 to 70 percent of the bole merchantable as sawlogs was sampled, as follows: The bole of each tree was sawn into logs 16 feet in length. The minimum diameter at the uppermost cut was about 10 inches; thus the upper log often measured less than 16 feet in length. The number of logs per tree varied from 2 to 14, depending on tree height. Data collected included diagrams of all defects (decay, fir engraver attack scars, etc.) visible on the cut surface at the lower end of each log; measurements of height, diameter, and age at stump for each tree; and measurements of the radius and age of each sample cross section. The crown class of each sample tree was noted as dominant, intermediate or suppressed (Ford-Robertson 1971). Sample sizes within each crown class were:

	Trees	*Bole cross sections*
	(No.)	
Plot and crown class:		
Madsen Mill		
Suppressed	29	131
Intermediate	35	190
Dominant	195	1,558
Ellis Meadow		
Suppressed	48	202
Intermediate	58	260
Dominant	165	854

Cutover Plots

The method of sampling on these plots was similar to that used for the virgin plots. The 32 fir sampled at Dersch Meadow had been killed by the fir engraver in 1969, however, and were selected for convenient proximity to roads. The minimum diameter at the uppermost cut was 4 inches, and a 1-inch-thick cross section, or disk, was removed at each cut, resulting in 3 to 5 disks per tree and a plot total of 118 disks. The 41 fir sampled at Beal's Place were living when felled, and were selected by foresters as vulnerable to the insect (high-risk trees) based on an appearance of poor vigor. The lowest log was about 32 feet long. From these trees 116 disks were obtained. One surface of each sample disk was sanded with both coarse and fine grit papers to increase the visibility of both small fir engraver scars and the annual rings. The data recorded were the same as for the old-growth plots, except that crown classification of individual sample trees on these plots was not attempted because stand structure had been altered by logging. The small size of these trees in relation to the remaining overstory trees indicated they were formerly of the suppressed or intermediate crown classes.

Two additional expressions of the size and vigor of fir on all plots were calculated from measurements of tree diameter, height, and age: (a) stem volume (cubic feet), expressing both tree diameter and height, obtained by the formula for a paraboloid frustum, a common bole form for conifers (Bruce and Schumacher 1935); and (b) mean annual volume increment, or growth rate (cubic feet per year), expressing average lifetime vigor, obtained by dividing the tree's volume by its age.

I reasoned that if the beetles had attacked the trees at random, larger and older fir could be expected to contain more scars than smaller or younger trees, by virtue of having a larger bole surface exposed to the beetles over a greater period of years, all else being equal. To eliminate or reduce this possible source of bias, the density of scars per unit of disk volume and age was calculated. Volume was chosen as an expression of the sum of all past surface areas. The number of scars visible on the sample surface of each cross section was considered to represent the number present in a 1-inch-thick cross-sectional disk. The result, referred to as a disk's "attack scar density," was expressed as scars per 10 cubic feet per decade for convenience of scale.

The trees were grouped by crown class on the virgin plots, and by plot on the cutover sites where the crown classifications could not be made due to stand alteration. Mean and variance in attack scar density were calculated for all sample disks from each tree grouping. Variance-to-mean ratios were large and increased disproportionately as mean attack density increased, indicating the scars were distributed in highly aggregated fashion among the sample disks. Such a distribution was not unexpected in light of the aggregated distribution of fir engraver attacks in response to the attraction produced by the mining beetles (Ashraf and Berryman 1969; Ferrell 1971). I wanted to determine if the variation in scar density between the groups of firs so defined was significant compared to variation within the groups, and if so, to test differences between group means. To satisfy the assumptions underlying these analyses, it was necessary to stabilize the variance-to-mean ratios, which was accomplished by transforming the scar densities ($\log x + 1$). The value of one was added so that a definite logarithm could be obtained for disks for which the scar density was zero. Differences between means were compared with least significant differences (Lsd) at the 5 percent level. The mean ± 2 standard errors ($\bar{x} \pm tse$ = approximate 95 percent confidence interval) was calculated for tree diameter, height, volume, age, and growth rate of the sample trees grouped by crown class and plot. Nonoverlap of confidence intervals was used as an approximate method for identifying significant differences between means as this criterion is conservative, with actual confidence limits usually well above the stipulated 95 percent level (Lidicker 1962).

RESULTS

Variation in scar density among the fir grouped by crown class and plot was significant ($F = 82.81$, $df = 7{,}3422$, $p < .01$).

Mean attack scar densities in living fir were higher in suppressed and intermediate than in dominant trees, and on Site II than on Site I plots. Also, in all crown classes, mean scar densities were at least twice as high in trees on the Site II plots, which had attained lesser diameters, heights, volumes, and growth rates than trees on the Site I plot *(table 1)*. The highest mean scar density occurred in the suppressed and intermediate fir at Dersch Meadow. These trees were growing in a heavily logged stand on the poorest site studied (Sites II and III). These conditions probably contributed to poor tree vigor as expressed by low growth rates, and to the eventual loss of the trees to the beetles. Apparently, the relatively light logging at Beal's Place was unimportant, as the growth rates and scar densities in these fir were similar to those of comparable crown classes (intermediate, suppressed) and site class (II) at Ellis Meadow which had not been logged. Fir growing on the best site (Madsen Mill) had the lowest scar densities and the greatest volumes and growth rates. Tree age was not an important factor. Although there was some tendency for younger trees to have high scar densities, this relationship was not evident on the old-growth plots, where there was little difference between the average ages of fir in the various crown classes and suppressed fir contained about four times the scar density of dominants.

DISCUSSION

The density of scars formed in white fir in response to past fir engraver attacks was inversely related to tree vigor as expressed by crown class, growth rate, and quality of growing site (site class). These results agree with other studies reporting increased abundance of the scars in annual rings formed by white fir in years of drought and reduced radial growth (Ferrell 1973), and in white fir heavily in-

Table 1–*Stand and tree characteristics related to fir engraver attack scar densities in white fir, by crown class, at four locations in northern and central California*

Crown class	Mean ± 2 standard errors[1] per tree					Mean (standard error)
	Stump diameter (in.)	Height (ft.)	Volume (cu. ft.)	Stump age (yrs.)	Growth rate (cu. ft./yr.)	Scar density[2] (cu. ft./yr.)
	Madsen Mill (Site I, virgin old-growth, live sample trees)					
Suppressed	25 ± 3	98 ± 9	193 ± 51	159 ± 9	1.2 ± 0.3	10.2 (2.6) d
Intermediate	31 ± 2	123 ± 7	360 ± 66	178 ± 13	2.0 ± .3	6.7 (1.4) d
Dominant	45 ± 1	159 ± 4	971 ± 69	185 ± 7	5.3 ± .3	2.8 (.3) e
	Ellis Meadow (Site II, virgin old-growth, live sample trees)					
Suppressed	21 ± 2	90 ± 5	128 ± 37	175 ± 9	.7 ± .2	29.2 (3.9) b
Intermediate	28 ± 1	116 ± 4	254 ± 32	180 ± 12	1.4 ± .1	10.7 (1.6) c
Dominant	34 ± 1	132 ± 3	451 ± 37	178 ± 8	2.5 ± .2	6.6 (.8) d
	Beal's Place (Site II, cutover, live, high-risk sample trees)					
Suppressed and intermediate	22 ± 1	75 ± 6	110 ± 17	126 ± 10	.9 ± .1	21.5 (5.0) c
	Dersch Meadow (Site II-III, heavily cutover, sample trees killed by fir engraver)					
Suppressed and intermediate	15 ± 1	63 ± 4	44 ± 8	100 ± 7	.4 ± .2	180.3 (58.4) a

[1] Approximate 95 percent confidence interval.

[2] Number of scars per 10 cubic feet per decade, sample disk basis. Differences between transformed means followed by dissimilar letters exceeded least significant difference at 5 percent level.

fected by mistletoe, especially in drought years (Felix, *et al.* 1971). The lower scar densities observed in more vigorous fir may be attributable to more rapid resinous responses of the host tissues to the attacks. Such high host resistance causes some attacks to fail to penetrate to the cambium and hence to form scars in the xylem; other attacks that do penetrate produce only small scars (Berryman 1969). Small scars would probably be less frequently detected on the surfaces of stem cross sections, the method of sampling used in this study.

In addition to variations in resistance associated with host vigor, other circumstances could have contributed to the observed variations in scar density. Logging slash on the cutover plots may have increased fir engraver populations on these plots by providing an abundance of nonresistant host material; the fir engraver readily attacks and reproduces in logging slash. Nevertheless, although previous study established that scar frequency increased in annual rings formed during logging operations at Beal's Place (Ferrell 1973), mean scar densities in these trees did not differ from those in fir of the same crown classes in the virgin stand at Ellis Meadow. (The two plots were similar in quality of growing site; both were Site II.)

Another possible source of variation in scar density was that some fir may have been selectively attacked because they were more attractive to the beetles. The possible role of attraction was not assessed, as this would require a representative sample of all fir engraver attacks within a given fir stand. The sampling methods used in this study did not represent the full spectrum of fir engraver attacks. Only a portion of the attacks form scars in the annual rings as discussed above, and attacks in fir killed by the beetles in years long past could not be sampled because the resulting snags had since fallen to the forest floor and decomposed.

It was possible to distinguish less resistant fir with high densities of embedded attack scars by observable characteristics such as crown class and growth rate. These results suggest that a risk rating system could be developed for white fir. Such a risk rating, if reliable and followed by selective removal of vulnerable fir (sanitation-salvage logging), would allow forest managers to reduce stand hazard and tree mortality from the fir engraver. Risk rating systems, using visible age and vigor characteristics, have been developed for ponderosa and Jeffrey pine stands in northeastern California subject to attack by subcortical insects (Salmon and Bongberg 1942), and have been successful in reducing subsequent timber loss caused by these insects (Wickman and Eaton 1962). The development of such a risk rating system for white fir requires further investigation of the characteristics of white fir killed by the fir engraver. An important byproduct of such mortality studies would be an assessment of the impact of the fir engraver upon the growth, stocking, and yield of both second- and old-growth stands.

Results of this study also indicate that lumber from white fir of low vigor (suppressed, intermediate, and high-risk trees) contains greater densities of stem defects produced by the embedded scars. This fact suggests that fir trees could be visually rated for the quality of wood products they would produce.

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Density of embedded scars resulting from old fir engraver *(Scolytus ventralis* Lec.*)* attacks was assessed in 3,430 bole cross sections cut from 603 white firs growing in both cutover and in virgin old-growth stands in northern California. Mean scar density was directly related to percentage of mature stand removed by logging and was higher in suppressed and intermediate, compared to dominant, fir. Inverse relationships were found between scar density and site quality, tree diameter, height, age, volume, and mean growth rate. A risk rating system based on tree and stand characteristics appears possible and would be useful in identifying for removal white fir with decreased resistance to beetle attacks. Such trees might also have a high probability of lumber defects caused by high scar densities.

Oxford: 453–145.7x19.92: 174.7 *Abies concolor.*
Retrieval Terms: Abies concolor; Scolytus ventralis; predator-host relations; damage indexes; attack scars; tree vigor; host resistance; host tree mortality; risk rating; lumber defects.

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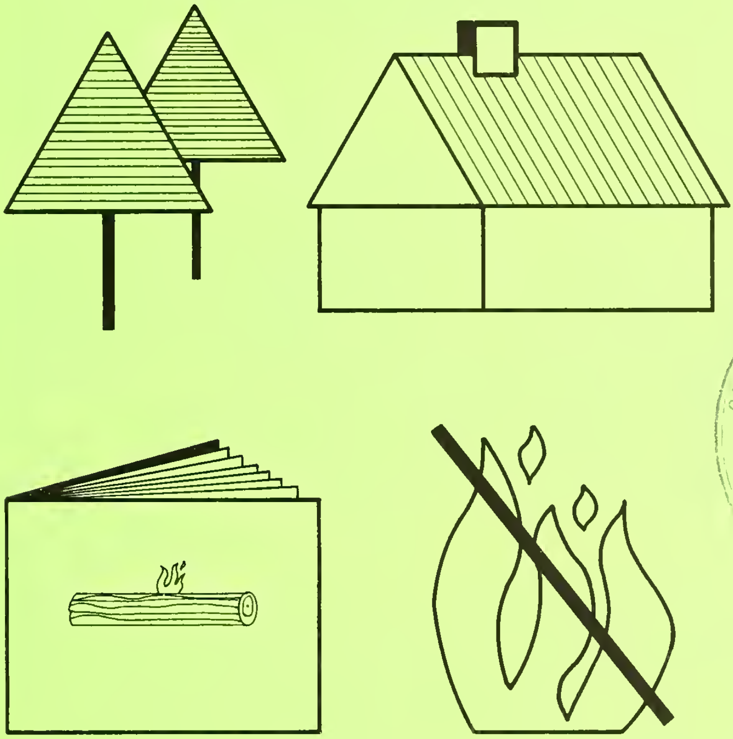

FIRE PREVENTION IN BUTTE COUNTY, CALIFORNIA. . .
evaluation of an experimental program

William S. Folkman

USDA FOREST SERVICE RESEARCH PAPER PSW-98 /1973

CONTENTS

The Author

WILLIAM S. FOLKMAN is responsible for the Station's research on sociological problems in the prevention of man-caused forest fires, with headquarters in Berkeley, Calif. 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 joined the Station staff in 1962.

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SUMMARY

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Retrieval Terms: fire prevention programs; fire starts; public attitude; BUCO Project; Butte County, California.

Fire protection agencies in California became increasingly concerned in the 1950's that their fire prevention and control efforts were inadequate to keep abreast of a situation that had steadily worsened. This decline had come about because of the increased use of wildlands coupled with rapidly increasing values at risk. The characteristics of topography, climate, fuel accumulation, as well as the human population, combined to give California a fire problem of growing complexity and severity.

Previous efforts at fire prevention had been hampered by limited resources and minimal staffing. It was proposed that the U.S. Forest Service and the California Division of Forestry join forces in an experimental, coordinated fire prevention program to be conducted in an operational situation. The program would be carried out with a sufficient staff of competent fire prevention specialists and adequate support to mount a well-rounded program.

The design of the program was essentially that of a before- and after-study. Butte County, in north-central California, was selected as the locus of the experiment that became known as the *BUCO Project.* An initial survey measured the existing levels of knowledge and attitudes concerning the use and abuse of fire in wildland areas among the resident population of the county. Some difficulty was experienced in assembling the staff of prevention personnel for carrying out the intensive program. Consequently, only during 2 years (1968 and 1969) out of the six did the program approach that planned. The fire prevention program conducted included emphasis on information and education, engineering, and law enforcement. In 1970, a resurvey was conducted from which changes induced by the experimental program might be measured.

A comparison of the data from the two surveys showed little change in the levels of knowledge and attitudes among the resident population from 1964 to 1970 in spite of the diligent efforts of all members of the fire prevention staff. Some differences were observed in areas of the county where special programs, such as intensive hazard reduction programs, were conducted. Fire records do show a drop in fire starts in the county during the period of intensive prevention action–1968 and 1969. Regression analysis of these records and those of adjacent counties was not conclusive in showing this drop to be due to the experimental program, however.

The experiment demonstrated that it is difficult to produce large-scale, rapid changes in autonomous individuals. The initial character of the population involved also affect the outcome. Pre-existent, generally favorable attitudes, for example, may be reinforced, but are not amenable to marked intensification. Results from program activities were most apparent from such specific actions as hazard reduction contacts and direct "Team Teaching" education efforts with children in the schools. The experience was effective in revealing important factors concerning organization and admininstration of fire prevention personnel, time and cost of specific operations, and similar operational matters.

In the mid-1950's, wildland fire protection agencies in California—primarily the California Division of Forestry and the U.S. Forest Service—became uncomfortably aware that they faced a problem that threatened to overpower their control efforts. Soaring values at risk and ballooning control costs suggested greater concentration on stopping fires before they began.

About 90 percent of all forest fires in areas protected by the State and more than 50 percent of those in areas under U.S. Forest Service protection are man-caused; that is, they result from the ignorance, carelessness, indifference, or malice of people in their varied uses of the forests. The prevention of such fires was seen to involve the modification of the knowledge, attitudes, and behavior patterns of forest users, but the most effective ways of accomplishing this puzzled the protection agencies.

In 1955, a jointly sponsored research contract was awarded to the University of Southern California to make some preliminary studies of the human behavioral aspects of forest fire protection. The recommendations of the report that resulted were later incorporated in a research program assigned to the Pacific Southwest Forest and Range Experiment Station.

This paper evaluates the effectiveness of an experimental, coordinated fire prevention program in Butte County, in north-central California, and reports the findings of what became known as the *BUCO Project.*

BUCO PROJECT

Research Approach

Researchers at the University of Southern California defined 8 criteria they considered *essential* in determining the location of the test community for an experimental fire prevention program. These included: (a) availability of data on the incidence of man-caused forest and wildland fires for a five year period; (b) facilities for ascertaining a risk factor; (c) a representative pattern of fire causation; (d) a cooperative organizational climate; (e) availability for data gathering facilities; (f) a pattern of use including residency, logging, and recreation; (g) cooperative mass communications media; and (h) population stability.

An additional seven criteria were proposed as *desirable:* (a) substantial areas under the jurisdiction of the California Division of Forestry and the U.S. Forest Service; (b) availability of data on risk rating for the previous five-year period; (c) availability of data on the characteristics of the resident population; (d) availability of additional data on the incidence of man-caused forest and wildland fires; (e) availability of data on fire prevention efforts; (f) cooperation of private forest landowners, and (g) availability of information on the violations of fire laws and regulations in previous 5 years.

In consultation with Division of Forestry and Forest Service representatives the University researchers determined that a county, rather than a community—was the unit of study best suited to meet the criteria. The uniformity of county ordinances and relative autonomy of administrative jurisdiction were among the considerations in making this decision. (The boundaries of a Ranger Unit, a basic administrative division of the California Division of Forestry, usually coincide with county boundaries.)

On the basis of the criteria previously outlined, the number of qualifying counties of the State was reduced to 12 and then to five. Butte County was finally selected as the county possessing the greatest number of essential and desirable qualities for such a study *(fig. 1).*

The planning, collection of background data, and establishing of working relations culminated in a survey of the resident population of Butte County in fall 1964. This survey determined the existing level of attitudes and understanding of the local residents per-

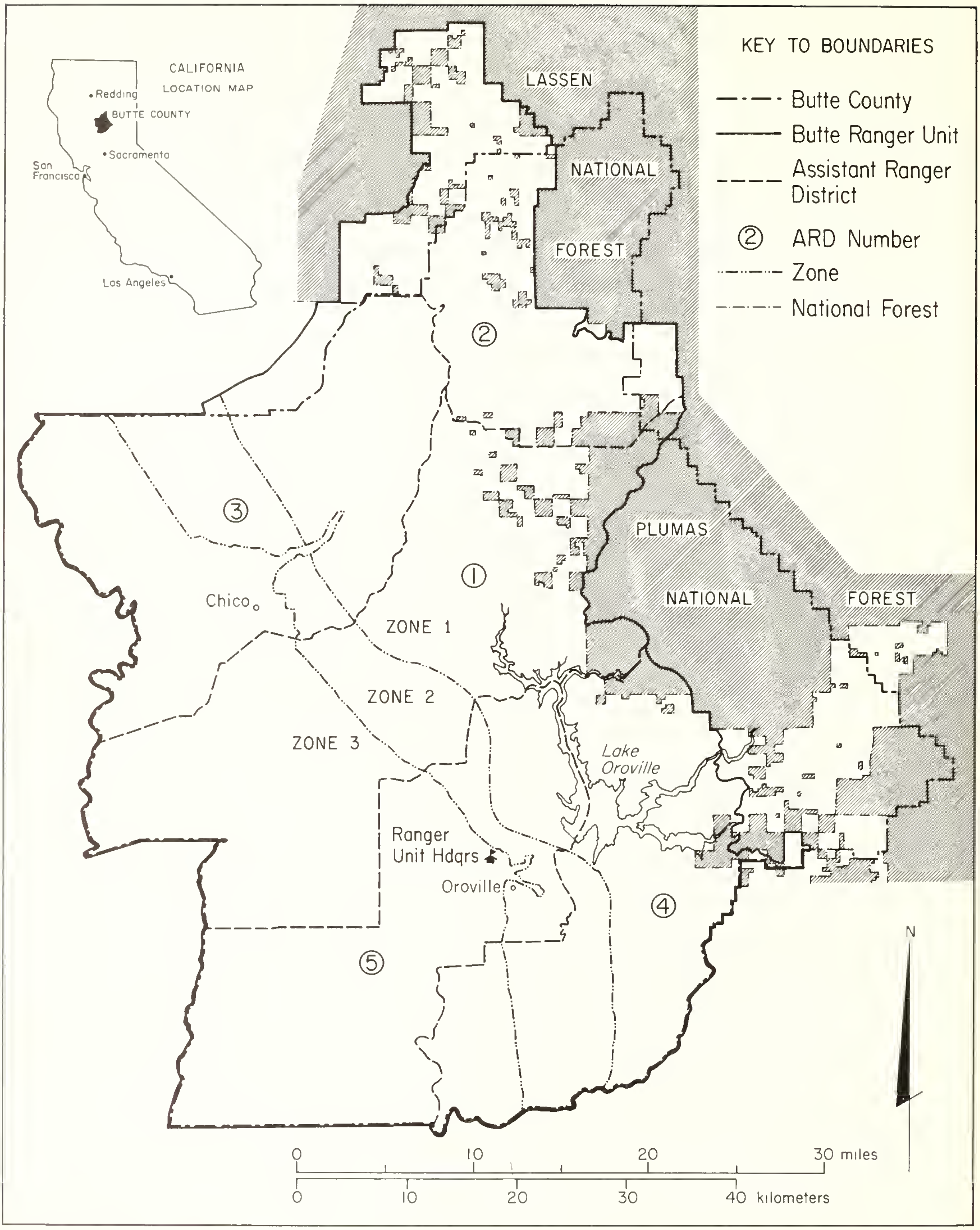


Figure 1—The Butte Ranger Unit, California Division of Forestry, served as the site for an experimental fire prevention program carried out from 1964 to 1970. It is divided into five Assistant Ranger Districts. Zone I lands are forest or watershed lands; Zone II lands are primarily rangelands; and Zone III lands are areas without State or Federal interest in timber, watershed, range, or erosion.

taining to the use of fire and of fire prevention (Folkman 1965). The survey results served as a benchmark from which changes induced by the experimental program would be measured.

Ideally, the classic research approach, with control and test subjects, would have been used. But the University of Southern California scientists concluded that the variance between counties was too great, and the control of extrinsic variables too limited for this approach to be feasible. Consequently an alternative method was selected, i.e., the test-retest procedure, in which one county would be compared with itself at different times.

The reliance on determining the effect of the program by means of measuring changes in levels of attitude and knowledge, rather than using actual changes in fire starts, may require some justification. Feelings and understandings have only a limited relationship to actual behavior, so to use measures of these attributes as *criteria* of program success is not particularly satisfactory. On the other hand, the number of fire starts varies so markedly from season to season as influenced by such uncontrolled, and uncontrollable, factors as variations in rainfall, wind, fuel accumulations, that such variation in numbers of fire starts attributable to the program would most likely be masked by these other, more powerful, influences. The use of indirect criteria, therefore, was considered to be unavoidable.

Implementing the BUCO Project met with initial discouragement. The large-scale funding anticipated by the original planners did not materialize and no additional funds or staffing were immediately forthcoming to carry out the proposed experimental program. It became evident that in an action program, such as this, considerable improvisation and alteration of plans is to be expected.

For some time the action program was limited to such additional emphasis to fire prevention that the existing staff could give as other duties permitted. Research studies concerned with roadside fire prevention signing (Ruckel and Folkman 1965, Folkman 1966a) conducted in the county, experiments involving inspections for fire hazard reduction (Folkman 1967, 1968), and development of conservation/fire prevention education in public schools (Gladen and Carkin 1970) also provided some inputs to the fire prevention activity in the county.

The California Division of Forestry conducted a workload inventory of the Butte Ranger Unit. This inventory defined the fire prevention job for Butte County and provided the basis for calculating the number of man-hours per year needed to do the fire prevention job. This anaylsis formed the basis for a budget request to the State Legislature for optimum staffing of the Unit. The request provided for 16 fire prevention positions. (Up to then the Unit had no one assigned full time as a fire prevention officer.) The proposed 16 new positions were considered adequate to handle 75 percent of the workload inventory (Moore 1970). It was estimated that 25 percent of the prevention work was of such a nature that fire control, administrative, and professional (foresters, engineers, etc.) personnel could do it with a minimum of additional training. Under provisions whereby the State reimburses the U.S. Forest Service for protection of private land within National Forest boundaries, it was proposed to finance two fire prevention personnel to work in the units of the Plumas and Lassen National Forests within Butte County boundaries.

Staffing

Project Butte[1] was authorized by the State Legislature for activation during the 1966-67 fiscal year. This provided funding for the 16 fire prevention positions within the Butte Ranger Unit, but not for the two positions for the National Forests. These two positions were never filled. The original intent was that the project would be activated in stages throughout the first 10 months of the fiscal year so as to be fully operational before the 1967 fire season. Because of problems in meeting this timetable, however, Project Butte was not completely staffed before the end of that season. Except for normal vacancies it remained fully staffed through the 1968 and 1969 fire seasons.

Since this staffing was to serve as a pilot model for future normal operations in other ranger units, it was fully integrated into the existing ranger unit organization *(fig. 2)*. The Ranger in charge of the Ranger Unit directed the work of two Associate Rangers. Assigned to the Associate Ranger for Fire Prevention were: three Fire Prevention Officers II (one each responsible for information and education, fire prevention engineering, and law enforcement), a stenographer, and a Fire Prevention Officer I, who worked under the Fire Prevention Officer II in charge of law enforcement. The existing structure provided an Associate Ranger for Administration to whom were assigned Assistant Rangers who headed each of the

[1]The field input of the experimental fire prevention staff was given this title by the California Division of Forestry to preserve a distinction from the over-all research study known as the BUCO Project.

RANGER

- Assoc. Ranger Fire Prevention
  - Asst. Ranger Dist. 1
    - Fire Prev. Off.
    - Fire Prev. Off.
  - Asst. Ranger Dist. 2
    - Fire Prev. Off.
  - Asst. Ranger Dist. 3
    - Fire Prev. Off.
    - Fire Prev. Off.
  - Asst. Ranger Dist. 4
    - Fire Prev. Off. - Inf. & Educ.
    - Fire Prev. Off. - Engr.
    - Fire Prev. Off. - Law Enf.
  - Asst. Ranger Dist. 5
    - Fire Prev. Off.
    - Fire Prev. Off.
- Assoc. Ranger Administration
  - Fire Prev. Off. - Inf. & Educ.
  - Fire Prev. Off. - Engr.
  - Fire Prev. Off. - Law Enf.
    - Fire Prev. Off.

Figure 2—Fire prevention work in the Butte Ranger Unit was carried out by the Associate Ranger and his staff at Unit headquarters and fire prevention officers administratively assigned to each of the five Assistant Ranger Districts.

five Assistant Ranger Districts into which the Unit was divided. Depending on fire prevention work load, from one to three of the other 10 Fire Prevention Officers were added to each of these Assistant Ranger Districts. These fire prevention personnel were originally assigned to geographic subdistricts in which each person was responsible for the full fire prevention program.

The original assignment of positions and duties at the headquarters staff level proved effective and no changes in organization at this level were deemed necessary during the course of the project. The organization in the Assistant Ranger Districts, however, was modified after about a year's trial. It was found that functional, rather than geographical assignments provided more flexibility and efficiency—both within and between Districts. Each Fire Prevention Officer was given primary responsibility within a District for one of the three major components of the fire prevention program: information and education, engineering, or law enforcement. Assignment of secondary and tertiary responsibilities allowed any officer to fill in for another when necessary, and all officers were thus kept familiar with the total prevention situation within the Assistant Ranger District to which he was assigned. It was not uncommon for a problem to arise requiring the participation of a number of officers on an inter-District basis. The Associate Ranger for Fire Prevention had authority to withdraw Fire Prevention Officer I's as necessary from Assistant Ranger Districts to handle these emergency situations. Under the reorganization this could be done without leaving major components of the fire prevention program unmanned in any District. This increase in efficiency and promptness in meeting emergencies quite outweighed the advantages of having one individual intimately acquainted with one geographical sub-District.

During fiscal year 1970-71 some of the Project Butte positions were reassigned to other Ranger Units in other parts of the State. By the close of 1970 fire season, when the resurvey of the resident population of the county was made, the Project Butte staff had been gradually reduced to one FPO II and four FPO I's as called for by a new fire protection plan approved by the State Board of Forestry.

FIRE PREVENTION ACTIVITIES

The fire prevention activities in this experimental program consisted of hazard reduction work, information and education, and law enforcement. Statistics reporting numbers of contacts, programs given, or fire prevention supplies distributed are only rough indicators of the magnitude of the program. They, in themselves, convey little of the quality of the activities, the emphasis given, or the effect on the behavior of recipients. The records, however, do show a marked increase in most prevention activities during the experiment. This is particularly true in 1968 and 1969 *(table 1)*.

Some increases in certain types of prevention activity would no doubt have occurred regardless of the experimental program (albeit, at the expense of other lower priority activities) because of significant changes taking place in the Butte Ranger Unit that increased fire prevention work load during the time of the study. Although population stability was one of the "essential criteria" used in selecting the area, the construction of the Oroville Dam on the Feather River and associated facilities in Butte County between 1961 and 1968 resulted in a tremendous increase in certain types of hazards and risks. This was particularly true from 1964 through 1966, when construction reached its peak and there was a temporary influx of workers into the area. In addition to this population increase, Butte County also shared in the

Table 1–*Forest fire prevention activities in Butte County, California, 1964-71*[1]

Activity	1964	1965	1966	1967	1968	1969	1970	1971
	Number							
Prevention effort contacts:								
Fire station personnel	7,219	3,140	4,785	11,267	20,861	9,619	14,542	15,428
Patrolmen	3,367	12,985	13,682	21,708	69,003	27,791	12,010	9,844
Assistant rangers	2,877	2,411	2,579	3,973	2,377	2,691	2,488	2,176
Others	905	404	813	5,956	3,294	4,537	4,313	6,289
Total	14,368	18,940	21,859	42,904	95,535	44,638	33,353	33,737
Outlets–contacts–programs:								
Newspapers	20	10	51	330	1,566	1,012	614	653
Radio	2	5	15	28	864	850	364	237
Television	6	2	5	1	793	112	189	170
Theater	18	12	0	6	34	8	0	0
Others	5	7	2	0	0	0	0	0
Total	51	36	73	365	3,257	1,982	1,167	1,060
Schools	2,538	2,179	1,461	1,298	7,356	8,856	6,982	3,556
Service groups	291	202	83	830	782	233	303	272
Women's groups	0	42	350	253	160	376	21	153
Youth groups	180	307	988	1,446	2,057	917	1,271	318
Agricultural groups	75	132	68	100	584	203	141	153
Sportsmen's groups	0	0	0	50	588	738	201	13
Conservation groups	296	0	0	120	223	40	18	3
Others	90	424	135	0	587	464	485	306
Total	932	1,107	1,624	2,799	4,981	2,971	2,440	1,218
Fire prevention materials postings:								
Posters								
By Calif. Div. For.	69,826	31,310	1,348	896	2,005	1,221	907	5,622
By cooperators	1,195	1,320	268	600	2,163	399	557	662
Other materials								
By Calif. Div. For.	22,890	3,650	76,342	30,514	75,699	383,216	25,473	41,903
By cooperators	267,925	442,297	353,822	393,465	422,953	312,155	363	9,036
Roadside signs	23	18	27	22	28	44	47	40
Burning:								
Permits issued	6,731	4,480	4,755	4,367	4,569	6,819	6,731	8,062
Burning sites inspections	2,942	2,111	2,624	1,559	2,571	3,374	2,753	1,350
Existing or potential hazards and risks:								
Mechanical equipment (inspections):								
Agricultural	50	21	79	65	57	13	1	0
Forest products	54	35	299	455	82	70	86	30
Construction	265	982	3,279	346	50	44	48	8
Other industrial	3	2	2	5	32	17	23	10
Total	372	1,040	3,659	871	221	144	158	48

continued

Table 1–*Forest fire prevention activities in Butte County, California, 1964-71* [1]–Continued

Activity	1964	1965	1966	1967	1968	1969	1970	1971
	Number							
Roadside (miles treated):								
State highways	0	0	29	15	104	79	60	25
Country roads	116	60	130	225	50	139	18	18
Cal. Div. For. Admin. Rds.	0	0	40	55	15	30	0	0
Utilities (miles treated):								
Railroads	62	33	54	33	42	59	46	46
Powerlines	0	18	93	227	355	551	331	211
Other	20	20	0	0	0	0	0	0
Dumps (inspections)–public, private	31	20	32	28	41	47	44	12
Recreation (inspections):								
Resorts	16	8	6	13	19	6	2	2
Organized camps	5	1	10	7	8	3	10	4
Campgrounds	126	78	218	219	234	119	155	1
Other	0	0	0	17	36	12	24	8
Total	147	87	234	256	297	140	191	15
Forest products (inspections):								
Sawmills	13	10	6	9	11	6	4	8
Other mills	2	0	2	3	1	13	3	0
Operating areas	61	65	60	64	30	21	25	15
Total	76	75	68	76	42	40	32	23
Industrial operations (inspections):								
Agricultural	19	15	19	18	7	2	2	0
Mineral	3	1	2	8	7	7	1	1
Construction	49	18	512	28	54	46	19	2
Other	0	0	0	5	54	10	14	0
Total	71	34	533	59	122	65	36	3
Structures, premises (inspections):								
Mountain cabins	811	296	384	621	547	371	395	287
Ranches, farms	188	45	170	431	416	251	136	23
Rural dwellings	1,186	337	2,048	2,296	2,297	2,644	2,109	600
Other	0	0	31	49	93	91	370	17
Total	2,185	678	2,633	3,397	3,353	3,357	3,010	927

[1]Source: Annual Reports (Form FPE-2) of California Division of Forestry 1964-1971.

general population growth that California was then experiencing. During the decade 1960 to 1970 the population of the county increased 24.3 percent—from 82,030 to 101,969 (U.S. Bureau of the Census 1971). This growth in population was concentrated in the urban areas. The rural population declined 3.9 percent, while the urban population increased 49.3 percent.

Because of these changes, the reported increase in numbers of inspections of industrial operations and of mechanical equipment over the course of the experiment is only partly attributable to the experimental program. Similarly the development of new campgrounds and other recreational facilities about the anticipated lake resulting from the dam construction added further to the workload and precipitated a need for additional inspections in this area.

Hazard Reduction

A legislative change in the State Public Resources Code in 1963 placed greater emphasis on the clearing of inflammable vegetation and other materials from around rural structures. This change was not immediately felt, but by 1966 it was providing impetus for intensified hazard reduction inspections of rural residences and mountain cabins in high-risk areas as part of the experimental program input. The record concerning inspections of structures and premises reflects this emphasis *(table 1)*.

In 1966, five selected areas in the county near Oroville, were studied to assess the effectiveness of various fire hazard inspection procedures in securing compliance with fire safety requirements of the revised code. A specially trained crew of inspectors was used. The effects of different types and combinations of contacts and timing in the inspection of rural properties and the time expended were measured. The results suggested that fire law inspection is most effective when the fire prevention education function, rather than law enforcement, is stressed (Folkman 1967).

In 1967 this fire hazard inspection study was repeated in the same areas. In this study the carry-over effect of the inspection procedure was demonstrated (Folkman 1968). The area covered in these two studies continued to receive special attention by fire prevention personnel throughout the course of the project.

Project Butte also included working closely with State and county highway departments, railroad companies, and public utilities to secure their cooperation in reducing fire hazards. Training sessions were held with personnel of these organizations to help them to identify areas needing special attention and to give them instruction in prevention measures. Rights-of-way and facilities were periodically inspected to insure compliance with the Public Resources Code *(table 1)*.

Information and Education

Informing and educating the general public by means of newspapers, television, and radio were emphasized during the experimental program. The magnitude of these efforts is suggested by the increased number of contacts with these media reported, especially in 1968 and 1969 *(table 1)*. These contacts sought to encourage the mass media to keep the public sensitive to the fire problem and aware of subjects of particular concern at specific times (such as problems with debris burning, children-caused fires, incendiarism, etc.) and to educate them as to sound fire prevention measures appropriate to their use.

In carrying out the assignment, information and education officers encountered difficulty in competing with their own organization's more "news worthy" fire control activities. Their fire prevention effort was further diluted by the necessity for them to report other Division of Forestry activities, such as station or facility construction, truck trail maintenance, personnel assignments, and social events. (Presumably, all of this, by keeping the Division before the public, has a latent if not manifest function of keeping the public fire and fire prevention conscious.)

To get some objective measure of the fire-related content actually appearing in the newspapers, and to determine the changes in amount and emphasis, I did a content analysis of the newspapers serving the county from 1958 through 1968. The newspapers analyzed were the *Chico Enterprise Record, Oroville Mercury Register, Gridley Herald, Feather River Times, Biggs News,* and—for comparative purposes—*Sacramento Bee.* Similar measures of the use of radio and television would have been desired, also, but the logs kept by the stations did not provide the detail (particularly of spot announcements, etc.) which was necessary for such an analysis.

The analysis shows that the number of fire-related items (exclusive of reports of fires) appearing in the local newspapers did increase during the period of the project, especially fire prevention articles and news *(table 2). The Sacramento Bee*, which covers a wider area than the other five newspapers consistently published fewer such articles, and it did not show a consistent increase in number of items over the time period studied. The local papers increased the number of fire warning articles, fire prevention ads, reports of fire arrests, and in reports of other Division of Forestry activities not specifically related to fire prevention.

Five radio stations serve the Butte County area, but their coverage is not confined to it. Their combined daily listening audience is estimated at 250,000 people—two and one-half times the population of Butte County. The number of reported contacts with radio stations ranged from only two in 1964 to 864 in 1968 *(table 1)*. The figure 864, by itself, may seem unimpressive, but summarizes the effort to write and tape 38 fire prevention spot announcements—each 15

Table 2–*Average number per year of fire prevention articles and related items appearing in Butte County, California, newspapers*[1] *and in* The Sacramento Bee, *by groups of years, 1958 to 1968*

Article or item	*The Sacramento Bee*			Butte County Newspapers[1]		
	1958-62	1963-66	1967-68	1958-62	1963-66	1967-68
Fire prevention speech to adults	2.0	0.0	0.0	4.2	0.0	4.5
Fire prevention speech to children	.0	.0	.0	4.2	5.0	7.5
Training program for adults	2.2	.0	.0	1.2	.0	1.5
Training program for children	.0	.0	.0	.0	.0	.5
Fire warnings	11.2	10.0	12.5	33.0	42.5	49.5
Firemen sports teams	2.0	.0	.0	6.0	10.0	5.0
Firemen women's auxiliary	.0	.0	.0	4.4	10.0	11.5
Insurance	1.0	.0	1.5	4.4	7.5	4.5
Insurance ads	.0	.0	.0	9.6	.0	6.5
Fire prevention ads	.0	.0	.0	1.2	5.0	12.0
Fire prevention ads–private sponsored	.0	.0	4.5	2.0	.0	5.5
Fire calls (summary)	.0	.0	.0	.0	.0	1.0
Fire Prevention District Articles (or pictures)	13.8	70.0	29.5	24.6	37.5	59.5
Fire Information reports (statistic on No. of fires, etc.)	23.8	12.5	4.5	45.2	27.5	20.5
Fire Information–human interest–Smokey Bear, etc.	7.8	17.5	15.0	15.8	22.5	13.0
Fire arrests, fire starts–not arson	1.0	2.5	.5	11.2	2.5	26.5
Fire arrests–arson	.0	.0	.0	2.2	.0	.5
Letters to editors	3.6	2.5	.5	4.8	2.5	6.5
Firemen's social events	4.6	12.5	3.5	9.0	17.5	13.0
Fire prevention–human interest	.0	.0	4.0	3.2	2.5	.0
Fire prevention–research article	1.6	.0	1.0	6.0	5.0	.5
Editorials	.0	.0	.0	3.8	.0	2.0
Other	4.6	2.5	4.0	3.6	2.5	1.0
Total	79.2	130.0	77.0	199.6	200.0	252.5

[1]*Chico Enterprise Record, Oroville Mercury Register, Gridley Herald, Feather River Times,* and *Biggs News.*

seconds to one minute in length. All stations transmitted an average of three spots per day during the fire season. It includes the 70 news releases which were provided to the radio stations. (These were generally condensed versions of stories released to the newspapers.) Also included are the 80 tape-recorded "on-the-spot" interviews which were given to the stations' mobile reporters. Generally these were fire activities.

Butte County has one television station. The station claims a viewing audience of about 150,000 people during peak viewing hours. In 1968, the Butte Ranger Unit personnel provided 793 releases to this station. Most were transmitted twice daily–during the 6 p.m. and 11 p.m. news reports. A fire response board was prepared on which was shown the fire activity daily for the area. During the showing of the board, the newscaster would insert a fire prevention message and, possibly, supplement it with a short film clip of a current fire.

During 1968, the Butte Ranger Unit information and education officer appeared 10 times on television. He covered such subjects as children-caused fires, incendiary fires, incinerator standards and use, and fire safety during the deer season.

Children contribute significantly to the fire problem in Butte County. They are responsible for about one-fourth of the forest fires reported. Of the 30,247 children under the age of 18 in Butte County in 1970 (U.S. Bureau of the Census 1971a), 8,818 (29.2 percent) were in the critical ages of 5 to 10, when experimentation with fire is most prevalent (Folkman 1966b). Special efforts were made by Project Butte personnel (Goings 1968) and BUCO Project researchers to develop new methods and materials for effectively teaching fire prevention and conservation of natural resources to children in kindergarten through the third grade. Much of this work was done through California State University, Chico (Gladen and Carkin 1970). A particularly successful system of "team teaching" was worked out, in which California Division of Forestry employees would divide a class into small groups of children, five to seven per group, and lead them in a discussion of a limted number of prevention ideas. These discussions were limited to 8 to 10 minutes to accommodate the limited attention span of children of this age level. For a grand finale, Smokey would appear briefly before the reassembled class to reinforce what the children had learned and the commitments to fire safety they had made. A significant proportion of the school children were reached in this and other school programs during the 1968 to 1970 period *(table 1)*.

The field fire prevention officers developed slide shows and programs using other types of visual aids for appearances before various types of groups of youths and adults. A fire prevention poster and essay contest was developed in cooperation with the Junior Women's Club.

Law Enforcement

One of the main functions performed by those with law enforcement responsibility is to investigate fire cause. A knowledge of fire cause is basic to any planning of fire prevention programs. Affixing cause in forest fire cases is extremely difficult, however. Before the experimental program was started, "known cause" was recorded in less than one-third of the forest fire reports in the Butte Ranger Unit. In 1967, the first year of operation in which specifically trained fire prevention officers were beginning to be available, the percent of known causes was 40 percent. In 1968 the percentage increased to 52 percent, and in 1969 the known causes increased further to 58 percent.

In the enforcement of fire laws, knowing the cause of a fire is only a preliminary to enforcement action. Establishing the identity of the person (or persons) responsible is generally an even more difficult procedure. Proving this identity to the satisfaction of a court of law adds increased complications. When investigation has provided satisfactory answers to these issues, the circumstances of the case are evaluated, taking into consideration all of the legal aspects and Division policy, to determine what enforcement action is applicable.

In the experimental program developed under Project Butte, law enforcement was regarded as complimenting the education and fire engineering components of the program. The objective of the whole program was reduction of man-caused fires. In general, law enforcement was accepted as a last resort measure—applicable in dealing with those relatively rare cases in which education and engineering were ineffective. It was anticipated that the publicizing of court cases would underline the legitimacy of fire regulations and the seriousness of any violation of them. Thus, this would reinforce the educational efforts being undertaken.

Butte Ranger Unit records show these law enforcement activities:

Activity:	1967	1968	1969	1970
Number of investigations	325	269	340	346
Misdemeanor cases	17	35	12	13
Felony cases	1	1	1	0
Misdemeanor convictions	15	33	9	13
Felony convictions	1	1	1	0

Throughout the course of the experiment, the knowledge that the county was being used as an experimental area was deliberately kept from the public in order to avoid the effect such knowledge, itself, may have had on their behavior. The final survey revealed that some people were aware of an increased prevention activity in their area, but, they appear to have remained unaware of the experimental program itself.

MEASURING THE RESULTS

Resurvey

The resurvey of the resident population of Butte County followed the same design as that used in the original survey (Folkman 1965). No attempt was made to interview the same people contacted in the first survey. Instead, an entirely new sample was drawn by using the same area sampling procedure. A comparison of social and demographic characteristics of the two samples revealed a reasonably close correspondence between them *(table 3)*. Most of the differences reflect changes that took place in the population during the interim period. The 1970 sample does appear somewhat under represented in the "under 25 years of age" category. An over representation of similar magnitude in the "over-65 years of age" group is also apparent. The distribution of the 1970 sample by place of residence reflects the rapid growth of the suburban population in Butte County and the decline in rural population.

Items reflecting exposure to the high fire risk

Table 3—*Comparison of certain social and demographic characteristics of Butte County, California, residents, 1964 and 1970 surveys*

Characteristics	1964 (n = 761)	1970 (n = 663)
	Percent	
Age:		
14-24 years	23.4	17.6
25-34 years	13.8	13.4
35-49 years	25.8	16.7
50-64 years	21.7	26.6
65 years and over	15.2	24.0
Not reported	.1	1.7
Total	100.0	100.0
Sex:		
Male	48.5	44.6
Female	51.5	55.1
Not reported	–	.3
Total	100.0	100.0
Marital status:		
Single	18.5	16.0
Married	68.5	65.1
Widowed, divorced or separated	13.0	18.7
Not reported	–	.2
Total	100.0	100.0
Race:		
White	97.5	96.6
Black	1.3	1.2
Other	1.2	1.1
Not reported	–	1.1
Total	100.0	100.0
Schooling completed:		
0-4 years	3.7	2.6
5-7 years	6.7	6.2
8 years	14.8	14.2
Some high school	25.8	24.6
High school graduate	23.1	25.6
Some college	17.6	19.0
College graduate	4.7	4.0
Post-graduate	3.6	3.0
Not reported	–	.8
Total	100.0	100.0
Occupational status:		
Employed, full time	37.3	32.9
Employed, part time	15.3	15.1
Retired or disabled	13.1	21.3
Housewife	22.2	24.7
Student	11.8	3.8
Not reported	.3	2.0
Other	–	.2
Total	100.0	100.0

Characteristics	1964 (n = 761)	1970 (n = 663)
	Percent	
Family income (dollars):[1]		
Under 1,500	8.0	5.1
1,500-2,999	12.8	13.4
3,000-4,499	13.3	15.7
4,500-5,999	13.1	11.3
6,000-7,999	17.3	13.3
8,000-9,999	10.8	11.9
10,000-14,999	12.9	18.8
15,000-19,999	2.5	5.7
20,000 and more	.9	1.5
Not reported	8.4	3.3
Total	100.0	100.0
Length of residence in neighborhood (years):		
Less than 1	18.4	8.0
1-2	17.5	24.2
3-5	17.6	13.1
6-10	12.2	19.6
10 or more	34.3	35.1
Not reported	–	–
Total	100.0	100.0
Place last lived:		
Elsewhere in Butte County	32.3	40.1
Other county, Northern California	31.0	25.2
Other county, Southern California	12.9	13.1
Other states	14.4	10.7
Always lived here	9.3	10.9
Not reported	.1	–
Total	100.0	100.0
Present residence:		
City	47.8	43.0
Suburb	18.9	33.0
Small town or village	13.3	7.2
Open country, farm	8.9	6.3
Open country, non-farm	6.1	9.4
Not reported	–	1.1
Total	100.0	100.0

[1]Median income in 1964: $5,842; in 1967: $6,420.

forest, or wildland, environment show that most Butte County residents continue to use these areas *(table 4)*. However, the proportion reporting no wildland visits during the preceding year was higher than in the 1964 survey. This may be a reflection of the higher proportion of older people included in the

Table 4—*Comparison of wildland and fire use of Butte County, California, residents, 1964 and 1970 surveys*

Characteristics	1964	1970
	Percent	
Number of wildland visits:		
None	24.0	31.5
1-2	11.3	13.3
3-5	16.6	13.0
6-10	16.0	9.6
11 or more	32.1	31.4
Don't know	–	–
Not reported	–	1.2
Total	100.0	100.0
Frequency of use of fire in wildlands:		
Not at all	71.2	73.4
1-2	10.9	9.8
3-4	6.8	5.6
5 or more times	12.0	10.9
Don't know	–	–
Not reported	.1	.3
Total	100.0	100.0
Obtained a campfire permit?		
Yes	29.0	18.0
No	70.2	81.4
Don't know	.7	–
Not reported	.1	.6
Total	100.0	100.0
Obtained a burning permit?		
Yes	35.6	41.2
No	63.3	58.2
Don't know	1.1	.3
Not reported	–	.3
Total	100.0	100.0
Ever helped fight a forest fire?		
Yes	30.4	21.4
No	69.3	78.1
Not reported	.3	.5
Total	100.0	100.0

1970 survey—wildland use being closely correlated with age. The proportion reporting over 10 visits remained essentially unchanged from the earlier study. This was also true of the reports of frequency of use of fire in wildland areas. Possession of a *campfire* permit has dropped sharply in the years between the two surveys, while the obtaining of a *burning* permit experienced a slight increase. In summer 1970, the U.S. Forest Service changed its regulations regarding campfire permits, making them no longer required in established campgrounds in the National Forests. This change undoubtedly was responsible for the drop in the possession of campfire permits. The reduction in the proportion reported having helped fight a forest fire at anytime in the past is inexplicable.

Results

Knowledge about fire prevention and fire behavior was measured by the same 20-item multiple choice instrument used in the original survey *(table 5)*. Mean scores for the two tests did not differ significantly: 58.1 percent correct in 1964 and 57.6 percent in 1970. However, the average figures mask significant differences in the distribution of scores *(table 6)*. There were fewer very low scores (less than 50 percent correct) and more high scores (75 percent or more) in the 1970 survey than in the 1964 survey. It was the distributions within the middle range that resulted in near identical scores.

The California Division of Forestry at the time of the study classified the lands within its area of responsibility into three zones *(fig. 1)*. Fire prevention and fire control plans and operations were strongly influenced by this classification. The three zones were: Zone I—lands covered wholly or in part by forests or by trees producing or capable of producing forest products; and lands covered wholly or in part by timber, brush, undergrowth, or grass, whether of commercial value or not, which protect the soil from excessive erosion, retard runoff or water or accelerate water percolation, where such areas are sources of water which is available for irrigation or for domestic or industrial use; Zone II—lands in areas which are principally used or useful for range or forage purposes which are contiguous to the lands in Zone I; Zone III—those valley lands having no State or Federal interest in timber, watershed, range or erosion and are the fire protection responsibility of local agencies.

The State Division of Forestry contracts with counties for Zone III protection where the State is already protecting mountain areas and is established in the fire protection business. Through these contracts, the State does the entire protection job and is reimbursed by the county concerned for the effort expended on non-State interest land.

In 1972, the California Division of Forestry discarded the Zone classification. It no longer distinguishes between the former Zone I and II lands, but refers to them collectively as Clarke-McNary lands. Former Zone III lands are referred to as Contract Lands.

Table 5–*Distribution of responses to items in the Knowledge Test, 1964 and 1970 surveys*

Knowledge Test item	1964 (n = 761)	1970 (n = 663)
	Percent	
Green trees and shrubs of California:		
Are very difficult to burn	19.6	21.9
Will not burn at all	1.6	2.7
Will catch fire and burn very rapidly[1]	43.4	46.6
Will burn only in the hot summer months	27.7	21.1
Do not know	7.7	7.7
	100.0	100.0
If you take extra gasoline for your camp stove, you should carry it in:		
A glass jar or jug	1.6	.8
A safety can[1]	72.2	73.3
A container in which flammable liquids are purchased	21.9	20.9
A plastic container such as is used in the kitchen	1.7	1.8
Do not know	2.6	3.2
	100.0	100.0
The safest method for lighting cigarettes in the forest area is to use:		
Book-type safety matches	19.3	16.7
Strike anywhere, stick-type matches	1.2	1.4
Stick-type safety matches	8.3	9.2
A cigarette lighter[1]	65.4	63.5
Do not know	5.8	9.2
	100.0	100.0
The surest way to put out a campfire assuming all these methods are available, is to:		
Pour water on it	7.1	12.1
Completely cover it with dirt	34.3	29.3
Pour water on it and stir thoroughly[1]	56.6	55.0
Spread out the embers and let it burn itself out	1.2	2.3
Do not know	.8	1.3
	100.0	100.0
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:		
Not liable for damages	.5	.6
Criminally liable, but not civilly liable	4.3	3.0
Civilly liable, but not criminally liable	15.7	19.0
Both criminally and civilly liable[1]	32.2	33.6
Liable, but don't know which	37.6	32.6
Do not know	9.7	11.2
	100.0	100.0

Knowledge Test item	1964 (n = 761)	1970 (n = 663)
	Percent	
If you drive your car off the road in dry grass areas:		
Exhaust sparks can start a fire	18.3	17.8
Sparks made by contact of metal parts of the car with rocks can set fires	3.7	3.3
Both 1 and 2 are correct[1]	61.8	66.7
Neither 1 or 2 are correct	5.0	2.0
Do not know	11.2	10.2
	100.0	100.0
A sign in a National Forest that reads "Closed Area" means:		
That you may enter, but not smoke in the area	3.3	1.4
You may enter, but not build any campfires in the area	6.4	6.5
You may not enter the area[1]	74.3	80.2
You may not hunt or shoot within the area	5.6	3.3
Do not know	10.4	8.6
	100.0	100.0
Windy weather:		
Tends to put out fires	.3	.5
Affects only poorly built fires	.6	1.3
Makes necessary more precautions with fires[1]	97.1	94.9
Has little or no influence on fires	.4	.6
Do not know	1.6	2.7
	100.0	100.0
Prevention of man-caused forest fires ultimately depends upon:		
More and better trained personnel	6.4	7.4
More and better equipment	4.1	5.4
Public cooperation and recognition of personal responsibility[1]	80.2	74.8
Better techniques of fire fighting with the equipment we have	5.1	5.4
Do not know	4.2	7.0
	100.0	100.0
When you are in a National Forest area in California, the law permits you to:		
Never smoke or build campfires	2.4	1.5
Smoke, but never build campfires	1.8	.9
Smoke and build campfires only in areas so designated, during specified periods[1]	85.4	86.5
Smoke and build campfires only during the wet season	3.3	3.7
Do not know	7.1	7.4
	100.0	100.0

[1]Indicates correct response.

continued

Table 5–*Distribution of responses to items in the Knowledge Test, 1964 and 1970 surveys*–Continued

Knowledge Test item	1964 (n = 761)	1970 (n = 663)
	Percent	
"Humidity" is a measure of:		
Temperature of the air	7.5	7.1
Amount of rainfall that has fallen in last 24 hours	2.9	1.5
Percent of cloudiness during the daylight hours	.9	.8
Amount of moisture in the air[1]	81.2	81.4
Do not know	7.5	9.2
	100.0	100.0
"Watersheds" are:		
Areas where rain falls or snow melts to supply water to springs and creeks[1]	47.1	49.1
Structures over railroads for protection against heavy snow and rain	6.7	5.9
Buildings with gutters that run water to a cistern	3.4	3.4
Lakes and reservoirs which collect the water runoff from forests	20.4	18.6
Do not know	22.4	23.0
	100.0	100.0
The time of day that forest fires typically will spread most rapidly:		
Sundown to midnight	8.8	8.0
Midnight to sunrise	4.3	2.1
10 a.m. to sundown[1]	58.0	58.8
Sunrise to 10 a.m.	4.5	5.7
Do not know	24.4	25.4
	100.0	100.0
A fire is more apt to start where there is:		
Low temperature and low humidity	1.6	1.2
High temperature and low humidity[1]	62.6	63.4
High temperature and high humidity	21.9	22.3
Low temperature and high humidity	3.0	1.4
Do not know	10.9	12.7
	100.0	100.0
A fire in the rotten vegetation found on the forest floor:		
Burns very rapidly–almost like a dry gunpowder train	18.6	17.8
Smolders slowly as in punk or cotton with little or no visible smoke[1]	49.5	42.7
Burns slowly along the top of the ground with easily detected production of smoke	17.1	20.9
Will not burn at all	1.8	1.7
Do not know	13.0	16.9
	100.0	100.0
The chief cause of forest fires in Butte County is:		
Lightning	17.5	16.0
Campfires	5.9	10.3
Children playing with matches	3.0	11.4
Smokers' cigarettes and matches[1]	58.8	45.4
Do not know	14.8	16.9
	100.0	100.0
The term "forest fire" means a fire which is burning out of control on lands covered wholly or in part by:		
Timber only	7.1	3.2
Timber and brush only	22.9	17.8
Timber, brush, and grass only	25.2	23.5
Timber, brush, grass, grain or other flammable vegetation[1]	39.5	50.5
Do not know	5.3	5.0
	100.0	100.0
The people responsible for starting most forest fires are:		
Hunters	12.4	11.4
Hikers	4.5	4.1
Campers	45.5	44.1
Local residents[1]	10.4	14.9
Do not know	27.2	25.5
	100.0	100.0
Of the approximately 3,000 forest fires in California each year, what percent are human caused:		
10 percent	6.2	3.5
50 percent	19.4	17.7
70 percent[1]	26.8	30.4
90 percent	25.3	26.4
Do not know	22.3	22.0
	100.0	100.0
Campfire permits are required for the use of:		
Gasoline or propane type camp stoves	2.2	1.4
Fire grates and charcoal burners	1.2	4.7
Open campfires	28.6	45.3
All of these[1]	58.7	40.6
Do not know	9.3	8.0
	100.0	100.0

[1]Indicates correct response.

Table 6–*Comparison of Knowledge Test scores*[1] *of Butte County, California, residents, 1964 and 1970 surveys*

Knowledge Test Score (percent)	1964	1970
	No. respondents[2]	
Less than 50	257 (224)	162 (195)
50-64	185 (214)	216 (187)
65-74	203 (195)	162 (170)
75 or more	116 (128)	123 (111)
Total	761	663

[1]Mean scores (percent correct): 1964–58.1; 1970–57.6.
[2]Figures in parentheses show expected frequencies. Test of statistical significance yielded $x^2 = 22.11$, df = 3, $P < .001$.

Table 7–*Comparison of knowledge scores*[1] *of residents of different geographic divisions of Butte County, California, 1970*

Knowledge Scores (percent)	Zone		
	I	II	III
	No. respondents[1]		
Less than 50	22 (21)	29 (33)	111 (108)
50-64	28 (28)	44 (44)	144 (144)
65-74	22 (21)	28 (33)	112 (108)
75 or more	14 (16)	35 (25)	74 (82)
Total	86	136	441

[1]Figures in parentheses represent expected frequencies. Test of statistical significance yielded $x^2 = 6.49$, 6df, $.30 < P < .50$.

Because of their presumed differential exposure to wildfire risks and to fire prevention efforts, it was expected that residents in the various Zones would differ in their knowledge of fire prevention and fire use. The 1970 survey revealed no significant differences among these residents, however *(table 7)*. A similar comparison of residents from the area in which especially intensive fire hazard inspections were conducted (Folkman 1967, 1968) with those residing in Zone III resulted in differences that approached statistical significance *(table 8)*. Those from the experimental area tended to have higher scores.

Special tabulations were made, by cause, of the fire statistics for these areas which were subject to the intensive fire hazard inspection procedures *(table 9)*. They show a marked drop in the number of fires attributed to debris burning and to children playing with matches. These types of fires were the subjects of special concern in this aspect of the program.

Butte County residents still have a limited awareness of the forest fire incidence in their county. Half of the respondents in 1970 said they did not know the number of fires and nearly all who ventured an estimate fell far short of the actual number *(table 10)*. Even so, they were more inclined than those in 1964 to feel that the number was more than usual. Actually, the number in 1970 (214) was near the long-term average for the county, while the number in 1964 (331) represented the highest number in recent years.

The proportion of respondents in the two surveys who were familiar with the nature of fire danger in California (i.e., that it gets progressively higher throughout the season, with periods of extreme danger) was not markedly different, except for the proportions in 1970 who admitted they did not know *(table 10)*.

To measure attitudes regarding fire prevention and fire use in wildland areas, respondents were asked to express their agreement or disagreement with 18 statements dealing with these matters. Responses were in terms of a five-place scale ranging from "strongly agree" to "strongly disagree." Fifteen of the statements were identical to those used in the 1964 survey. Items 2, 10, and 18 were found to contribute little to the total statistical variance in the 1964 survey, and new items were substituted for them.

Table 8–*Comparison of knowledge scores of residents of BUCO experimental area*[1] *with Zone III*[2] *residents, Butte County, California, 1970*

Knowledge score (percent)	BUCO experimental area	Zone III
	No. respondents[3]	
Less than 50	4 (10)	111 (105)
50-64	16 (13)	144 (146)
65-74	10 (10)	112 (111)
75 or more	10 (7)	74 (77)
Total	40	441

[1]Area near Oroville, California, where special fire prevention activities were conducted.

[2]Valley lands having no Federal or State interest in timber, watershed, range, or soil erosion.

[3]Figures in parentheses represent expected frequencies. Test of statistical significance yielded $x^2 = 6.64$, 3df, $.05 < P < .10$.

Table 9–*Fires in BUCO experimental area*[1] *of Butte County, California, by causes, 1964-1972*

Cause	1964	1965	1966	1967	1968	1969	1970	1971	1972
Children/matches	12	7	9	16	12	5	6	4	4
Debris burning	12	13	17	8	3	2	5	5	3
Incendiary	1	1	1	8	2	3	6	1	1
Smoker	8	4	1	8	1	4	5	3	3
Structure	4	7	10	10	8	2	12	3	8
Miscellaneous	5	1	1	6	5	7	5	12	4
Total	42	33	39	56	31	23	39	28	23

[1]Area near Oroville, California, where special fire prevention activities were conducted.

Comparison of the responses to the individual items, common to both surveys, reveals what appears to be a strong decline in attitudes in the interval between the two surveys *(table 11)*. The difference represents a shift from a "strongly agree" to merely "agree," or, for those items negatively worded, from "strongly disagree" to "disagree." It should be recognized that attitude items of this type are notoriously unstable in distinguishing between adjacent categories. Consequently, the change in attitude between the two surveys may be more apparent than real. When the two categories in question are combined into one general "agree" response, the difference between the two surveys is no longer statistically significant.

Forty-one percent of the respondents in the 1970 survey felt the California Division of Forestry did an "excellent" fire prevention job, while 53 percent felt that the Division did a "satisfactory" job *(table 12)*. The respondents were asked to compare the job the Division had done in the past 3 to 4 years with that done before that time. Their responses seem to demonstrate that these people were aware that there had been changes in the operation of the Division during the test period (although, they were not aware of the experimental program, as such). And 55 percent of them felt that this change had been for the better *(table 12)*. Thirty-three percent said the Division had been doing "almost the same." Only a few gave a negative appraisal.

For the most part, these impressions were based on limited or indirect evidence.

Sixty percent of the respondents reported no contact with the State Division of Forestry during the period in question. Of those who reported contact the bulk considered the contact "satisfactory" or "very satisfactory." Most contacts reported were made through the process of obtaining a burning or

Table 10–*Impressions of forest fire incidence by Butte County, California, residents, 1964 and 1970 surveys*

Characteristics	1964	1970
	—Percent—	
Estimate of number of forest fires in Butte County during the past year:[1]		
Less than 25	20.9	20.4
25-49	8.1	5.7
50-99	8.1	5.1
100-199	10.7	7.5
200-299	6.6	3.9
300-499	4.3	2.1
500 or more	8.2	4.8
Don't know	33.1	49.1
Not reported	–	1.4
Total	100.0	100.0
Impressions of number of forest fires in the county during the past year:		
More than usual	8.8	21.0
About the same	20.0	47.0
Less than usual	45.6	21.7
Don't know	4.6	10.3
Not reported	–	–
Total	100.0	100.0
Fire danger in California:		
Stays uniformly high throughout the season	10.1	7.1
Gets progressively higher	19.2	22.6
Gets progressively higher, with periods of extreme danger	45.4	42.8
Reaches a peak then tapers off	20.4	13.9
Don't know	4.6	13.3
Not reported	.3	.3
Total	100.0	100.0

[1]Actual number of forest fires in 1964–331; in 1970–214.

Table 11–*Distributions of responses to items in the Attitude Test, 1964 and 1970 surveys*

Attitude Test item	1964 (n = 761)	1970 (n = 663)
	Percent	
1. Fire prevention instruction should be given to each person applying for a campfire permit:		
Strongly agree	60.0	33.3
Agree	35.2	58.8
Undecided	2.5	2.6
Disagree	2.0	5.1
Strongly disagree	.3	.2
Don't know, or no answer	–	–
	100.0	100.0
2. The National Forests belong to the public and people should be free to come and go as they please in them:		
Strongly agree	15.9	
Agree	31.3	
Undecided	9.8	
Disagree	30.5	
Strongly disagree	12.1	
Don't know, or no answer	.4	
	100.0	
Even though in an experienced camper's judgment it is perfectly safe to build a campfire, he nevertheless should be punished if he does so in a prohibited area:[1]		
Strongly agree		18.4
Agree		72.1
Undecided		3.0
Disagree		4.5
Strongly disagree		2.0
Don't know or no answer		–
		100.0
3. People who are careless with fire should be severely punished:		
Strongly agree	40.0	25.9
Agree	46.3	62.1
Undecided	10.2	7.9
Disagree	3.0	3.6
Strongly disagree	.1	.3
Don't know, or no answer	.4	.2
	100.0	100.0
4. Preventing forest fires is none of my concern:		
Strongly agree	2.1	1.3
Agree	3.8	3.9
Undecided	1.4	2.3
Disagree	42.2	62.5
Strongly disagree	50.1	30.0
Don't know, or no answer	.4	–
	100.0	100.0
5. Observing fire prevention rules is more important than obeying traffic regulations:		
Strongly agree	6.2	4.5
Agree	14.8	20.2
Undecided	38.5	33.2
Disagree	34.0	35.6
Strongly disagree	5.2	5.1
Don't know, or no answer	1.3	1.4
	100.0	100.0
6. I should report people who break fire prevention rules in forest or brush areas:		
Strongly agree	29.0	14.9
Agree	59.7	76.0
Undecided	8.7	5.7
Disagree	2.2	2.3
Strongly disagree	.3	.6
Don't know, or no answer	.1	.5
	100.0	100.0
7. "Smokey Bear" does a poor job of alerting the public to fire dangers:		
Strongly agree	2.3	2.0
Agree	4.9	9.8
Undecided	5.3	10.2
Disagree	58.8	61.5
Strongly disagree	28.7	15.6
Don't know, or no answer	–	.9
	100.0	100.0
8. Fire prevention literature is a waste of taxpayers' money:		
Strongly agree	2.5	1.1
Agree	2.0	9.8
Undecided	4.3	5.9
Disagree	61.9	71.5
Strongly disagree	29.2	11.3
Don't know, or no answer	.1	.4
	100.0	100.0
9. More space in school textbooks should be given to fire prevention:		
Strongly agree	17.0	8.1
Agree	48.9	59.7
Undecided	21.2	21.1
Disagree	8.5	8.8
Strongly disagree	.9	–
Don't know, or no answer	3.5	2.3
	100.0	100.0
10. Applicants for campfire permits should be required to pass an examination just as they do for a driver's permit:		
Strongly agree	16.2	
Agree	44.7	
Undecided	13.0	
Disagree	24.0	
Strongly disagree	1.8	
Don't know, or no answer	.3	
	100.0	

continued

Table 11–*Distributions of responses to items in the Attitude Test, 1964 and 1970 surveys*–Continued

Attitude Test item	1964 (n = 761)	1970 (n = 663)
	—— *Percent* ——	
Because things "just happen," there is no point in attempting to prevent fires and other accidents:[1]		
Strongly agree		1.2
Agree		3.0
Undecided		5.4
Disagree		61.2
Strongly disagree		28.8
Don't know, or no answers		.4
		100.0
11. School should not be permitted to use school time for instruction in forest fire prevention:		
Strongly agree	1.6	1.1
Agree	4.7	8.0
Undecided	4.7	4.8
Disagree	64.1	68.2
Strongly disagree	24.4	17.6
Don't know, or no answer	.5	.3
	100.0	100.0
12. Everyone should be required to attend a meeting at least once every three years, where he would get information and instruction on fire prevention:		
Strongly agree	14.4	3.9
Agree	40.2	47.2
Undecided	13.9	13.3
Disagree	27.5	32.4
Strongly disagree	3.7	3.0
Don't know, or no answer	.3	.2
	100.0	100.0
13. I would like to see school children bring home fire prevention literature from school:		
Strongly agree	16.8	8.7
Agree	68.5	76.6
Undecided	7.9	9.8
Disagree	5.4	4.1
Strongly disagree	.4	.2
Don't know, or no answer	–	.6
	100.0	100.0
14. Fire prevention people should establish closer relations with the Boy Scouts and similar organizations:		
Strongly agree	23.8	11.8
Agree	62.6	77.8
Undecided	10.2	7.2
Disagree	2.5	2.6
Strongly disagree	.4	–
Don't know, or no answer	.5	.6
	100.0	100.0

Attitude Test item	1964 (n = 761)	1970 (n = 663)
	—— *Percent* ——	
15. Rangers should have much more important things to do than going around checking on forest visitors:		
Strongly agree	2.5	.8
Agree	8.9	9.2
Undecided	7.6	6.9
Disagree	62.2	72.4
Strongly disagree	18.3	10.3
Don't know, or no answer	.5	.4
	100.0	100.0
16. Fire prevention efforts in forests are money well spent:		
Strongly agree	39.0	19.0
Agree	57.1	75.3
Undecided	2.8	3.3
Disagree	.6	2.0
Strongly disagree	.1	.3
Don't know, or no answer	.4	.1
	100.0	100.0
17. Forest fire danger in this area is highly overrated:		
Strongly agree	2.0	1.3
Agree	5.4	5.6
Undecided	18.4	11.8
Disagree	56.2	68.3
Strongly disagree	16.3	11.9
Don't know, or no answer	1.7	1.1
	100.0	100.0
18. All persons entering a forest area should be required to register:		
Strongly agree	19.6	
Agree	45.0	
Undecided	11.3	
Disagree	21.4	
Strongly disagree	2.4	
Don't know, or no answer	.3	
	100.0	
You don't have to worry about the woods, Mother Nature will always take care of the trees:[1]		
Strongly agree		.8
Agree		5.0
Undecided		1.5
Disagree		60.3
Strongly disagree		32.4
Don't know, or no answer		–
		100.0

[1] In the 1970 survey this item was substituted.

Table 12–*Impressions of the Butte County residents of fire prevention efforts by the California Division of Forestry (CDF) in Butte County, California, 1964 and 1970 surveys*

Characteristics	1964	1970
	Percent	
The fire prevention job done by the CDF is:		
Excellent	(1)	41.0
Satisfactory		53.4
Poor		2.0
Don't know		3.3
Not reported		.3
Total		100.0
How has the CDF done during the past 3-4 years:		
A much better job	(1)	13.4
A better job		41.7
About the same		32.7
A poorer job		.4
A much poorer job		.3
Don't know		11.5
Not reported		–
Total		100.0
Nature of contact with CDF:		
Obtaining burning or campfire permit	(1)	15.7
Social contact		7.1
Contact at campsite		5.4
Investigation of fire or fire regulation violation		3.8
Seeking advice or information		3.3
Occupation brings into contact		3.0
Routine inspection for fire law compliance		.9
Through schools		.8
Through mass media		.4
Inspection of equipment		.4
Public meeting		.2
Don't know		61.2
Not reported		.6
Total		(2)

Characteristics	1964	1970
	Percent	
Contacts with CDF:		
Very unsatisfactory	(1)	2.3
Unsatisfactory		.3
Neutral		1.7
Satisfactory		18.7
Very satisfactory		14.8
Mixed, both satisfactory and unsatisfactory		2.4
Don't know		.2
No contact		59.6
Total		100.0
Fire prevention job done by schools is:		
Excellent	19.7	9.4
Satisfactory	42.3	51.7
Poor	13.9	17.2
Don't know	24.1	20.8
Not reported	–	.9
Total	100.0	100.0
How have the schools done during the past 3-4 years:		
A much better job	(1)	6.9
A better job		25.6
About the same		34.5
A poorer job		2.7
A much poorer job		.8
Don't know		29.2
Not reported		.3
Total		100.0
Fire Control Laws in the State are:		
Too strict	.8	.6
Not strict enough	39.8	49.2
About right	53.6	46.1
Don't know	5.8	3.5
Not reported	–	.6
Total	100.0	100.0
Enforcement of such laws is:		
Too strict	.1	.7
Not strict enough	38.2	48.7
About right	54.7	44.5
Don't know	7.0	5.9
Not reported	–	.2
Total	100.0	100.0

[1] Question not asked in 1964 survey.

[2] Does not total 100 percent because multiple responses reported.

campfire permit *(table 12).* The next most frequent type of contact mentioned was as a friend or relative of Division personnel in social relationships. Another frequent mention was contact at campsites. (There is always a certain amount of confusion of government agencies in the public mind. Some of these contacts at campsites may actually have been with U.S. Forest Service personnel rather than representations of the State Division of Forestry. However, Division personnel were involved in inspecting use of recreation facilities about Lake Oroville.)

Over 60 percent of the respondents in both 1964 and 1970 were favorably impressed with the job in fire prevention education for children being done in the schools *(table 12).* The proportion considering the job "excellent" was only half as large in 1970 as it was in the original survey, however. Still, 33 percent felt that the schools had been doing a better job during the past 3-4 years as compared to earlier. An additional 34 percent felt the schools were doing about the same, while nearly all of the remaining one-third said they did not know.

An increased percentage of the respondents in 1970 survey judged that fire control laws in California were not strict enough and that their enforcement was likewise, not strict enough *(table 12).*

DISCUSSION

A fire prevention program has the obvious goal of reducing the number of undesired, uncontrolled fires in wildland areas. To expect such a program to *eliminate* all these fires would be patently unrealistic. But how many, or what proportion is a reasonable goal? Although not explicitly expressed, expectations from this study were undoubtedly unrealistically high. Fire prevention has been actively promoted in California and nationally for a number of years. The higher the level of fire prevention already achieved, the harder it is to make significant changes. The easy gains have already been made. The analogy might be made to providing potable water in a community which has been accustomed to using polluted water. Dramatic reduction in mortality will result. However, in a community with relatively good public health practices, each new gain in reduction of morbidity and mortality can be achieved only at the expense of increased effort and complex developments.

From previous experience it was considered infeasible to measure the effect of the program solely in terms of changes in absolute or relative numbers of fire starts. Effectiveness was to be determined by using indirect criteria (knowledge and attitudes concerning fire and its use) which were assumed to be related to actual fire associated behavior. There was no implication of a one-to-one relationship between attitude/knowledge levels and fire related behavior. That some relationship might be expected is evidenced by a large body of social science research. However, questions concerning the actual relationship between behavior and knowledge and/or attitude states become academic in this instance, as the before and after surveys reveal very little influence of the program on either knowledge or attitudes.

The failure of the test instruments to detect significant changes resulting from the intensive prevention program mounted in Butte County was disappointing. The program was experimental. Objectively, failure should be as acceptable as success. However, involvement in such an endeavor results in the participants developing vested interests in its success. And that interest is to find *positive* effects and not *negative* effects or no effects at all. The first impulse is to question the validity of the study—did the test instruments really tap the significant dimensions of the situation. If only disproportionately small improvements over existing programs are possible, more high-powered evaluation methods may well be needed to demonstrate effectiveness.

With the 20-item multiple choice instrument used to test knowledge of fire prevention and fire behavior, the mean scores from the before and after surveys did not differ significantly. The distribution of scores, however, was significantly different. The program appears to have been effective in reducing the proportion of respondents receiving very low scores (below 50 percent correct) and increasing the proportion receiving high scores (75 percent or more correct).

If these results do not meet expectations, it should be recognized that the main thrust of the experimental fire prevention program was in operation during two seasons only: 1968 and 1969. Education is a slow, continuous process, and modification of behavior depends on repeated reinforcement. In this educational program, efforts were directed primarily toward changing autonomous individuals, a process less amenable to rapid change than one involving changes in institutions or technology under tight control. In addition, much of the direct educational effort of the program was aimed at children in the early elementary grades. They were not included in the survey sample. And although the efforts expended might be expected to show up in reduction of children-induced fires, most of the response could be expected to manifest itself much later in the fire-related behavior of the children involved over a period of years.

Another factor to be considered is that the prevention program eventually implemented in Butte County was quite different from the one anticipated in the planning stages. The knowledge items used in the survey had been developed primarily in relation to problems associated with the recreational use of fire in National Forest-type situations. The prevention program that eventually evolved was focused on the main fire problems in State-protected areas, namely, home-centered fire activities such as debris burning, incinerator misuse, and related practices. If this orientation of the program had been anticipated, the test instruments might have more faithfully reflected the thrust of the program.

The experimental program in Butte County was not conducted in a social vacuum. The forces affecting the rest of the nation at that time impinged to some degree at least on the locus for the experiment. The 1960's were disturbed by civil and racial strife, youth revolt, assassinations of popular leaders, a long and controversial war, ecological crises, and other manifestations of social and political unrest. Forces of this magnitude might have accounted for most of the change noted in the responses to attitude items between the two surveys. The pervasive feeling that nothing was "very good" could well produce the shift from the most positive response, "strongly agree" in 1964, to merely "agree" in the 1970 survey. And the shift was probably not related to the experimental program at all.

That the over-all effects of the program were, in fact, positive is attested by the feeling on the part of more than 40 percent of the respondents that the Division of Forestry had done an "excellent" job during the test period, and nearly all rated the Division's job at least "satisfactory." They also recognized changes for the better in recent years. It is important to recognize, also, that despite the extensive efforts of the experimental personnel, contacts with the general public, as perceived by this public, still were limited and indirect in nature.

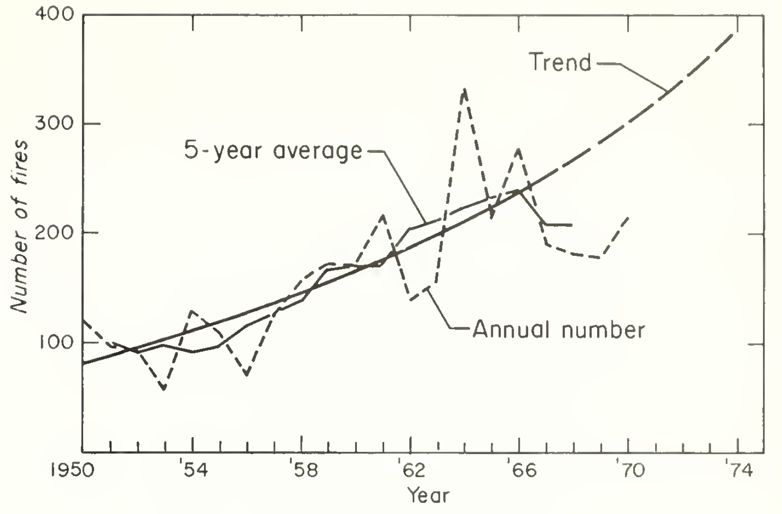
An examination of the fire records for Butte County showed a marked decline in number of man-caused forest fires in 1968 and 1969 *(fig. 3; table 13).* The departure from the expected was sufficiently great to suggest that, contrary to forecasts, the prevention program may have produced a reduction in fire starts for that period that was perceptable despite the large, and only grossly measurable, effects of various climatological and other variables. To determine if this observed departure from the anticipated was as real as it was apparent a comparison was made with neighboring counties (Nevada, Placer, Shasta, Tehama, and Yuba counties). I assumed that fire starts in Butte County would be linearly related to starts in these neighboring counties. I also assumed that other factors influencing fire starts in these counties would be comparable. Regression equations for fire starts in Butte County in terms of starts in the

Table 13–*Forest fires in Butte Ranger Unit, Zones I and II,*[1] *by cause, 1958–70*

Year	Lightning	Campfire	Smoking	Debris	Incendiary	Machine	Misc.	Man-caused	Total
1958	18	4	51	27	25	6	43	156	174
1959	9	6	47	17	20	15	67	172	181
1960	72	1	81	24	19	4	42	171	243
1961	7	4	83	28	33	5	63	216	223
1962	4	1	46	21	14	5	53	140	144
1963	3	3	56	25	25	16	31	156	159
1964	3	2	105	48	60	50	66	331	334
1965	15	3	50	35	28	43	56	215	230
1966	9	2	87	40	33	37	80	279	288
1967	10	5	39	28	51	17	51	191	201
1968	1	13	28	30	41	25	45	182	183
1969	63	5	28	17	59	31	39	179	242
1970	14	9	49	28	47	26	55	214	228
Average	17.5	4.5	57.7	28.3	35.0	21.5	53.2	200.1	217.7

[1]Lands consisting of forests or forested watersheds under State protection.

Figure 3—Man-caused forest fires in the Butte Ranger Unit of California fluctuated, by years, in lands classified as Zones I or II—areas of forests or forested watersheds under State protection, 1951-1970 (adopted from Moore 1970).



neighboring counties were derived by using available data for the years 1958 through 1967. These equations were used to predict fire starts in Butte in 1968 and 1969. Whether the change in fire starts in Butte County during the period of intensive fire prevention activity were significant could not be conclusively determined.

The resurvey of levels of knowledge and attitudes in fall 1970 marked the formal ending of the BUCO Project. No new research was planned, but for several years thereafter, the fire situation in Butte County is being monitored to determine if a new plan of fire prevention staffing could maintain the level of control achieved by the larger staff.

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Folkman, William S.

1973. **Fire prevention in Butte County, California . . . evaluation of an experimental program.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 23 p., illus. (USDA Forest Serv. Res. Paper PSW-98)

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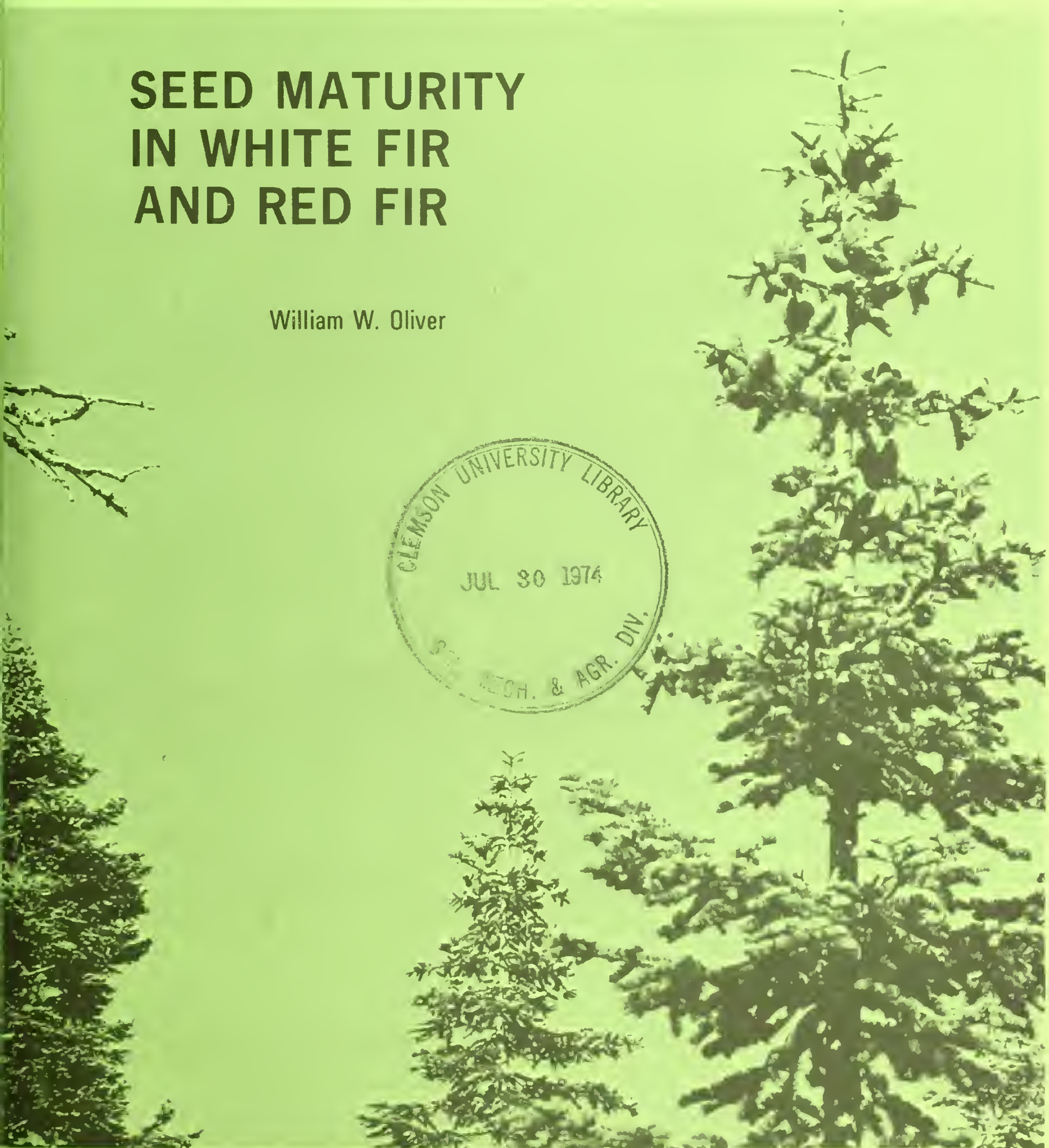
PACIFIC SOUTHWEST Forest and Range Experiment Station

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE
P.O. BOX 245, BERKELEY, CALIFORNIA 94701

SEED MATURITY IN WHITE FIR AND RED FIR

William W. Oliver



USDA FOREST SERVICE RESEARCH PAPER PSW-99 /1974

CONTENTS

THE AUTHOR

WILLIAM W. OLIVER is doing silvicultural research on Sierra Nevada conifer types with headquarters at Redding, California. He earned a B.S. degree (1956) in forestry from the University of New Hampshire, and an M.F. degree (1960) from the University of Michigan. A native of Pennsylvania, he joined the Station in 1962, after working for the Michigan Department of Natural Resources.

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I thank the California Division of Forestry for the use of the Latour State Forest in the study reported in this publication.

SUMMARY

Oliver, William W.
1974. *Seed maturity in white fir and red fir.* Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 12 p., illus. (USDA Forest Serv. Res. Paper PSW-99)

Oxford: 232.218:232.312.1 [+ 174.7 *Abies concolor* + 174.7 *Abies magnifica*].
Retrieval Terms: Abies concolor; Abies magnifica; germination tests; cone collection; Latour State Forest; California.

Low viability of white fir and red fir seeds often is the result of collecting immature seeds. Seed handlers need to know when acceptable seed viability is reached in the maturing cone. For this they need easily measured cone and seed characteristics that indicate this point has been reached. In this study, several cone and seed characteristics were evaluated as maturity indices for white and red fir. A limited test of artificially ripening white fir cones was also made.

Cones from six white fir and eight red fir trees on the west slope of the southern Cascade Range in northern California were collected biweekly in 1967. Collections began on August 15 and ended October 9—3 days before seed fall began. Cone specific gravity and several other cone and seed characteristics were measured for each collection, and seed germination was tested on both freshly harvested and stratified seeds.

White fir and red fir cone specific gravities were similar in pattern. Both held nearly constant until mid-September, but then dropped rapidly until seed fall began on October 12. In contrast, white fir and red fir seed germinability exhibited different patterns. There was little difference in pattern, however, between freshly harvested and stratified seeds of the same species. No seeds of either species germinated from cones collected in mid-August. White fir seed germinability increased rapidly in collections made up to mid-September and then tended to level off. Red fir seed germinability, however, tended to increase steadily for collections made up to the beginning of seed fall. In both firs, stratifying seeds affected germination capacity very little, but increased germination rate profoundly.

In 1968, biweekly cone collections were repeated in red fir and the vigor of red fir seedlings from stratified seed was tested. Both ovendry weight and proportion of healthy seedlings increased significantly until mid-September, and then nonsignificantly until seed fall began on October 8.

A limited test of artificially ripening white fir seeds was successful. Cones collected in mid-September—4 weeks before seed fall—and stored in a cool, moist environment for 4 weeks yielded seed which germinated as completely and speedily as stratified seeds from mature cones. This result supports the observation by others that maturation of seeds of many true firs can be completed independently of the tree. Storing immature white fir cones 2 weeks beyond beginning of seed fall boosted both speed and completeness of germination beyond that of stratified seeds from mature cones. This suggests that white fir requires some after-ripening for maximum germinability.

Many cone and seed characteristics were observed in an attempt to find a simple, effective index of cone and seed ripeness. Specific gravity was significantly correlated with nearly all measures of seed germination in both firs. Results indicate that white fir cones can be collected when cones average about 0.96 specific gravity—a point reached about 3½ weeks before seed fall began. A firm recommendation is more difficult to make for collecting red fir cones. Unlike that of white fir, red fir seed germinability continued to increase up to the beginning of seed fall. Nevertheless, we may conclude that red fir cones should not be picked if their average specific gravity exceeds 0.75—reached about 2 weeks before seed fall began in this study. To obtain a reliable estimate of average cone specific gravity at least three cones from each of four trees should be measured.

A method combining several seed characteristics seems more direct and simpler than using cone specific gravity as an index of seed maturity. White and red fir cones should be ready for harvest when

1. Seed wings are uniformly brown with a deep magenta edge.
2. Seeds are free or only loosely attached to cone scale.
3. Embryos are uniformly pale yellow-green.
4. Embryos entirely fill embryo cavities.

The ratio of embryo length to the length of the embryo cavity was the single most useful index of seed maturity found. Future studies should aim towards verifying this characteristic as a seed maturity index for all conifers.

The demand for white fir *(Abies concolor* Gord. & Glend.) and red fir *(A. magnifica* A. Murr.) seeds increases each year in response to increasing demands for planting stock. Often, forest nurseries cannot fill all requests for true fir seedlings.

Low viability of the seed is a major problem. Lanquist (1946) concluded that the relatively low germination he found in these two species probably was the result of seed immaturity. He warned that germinative capacity of seed is so vitally affected by time of cone harvest that this time must be selected with extreme care, especially when cones are collected on logging operations or on any down trees. To help solve this problem, forestry research must determine when acceptable seed viability is reached in the maturing cone, and find some easily measured characteristics of the cone or seed that indicate this point.

This paper explores the usefulness of cone specific gravity and several other cone and seed characteristics as maturity indices of white and red fir seeds, and reports a limited test of artificial ripening of white fir cones.

METHODS

Seeds tested in 1967 came from six white and eight red fir trees in a mixed stand at 6,000 feet elevation on the Latour State Forest. The Forest lies on the west slope of the Cascade Range, 37 miles east of Redding, California. The trees were vigorous, full-crowned specimens ranging from 48 to 92 years of age and from 14 to 28 inches d.b.h.

At least four cones were collected at random from each tree. Five biweekly collections began on August 15 for red fir and on August 17 for white fir. The last collection was on October 9 for both species–3 days before seed fall began.

In 1968, some tests were repeated on red fir because five of the eight sample trees had good repeat cone crops. Four nearby trees of similar size and age with abundant cones were selected for additional sampling. This time cones were collected at four biweekly intervals beginning on August 23 and ending September 30–8 days before red fir began casting seed.

At each collection, cones of each species were sealed in plastic bags immediately, and specific gravity was determined within 24 hours by the weight displacement method. The cones were grouped, then, into specific gravity classes, using an interval of 0.04 for white fir and 0.05 for red fir.

Testing Fresh Seeds

Germinability of freshly-harvested seed should measure its physiological maturity at time of collection. Therefore, at each collection (1967) half the cones in each specific gravity class were broken open, and the seeds were removed by hand. All insect-infested, broken, and aborted seeds were discarded; only seeds that appeared sound were kept for testing. Germination testing was begun within 24 hours of collection on four 100-seed samples of each specific gravity class. The seeds were kept moist during extraction and cleaning to prevent the possibility of inducing dormancy through drying of the seed coat (Kozlowski 1971). The samples were placed on a moist medium of two parts vermiculite and three parts sand in petri dishes placed in a darkened room held at 24 degrees C. for 100 days.

At the end of the 100-day germination period for each collection date, I attempted to determine the number of filled seeds in the ungerminated remainder. But many seeds had been destroyed by molds during the long germination test, and distinguishing between originally filled and empty seeds was difficult. Therefore, germination results are presented as a proportion of all seeds used in the test. Germination of stratified seeds is reported similarly to aid in comparing results.

Testing Stratified Seeds

Germination testing of fresh seeds may measure physiological maturity at time of cone collection but results do not represent the germination that can be expected in practice, because fresh seeds are not usually planted. Therefore, the remaining half of the cones of each specific gravity class at each collection were processed by methods similar to those used by commercial nurseries. Soon after specific gravity was determined, the fresh cones were spread on open racks in a well-ventilated room held at 24 degrees C. until the cones from all collections were completely dry. The cones were broken by tumbling, cone scales removed, seeds dewinged, and all apparently unsound seeds discarded. Four 100-seed samples from each specific gravity class collected on each collection date were stratified for 4 weeks at 2 degrees C. Following stratification, germination was tested by the methods used for fresh seeds, except that this test ran for only 30 days.

Seedling Vigor Tests

Germination is only the first step in producing a healthy seedling. Many hazards which can be lethal to seedlings with poor vigor must be overcome in the first few months. Red fir seedling vigor was tested in 1968 as follows: As seeds germinated in the germination test they were planted in flats containing two parts vermiculite and three parts sand. Planting was arranged in four randomized blocks with each block containing seed taken from one petri dish from each collection-date–specific-gravity class combination. The seedlings were grown in a greenhouse held at 25 degrees C. The test terminated 6 weeks after the end of the 30-day germination test. At the end of the test, seedlings were categorized as healthy, dead, or having the seed coat still adhering to the cotyledons (an indication of poor vigor). Healthy seedlings were carefully lifted from the flats, washed, and the ovendry weight determined.

Artificial Ripening Trial

Since true fir cones become fragile as they approach maturity, methods of artificially ripening seed from immature cones have been explored. Storing seed in cones placed in a cool, moist environment has increased germination of Douglas-fir *(Pseudotsuga menziesii* Mirb. Franco*)* (Silen 1958; Rediske 1961), noble fir *(Abies procera* Rehd.*)* (Rediske and Nicholson 1965; Edwards[1]) and grand fir *(A. grandis* [Dougl.] Lindl.*)* (Pfister 1966). Accordingly, in this study, the response of white fir and red fir cones to a similar treatment was tested.

Three additional cones from each sample tree were collected on August 17 and September 14 for white fir and on August 15 and September 12 for red fir. (Artificial ripening was not tested on the September 12 collection of red fir cones, however; these were found to be necessary to complete the seed maturity studies because of the low percentage of sound seed.) The cones were dipped in a water suspension of 50 percent Captan[2] and all, except the 0 week treatment, placed in individual, tightly-sealed plastic bags in a refrigerator at 10 degrees C. for the following time periods:

August 15 and 17 collections	*September 14 collection*
4 weeks	4 weeks
8 weeks	6 weeks

After each of the prescribed storage periods one cone from each tree was removed, the cones were air dried, seeds were removed and cleaned, and germination was tested for 30 days, duplicating the procedure described above for stratified seeds.

Other Observations

During hand extraction of seeds from fresh cones, five possible indices of seed maturity, other than cone specific gravity, were examined—seed wing color, firmness of attachment of the seeds to the cone scale, megagametophyte consistency, embryo color, and the ratio of embryo length to the length of the embryo cavity. Cone and seed wing colors were recorded by using Munsell (1952) color ratings. The firmness of attachment of the seeds to the cone scale was noted as firm, moderately firm, or loose. Megagametophyte consistency was recorded as milky or firm.

The ratio of embryo length to the length of the embryo cavity was measured on at least 50 filled seeds of each specific gravity class for each collection date. The seeds were broken open lengthwise and lengths were measured to the nearest 0.5 millimeter. The ratio of embryo length to the length of its cavity seems to be a better measure than embryo length alone because use of the ratio eliminates variability caused by differences in seed size. As the embryo was measured, morphological development and color of the cotyledons were noted.

[1] Edwards, David George Warrilow. *Investigations on the delayed germination of noble fir.* 1969. (Unpublished Ph.D. thesis on file at Univ. of Wash., Seattle, Wash.)

[2] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

RESULTS AND DISCUSSION

Cone Specific Gravity

In 1967, white fir and red fir cone specific gravities were similar in pattern *(fig. 1)*. The range for both species held almost constant in collections from mid-August through the end of the month. By mid-September average values had dropped slightly to 0.99 for white fir and 0.96 for red fir. The drop was not statistically significant,[3] however, until the end of September, when average values were 0.76 for white fir and 0.75 for red fir. On October 9, just 3 days before seed fall began, the average specific gravity had fallen to 0.57 for white fir and 0.60 for red fir.

In 1968, the pattern of red fir cone maturity was different. Average cone specific gravity had dropped significantly by the September 3 collection, nearly 3 weeks earlier than in 1967. Values continued to drop, but at a rate slightly lower than in 1967. By September 31, the average specific gravity of 0.66 was nearly identical to that of the year before at the same date.

[3]Differences between means exist at the 5 percent level of probability.

In both years, the between-tree variation in cone specific gravity in sample trees of each species was narrow until the values dropped significantly. While average specific gravity was dropping rapidly, the range in values widened. As cones reached their minimum values at the beginning of seed fall, the range tended to narrow again. Analyses of variance indicated that the pattern of decreasing cone specific gravity differed between trees.

Seed Germination, by Collection Date

Fresh Seeds

None of the seeds of either species collected in mid-August germinated, nor were any seeds living at the conclusion of the 100-day germination test. Fourteen percent of the white fir seeds in the late August collection germinated *(table 1)*. Seed collected in mid-September showed a further significant increase in germination, this time to 30 percent. Germination remained at this level for the succeeding collections.

Red fir seed germinated in a slightly different pattern *(table 1)*. Germination increased steadily to 11

Figure 1—Cone specific gravity decreases rapidly as beginning of seed fall approaches.

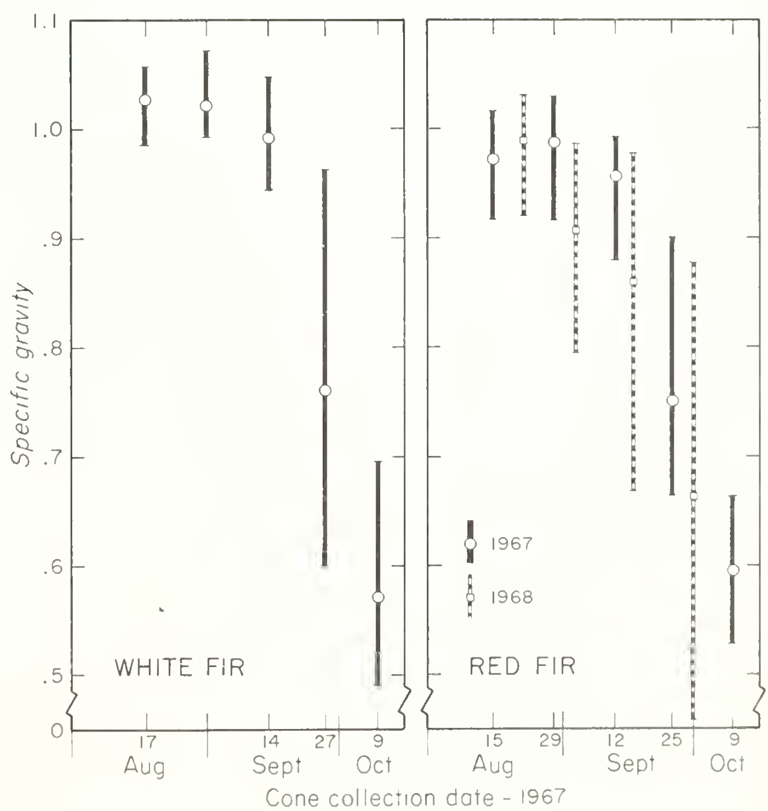

Table 1–*Germination of both fresh and stratified seeds of white and red fir by collection date, 1967*[1]

Collection date	Fresh seed		Stratified seed	
	Total germination	Peak germination	Total germination	Peak germination
	Pct.	*Days*	*Pct.*	*Days*
WHITE FIR				
August 17	0	–	0	–
August 31	14	68	17	8
September 14	30	54	26	11
September 27	33	52	36	9
October 9	31	52	39	8
RED FIR				
August 15	0	–	0	–
August 29	6	86	5	10
September 12	11	82	8	18
September 25	10	68	20	18
October 9	19	58	17	8

[1]Means not significantly different at 5 percent level are bracketed.

percent for the mid-September collection, remained at this level for the late September collection, then jumped to 19 percent for seed collected just before seed fall began. Variation in the data was high, however, preventing these differences from being statistically significant.

For seedling production, germination rate (the time required for germination) is as important as percent germination. In some situations, such as direct seeding, it is more important. The measure used here is the number of days required to reach peak germination. Peak germination is the maximum value found by dividing the cumulative germination percent on any one day by the number of days required to reach this percent. It differs from the measure proposed by Czabator (1962) in that percent germination is based on the total seeds used in the test rather than on filled seeds only.

Germination of fresh seeds was sluggish for all collections. In white fir, peak germination was not reached until the 68th day for the late August collection. The mid-September collection took 54 days to reach its peak value, a significant decrease. Germination rate, like percent germination, did not improve in later collections.

Again, the peak germination pattern differed in red fir. Peak germination was reached on the 86th day for the late August collection, and remained about constant through the mid-September collection. Peak germination for the late September collection was reached in 68 days, a significant decrease. It decreased again, but nonsignificantly, in the early October collection.

Stratified Seeds

Germination of stratified seeds of both species followed the general pattern for fresh seeds. Again, no seeds germinated from cones collected in mid-August. Germination from white fir cones collected in late August was 17 percent. It increased steadily with each succeeding collection date until it reached 39 percent for the early October collection. High variance within collections prevented these means from being significantly different, however.

Red fir seed germination was tested both in 1967 and in 1968. In both years, germination tended to increase with increasing cone maturity up to late September. But, in both years, the variation within collections was so great that except for the mid-August collection in 1967, collection means were not significantly different.

After mid-August, germination rate was unaffected by date of cone collection. Stratified white fir seeds took about 9 days to reach peak germination. Red fir took 14 days in 1967 and 26 days in 1968 to reach peak germination.

Stratification had little effect on germinative capacity. Results were similar to those for fresh seeds of each collection. The capacity of white fir (U.S. Forest Service 1948) and red fir seeds[4] to germinate fairly well without stratification has been reported previously. Nevertheless, fresh seed germination was higher than expected considering that these seeds had been tested for 100 days, a time period that led to

[4]See footnote 1.

more severe problems with mold than were encountered in the 30-day test.

It is likely that greater mortality from mold in the fresh seed test was offset by continued maturation and subsequent germination of the fresh seeds in the germination medium. Krugman (1966) hypothesized that maturation of sugar pine seed consists of two distinct periods: First, an early period in which the cones continue to provide organic materials necessary for seed maturity; and second, a period of continued maturation (often confused with "after ripening") after the accumulation of organic materials has been completed. Krugman concluded that during this second period the cone is not needed. Extracted seed will mature if simply stored in a moist medium.

Rediske and Nicholson (1965) reached a conclusion similar to Krugman's from their work on noble fir, except that they were uncertain whether the cone was necessary, not having tested extracted seeds. Stratified seeds were obtained from cones allowed to air dry. Maturation ceased when the cone dried, eliminating the second maturation period and cutting short the first period in earlier collections. Tests of neither fresh nor stratified seeds accurately measured physiological maturity at time of collection, but the stratified seed test may have been the more accurate of the two.

In the present study, in contrast to its lack of influence on percent germination, stratification had a pronounced effect on germination rate. Peak germination of stratified seeds was reached 47 days earlier in white fir and 60 days earlier in red fir than it was in the corresponding fresh seed tests. The pattern prominent in fresh seed (greater germination rate for seed samples whose collection dates approach the beginning of seed fall) was not seen in stratified seed.

It is difficult to explain why germination rates in stratified seed tests did not show this pattern. The study design may have been partly responsible. The seeds in all collections for stratified seed tests were cleaned at the same time. Thus, the cone (and seed) drying period was shorter for cones collected on dates closer to the beginning of seed fall. This may have resulted in elimination of more seeds of poor vigor from the earlier collections than from the later ones. Such low-vigor seeds would be expected to germinate sluggishly, and their absence may have affected the data pattern.

Seed Germination and Cone Specific Gravity

The correlation of seed germination with cone specific gravity was examined in the data according to specific gravity classes. The relation of germinative capacity to cone specific gravity was distinctly different in the two species, but similar in fresh and stratified seeds of the same species. Germination percentages for both fresh and stratified white fir seeds rose rapidly to about 30 percent, whereas cone specific gravity values dropped to 0.96. Germination of fresh seeds remained near 30 percent whereas corresponding cone specific gravities dropped further. Germination of stratified seeds, however, tended to increase gradually to about 45 percent for seed samples representing the lightest specific gravities *(fig. 2)*.

Germinative capacity of red fir was linearly related to cone specific gravity. The relationship was nearly identical for fresh and stratified seeds. Germination

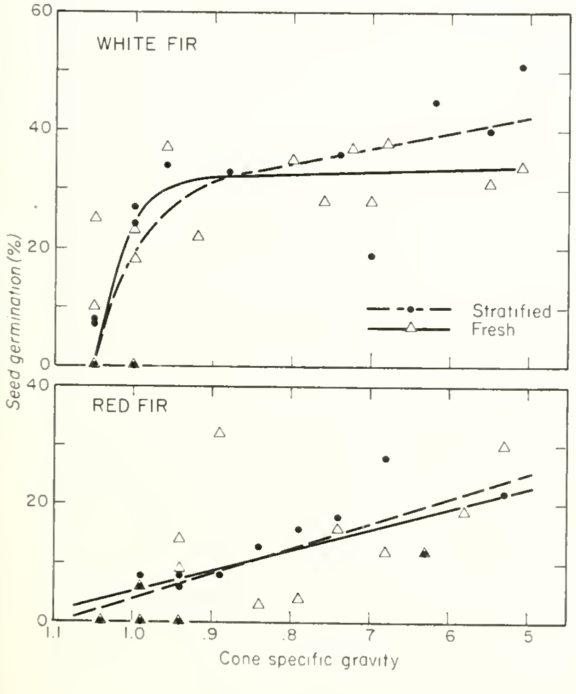

Figure 2—The relation between germinative capacity and cone specific gravity differed in the two species. In white fir, germinative capacity increased rapidly for successive classes of specific gravity, then tended to level off. In red fir, germinative capacity increased gradually.

Table 2–*Correlation coefficients of seed germination for both fresh and stratified seeds on cone specific gravity*

Species	Fresh seeds		Stratified seeds	
	Total germination	Days to peak germination	Total germination	Days to peak germination
White fir	0.66**	0.64*	0.79**	0.55*
Red fir	.57*	.84**	.84**	.40

* Statistically significant at 5 percent level.
** Statistically significant at 1 percent level.

values rose gradually to about 25 percent for both fresh and stratified seeds from cones with the lightest specific gravities *(fig. 2)*.

Required time to peak germination, like germinative capacity, was curvilinearly related to cone specific gravity in white fir and linearly related in red fir. The absolute values and curve shapes for rate were different, however, from those for capacity.

In white fir, germination rate for both fresh and stratified seeds rose rapidly to the point where cones reached a specific gravity of about 0.96, and then leveled off for lower cone specific gravities *(fig. 3)*. Values for fresh white fir seeds leveled off at about 50 days; for stratified seeds, at about 9 days.

Time to peak germination for fresh red fir seeds steadily shortened from more than 90 days at cone specific gravity of 1.00 to 52 days for seeds in cones with specific gravities of 0.53. For stratified seeds, it dropped from 22 days to 10 days throughout the same range of cone specific gravities *(fig. 3)*.

Over-all, when comparing both fresh and stratified seeds, I found little difference between species in the ability of cone specific gravity to predict seed germination *(table 2)*. But for stratified seeds only, cone specific gravity seems to predict germination rate of white fir slightly better than it does red fir. Information for stratified seed is the more relevant because in planting operations, seeds are routinely stratified.

For stratified seeds of both firs, cone specific gravity predicted germinative capacity much better than it did germination rate. The weak correlation between cone specific gravity and germination rate may be an

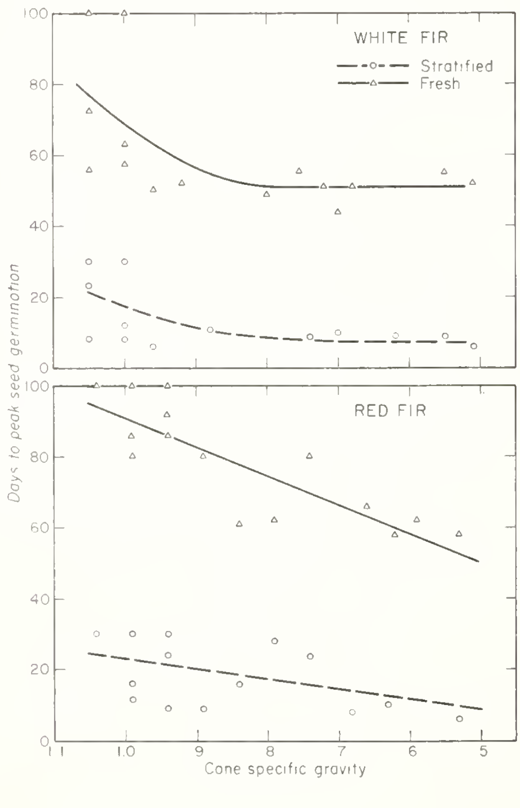

Figure 3 — The relation of time required for peak germination also differed between species. In white fir, the time dropped, then leveled off. In red fir, time decreased steadily throughout the range of specific gravity encountered.

artifact of the study procedure, as discussed previously.

Multiple regression analyses showed that seed collection date was a better predictor of seed germination than was cone specific gravity. For practical purposes, then, prediction of seed fall would be helpful. During a 4-year period, Cram and Worden (1957) found date of white spruce *(Picea glauca* [Moench] Voss*)* seed fall to be closely related to date of pollen shed. Using this kind of information requires, however, a degree of advance planning often not possible. And as Krugman (1966) points out, collection dates can be a less valuable indicator than cone specific gravity because of the variation in rate of seed maturation among localities, among trees, and even among individual cones on the same tree.

Red Fir Seedling Vigor

A higher proportion of healthy seedlings and larger seedlings was produced by seeds from cones collected closer to seed fall (October 8, 1968), as follows:

	Healthy seedlings[5]	
	(Dry weight/ 100 gm.)	*(Proportion pct.)*
Seed collection date:		
August 22	0	0
September 3	2.47	55
September 16	3.26	83
September 30	3.70	86

Both the proportion of healthy seedlings and their ovendry weights were significantly correlated with cone specific gravity. Cone specific gravity contributed 43 percent of the variation in proportion of vigorous seedlings and 38 percent of the variation in their ovendry weight.

Artificial Ripening of White Fir Seeds

None of the seeds from cones of either species collected in mid-August and subjected to four artificial ripening treatments germinated, nor were any seeds living at the end of the test.

Seeds from cones collected on September 14 germinated. The longer the artificial ripening treatment, the greater the percent germination and the greater the germination rate of white fir seeds, as follows:

[5]Means not significantly different at 5 percent level are bracketed.

Length of ripening treatment	*Total germination (pct.)*	*Time to peak germination*[6] *(days)*
0 weeks	31	12
4 weeks	38	7
6 weeks	47	4

In this test, cones collected in mid-September—4 weeks before seed fall began—and stored in a cool, moist environment for 4 weeks yielded seed which germinated as completely and speedily as stratified seed from mature cones. This result agrees with the observation of Rediske and Nicholson (1965) that the maturity of seed, when stored in cones in a cool, moist environment, seems to be associated with calendar date rather than with maturity at time of collection. By early September—nearly 5 weeks before seed fall began—the seeds apparently had reached the second period of the maturing process in which maturation can be completed independently of the tree (and possibly independently of the cone). This stage corresponds to the beginning of the rapid drop in cone specific gravity. Furthermore, the maturation rate of the seeds in the detached cones was the same as that of the seeds in the cones left on the trees even though their environments were radically different.

Two weeks of additional storage in cones boosted both total and peak germination for the artificially ripened seeds above that of stratified seeds from mature cones. This suggests that white fir requires some after-ripening for maximum germinability. Probably no more than 2 weeks of after-ripening is required. Seeds from cones stored 6 weeks (2 weeks beyond date when seed fall began) germinated more completely and in less time than any of the seeds tested by Lanquist (1946).

Other Maturity Indices

Many cone and seed characteristics were noted, but no single effective index of cone and seed ripeness was discovered.

Cone Characteristics

By the end of August the white fir cones had reached their mature size and were yellow-green in color. Munsell color varied from 7.5GY 8/8 to 2.5GY 8/6. The cones remained yellow-green through mid-September before turning straw-colored by the end of

[6]Means not significantly different at 5 percent level are bracketed.

the month. At the last collection—October 9— the cones were mature, and ranged in color from a dull greyish-yellow to a bright yellow-brown (5Y 6/4 to 7.5YR 7/8).

The red fir cones had reached their mature size by the time of the first collection in mid-August. In later collections the cones had shrunk in size slightly from curing. In mid-August the red fir cones ranged in color from bright yellow-green to yellowish olive (2.5GY 7/6 to 5Y 6/8). Changes in color were subtle until late September when the cones ranged from greenish yellow to bright yellow-brown (5Y 7/6 to 7.5YR 6/8). At the beginning of seed fall all cones were bright yellow-brown.

Cone color varied mostly with collection date, but specific gravity had some effect. At each collection, cones in the lighter specific gravity classes tended to be yellower or browner than cones in the heavier classes. Nevertheless, the variation between trees was too great and color descriptions too difficult to make cone color an effective index of maturity. Many investigators have reached a similar conclusion (Finnis 1950; Maki 1940).

Seed Characteristics

At the first collection in mid-August, seeds of both species were firmly attached to their cone scales, the megagametophyte had a milky consistency, and the embryo was transparent and difficult to see *(table 3)*. The color of the seed wings of both species was dark red (2.5R 4/10). By late August, the seed wings had turned magenta (5RP 5/6 to 4/12) and a brown streak appeared on the wings of the white fir seeds. The embryo in both species had lengthened noticeably, also, then occupying over half the length of its cavity in the megagametophyte. Red fir embryos, though still mostly transparent, were tinged with yellow on the cotyledons.

By mid-September, white fir seed wings had turned mostly brown except for the outer edge which remained deep magenta. Brown streaks appeared on many red fir seed wings, especially those in the lighter specific gravity classes. By then the megagametophytes of both species had firm consistency, and white fir embryos had a yellow tinge. The embryo in both species had grown rapidly, occupying nearly the entire cavity.

In late September, 2 weeks before seed fall began, seeds of both species were only loosely attached to their cone scales. The entire embryo was pale yellow-green and filled its cavity entirely. The seed wings were brown, edged with deep magenta.

Little change was noted in the last collection except that seeds were free of their scales.

Like the cone characteristics, these seed characteristics varied both with collection date and specific gravity, but collection date had greater influence.

APPLICATION

For both white fir and red fir, seeds collected later in the season germinated faster than those collected earlier. And more seeds in the later collections germinated than those in the earlier ones. Red fir seeds collected closer to seed fall also produced heavier and healthier seedlings. White fir seeds matured rapidly until cones reached an average specific gravity of about 0.96—about 3½ weeks before seed fall began in this study. Germination and seed characteristics changed little thereafter. Therefore, little loss of seed quality will result from collecting white fir cones with a specific gravity of 0.96 or less.

Red fir seed, on the other hand, tended to mature at a constant rate throughout the range of cone specific gravity. As a result, a firm specific gravity recommendation for cone collection is more difficult to make for red fir. Nevertheless, from the results of this study it seems that seed collected from cones with a specific gravity more than 0.75—the value reached about 2 weeks before seed fall began in 1967—will be of poor quality.

The differing patterns of seed maturity can be important to the seed harvester. White fir cones can be collected within 3½ weeks of seed fall with only a negligible loss of seed quality. Red fir cones, on the other hand, should be picked as close to beginning of seed fall as possible, since the later the picking the better the seed quality. Proper timing in the collection of red fir cones is especially important because even mature seed is often of poor quality.

Seed maturity patterns have been reported for grand fir (Pfister 1967) and noble fir (Rediske and Nicholson 1965; Franklin 1965; Edwards[7]). Even though grand fir is closely related taxonomically to white fir and, similarly, noble fir to red fir, the pat-

[7]See footnote 1.

Table 3–*Sequence of changes in white and red fir seed characteristics observed in collections from mid-August to just before the beginning of seed fall (October 12)*

Collection date	Seed wing color	Cone scale attachment	Megagametophyte consistency	Embryo color	Ratio of embryo length to cavity length	Germination of stratified seeds
					Percent	*Percent*
			WHITE FIR			
August 17	Dark red	Firm	Milky	Transparent	–	0
August 31	Deep magenta with brown streak	Firm	Milky	Transparent	54	17
September 14	Mostly brown with deep magenta edge	Firm to loose	Firm	Yellow tinge	96	26
September 27	Brown with deep magenta edge	Loose	Firm	Pale yellow-green	100	36
October 9	Brown with deep magenta edge	Free	Firm	Pale yellow-green	100	39
			RED FIR			
August 15	Dark red	Firm	Milky	Transparent	–	0
August 29	Deep magenta	Firm	Milky	Yellow tinge	59	5
September 12	Deep magenta with brown streak	Firm to loose	Firm	Pale yellow-green	98	8
September 25	Mostly brown with deep magenta edge	Loose	Firm	Pale yellow-green	96	20
October 9	Mostly brown with deep magenta edge	Free	Firm	Pale yellow-green	99	17

terns of seed maturity in grand and noble fir did not show the same contrasts evident between white and red fir. Grand fir germination increased steadily up to seed fall; noble fir germination leveled off prior to seed fall.

Fortunately, harvesting white fir cones within 4 weeks of seed fall and artificially ripening the seeds appears possible. Seeds thus treated may be of better quality than those harvested from mature cones if artificial ripening extends 2 weeks beyond beginning of seed fall. This artificial ripening treatment was not attempted for red fir cones. Probably it would be successful, however, as a similar treatment has been successful for noble fir (Edwards[8]; Rediske and Nicholson 1965), grand fir (Pfister 1966), and Douglas-fir (Rediske 1961; Silen 1958).

The artificial ripening treatment used here–refrigerated storage in individual bags–may not be practical for commercial operators. But storing cones in burlap sacks outside in the shade can be successful if the climate is cool. This was the artificial ripening treatment given noble fir, grand fir, and Douglas-fir cones. The major problem mentioned by all investigators is the deleterious effect of mold, which can be controlled only by keeping the sacks well ventilated.

These recommendations must be considered tentative because they are based solely on seed for immediate germination. Most seed is stored for several years, but little is known about the storing qualities of artificially ripened seed.

Cone specific gravity can be an index of seed maturity. But the variation among trees and among cones on the same tree is large, especially when the cones are actively drying–the stage when specific gravity normally would be determined. Results of sampling in this study indicate that at least three cones from each of four trees should be measured to obtain a reliable estimate of cone specific gravity.

A prediction method combining several seed characteristics seems more direct and simpler than measuring cone specific gravity. Taken individually, most seed characteristics examined in this study were little better than cone specific gravity as predictors. Several characteristics taken together, however, seem to offer an easy and effective index of seed maturity. White fir and red fir cones should be ready for harvest when

1. Seed wings are uniformly brown with a deep magenta edge.

[8]See footnote 1.

2. Seeds are free or only loosely attached to cone scale.

3. Embryos are uniformly pale yellow-green.

4. Embryos entirely fill embryo cavities.

Several of these seed characteristics have been recommended as indices of seed maturity for other species. Seedwing color and cone scale attachment are suggested as maturity indices for grand fir (Pfister 1967).

The ratio of embryo length to cavity length was the single most useful index of seed maturity found. It is a logical morphological characteristic easily seen and quantified in the field, and variation within a collection was lower than that of any other characteristic observed. At the earliest recommended collection time for white fir—3½ weeks before seed fall begins—94 percent of the embryos entirely filled their cavities. For red fir the earliest collection time is 2 weeks before seed fall begins. At that time 84 percent of the embryos entirely filled their cavities. Embryo length has been recommended as an index for Douglas-fir (Finnis 1950; Ching and Ching 1962). It seems probable that the embryo length/cavity length ratio would be an effective index for all conifers. Future studies should aim towards verifying and quantifying this characteristic as a seed maturity index for other conifers.

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1974. **Seed maturity in white fir and red fir.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 12 p., illus. (USDA Forest Serv. Res. Paper PSW-99)

White fir and red fir seed collected over a 2-month period in northern California was tested for germination of fresh and stratified seed. Ratio of embryo length to embryo cavity length was found to be the most useful index of seed maturity for white and red fir. Cone specific gravity also was correlated with nearly all measures of seed germination. Data suggest that red fir cones should be collected as close to beginning of seed fall as possible. White fir cones should be collected within 3½ weeks of seed fall. White fir cones collected 4 weeks before seed fall can be artificially ripened, however. These cones yielded seed which germinated as completely and speedily as stratified seed from mature cones.

Oxford: 232.218:232.312.1 [+ 174.7 *Abies concolor* + 174.7 *Abies magnifica*].

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Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701

ONE-SIDED TRUNCATED SEQUENTIAL t-TEST:

application to natural resource sampling

Gary W. Fowler William G. O'Regan

USDA FOREST SERVICE RESEARCH PAPER PSW-100/1974

CONTENTS

THE AUTHORS

GARY W. FOWLER is an associate professor of biometrics in the School of Natural Resources, University of Michigan, Ann Arbor. He earned his bachelor's (1961) and master's (1965) degrees and a doctorate (1969) in forestry, and a master's degree in statistics (1967) at the University of California, Berkeley. **WILLIAM G. O'REGAN** is Station biometrician, with headquarters in Berkeley. He is also a lecturer in the College of Natural Resources, University of California, Berkeley. He earned a bachelor's degree (1949) and a doctorate (1962) in agricultural economics at the University of California, Berkeley. He has been a member of the Station staff since 1957.

GLOSSARY

H_0:	null or test hypothesis
H_1:	alternative hypothesis
α:	level of significance (probability of Type I error)
δ:	non-centrality parameter
β:	probability of Type II error, at a specified value of δ
n_0:	truncation point
ADS:	average decision stage
ASN:	average sample number
BSTT:	Barnard's open one-sided sequential t-test
CALPRO:	computer program which calculates the decision probabilities for TSTT
OC:	operating characteristic (1-power)
OCASN:	computer program which calculates the OC and ASN functions of TSTT
power:	probability of rejecting H_0. For a given test, power is expressed as a function of δ
RAND:	fixed sample size t-test
SN:	sample number
SPRT:	sequential probability ratio test
STTEST:	computer program which approximates the decision boundaries for TSTT
TSTT:	one-sided truncated sequential t-test

SUMMARY

Fowler, Gary W., and William G. O'Regan

1974. **One-sided truncated sequential t-test: application to natural resource sampling.** USDA Forest Serv. Res. Paper PSW-100, 17 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 524.63 0.15 5.

Retrieval Terms: biometrics; sampling; sequential sampling; t-test.

The high degree of approximation in current sequential tests, the emphasis on two-sided tests, and the unpleasant possibility of large sample sizes have led us to develop a new procedure for constructing one-sided truncated sequential t-tests of the hypothesis

$$H_0: E(X) = \mu = \mu_0$$
$$H_1: \mu > \mu_0$$
$$X \sim \text{NIID}(\mu,\sigma^2)$$
$$\sigma^2 \text{ unknown}$$

Current tests specify α and β in advance, with α being the probability of rejection when $\mu=\mu_0$ and β being the probability of acceptance when $\mu=\mu_0+\delta\sigma$, and use maximum likelihood procedures weakened by various approximations to obtain decision boundaries.

The truncation point (n_0) is determined by α, β, and the approximation procedure and is not necessarily an integer. The actual values of α and β for such tests when estimated by Monte Carlo procedures seem to be distinctly different from the nominal values. Little is known about OC and ASN functions of these tests except for some empirical studies, due to the complexity of the mathematics involved.

Thinking that it might be more practical to specify n_0 in advance rather than β, we have developed a one-sided truncated sequential t-test based on a specified α, n_0, and probability boundary pattern. The probability boundary pattern sets the probabilities of accepting and rejecting H_0 (H_0 being true) at each stage of the test such that the overall probability of rejecting H_0 (H_0 being true) is equal to α. An algorithm was constructed to determine these acceptance and rejection probabilities at each stage of the test for a specified α, n_0, and probability boundary pattern. Three intuitively appealing boundary patterns were considered.

Monte Carlo procedures based on a pseudo-normal deviate generator were used to approximate the distributions of the conditional test statistic at each stage of the test. Acceptance and rejection points associated with the acceptance and rejection probabilities at each stage of the test were then determined to obtain the approximate decision boundaries of a specific one-sided truncated sequential t-test. For a given value of α and n_0, the power function of the test depends upon the probability boundary pattern.

The observed value of α when estimated by Monte Carlo procedures is quite close to the nominal value.

Five examples are presented. Each has α set at 0.05. Three have n_0=10, each with a different probability boundary pattern. One boundary pattern has two additional examples with n_0=4 and n_0=7.

The operating characteristic and average sample number functions were approximated for each of the tests. Monte Carlo procedures based on a pseudo-normal deviate generator were used to simulate sampling normal distributions 1000 times with each test for values of the non-centrality parameter (δ) varying from 0.0 to 4.0 with an interval of 0.5. These points give an adequate description of each function. Monte Carlo estimates of α were very close to the nominal α (0.05) and varied from 0.046 to 0.051.

The properties of a specific test are compared with the fixed sample size t-test and Barnard's one-sided sequential t-test having approximately the same reliability. The one-sided truncated sequential t-test yielded an estimated α and associated ASN (average sample number) of 0.047 and 5.185 (based on 20,000 samplings of the null distribution) with the nominal values being 0.050 and 5.180, respectively. This test yielded a Monte Carlo estimate of β = 0.057 at δ =1.5 (based on 1000 samplings of a normal distribution with δ = 1.5). The fixed sample size test yielded an estimated α and β at δ=1.5 of 0.048 and 0.041 with the nominal values being 0.050 and 0.039, respectively. Barnard's test yielded an estimated α and β at δ = 1.5 of 0.032 and 0.016, with the nominal values both being 0.050. The ASN function of the fixed sample size test is uniformly larger than that of the

new test while the ASN function of the new test is uniformly lower than that of Barnard's test for $\delta > 0.3$ with the reverse being true for other values of δ. Given the absolute guarantee of a limiting sample size, the new test compares quite favorably with the other two tests.

Since there have been no applications of sequential t-tests to natural resources sampling to date, examples of possible natural resources applications are considered and field procedures are outlined for the new test. The original test statistic is transformed to one that is easier to calculate in the field, and the possibility of a series of observations having the same value is considered. Recommendations are given to the potential user. The upper one-sided test presented can easily be modified to a lower one-sided test.

The researcher in natural resources is commonly faced with the problem of sampling populations that have unknown underlying distributions with the variance almost always being unknown. One- and two-sided open sequential t-procedures have been developed by Barnard (1952), Rushton (1950, 1952), and Wald (1947), and can be used for situations in which the variance is unknown. But these tests possess the major weakness of all open sequential procedures the possible occurrence of very large sample sizes. To date, we know of no applications of these procedures to the field of natural resources.

Schneiderman and Armitage (1962b) and Meyers, Schneiderman, and Armitage (1966) developed two forms of two-sided closed sequential t-tests. Suich and Iglewicz (1970) and Alexander and Suich (1973) proposed a truncated sequential t-test for the one- and two-sided case based on the method of Anderson (1960). These truncated procedures have been developed for nominal α (level of significance or probability of Type I error) and β (probability of a Type II error) at a specified value of δ, without fixing the truncation point of the test in advance. Because the truncation point is a function of α, β, and one or more mathematical approximations, it is not necessarily an integer.

In sequential hypothesis testing, the test procedures terminate according to some stopping rule related to the sequence of observations. These tests usually require, on the average, fewer observations than do equally reliable tests based on fixed sample size procedures. A major portion of the literature and application of sequential hypothesis tests is related to Wald's Sequential Probability Ratio Test (SPRT). Early applications of this test in the biological sciences were reported by Oakland (1950) and Morgan, *et al.* (1951). Such applications assume prior knowledge of the underlying distribution and related non-test parameters and are open in that they have parallel decision boundaries.

Applications of the SPRT in natural resources, and specifically forestry, can be found related to reproduction surveys and insect or disease control programs for the binomial, negative binomial, normal and Poisson distributions. Tests based on these distributions have been reported for classifying the following populations:

Distribution:	*Population*
Binomial:	Larch sawfly (Ives 1954; Ives and Prentice 1964)
Negative binomial:	Spruce budworm (Morris 1954; Waters 1955; Cole 1960)
	Forest tent caterpillar (Connola, Waters, and Smith 1957)
	Red-pine sawfly (Connola, Waters and Nason 1959)
	Engelmann spruce beetle (Knight 1960a)
	Black Hills beetle (Knight 1960b; Knight 1967)
	Cone and seed insects (Kozak 1964)
	White grubs (Ives and Warren 1965)
	Gooseberry or currant bushes or both (Offord 1966)
	Jack pine sawfly (Tostowaryk and McLeod 1972)
	Lygus bugs (Sevacherian and Stern 1972)
Normal:	Lodgepole needle miner (Stark 1952; Stark and Stevens 1962)
Poisson:	Winter moth (Reeks 1956)
	Spruce budworm (Cole 1960)

Smith and Ker (1958) described the application of a test based on the Poisson distribution in reproduction surveys.

Approximations to the operating characteristic (OC) and the average sample number (ASN) functions have been developed for the SPRT (Wald 1947). And while little is known about the OC and ASN functions of the sequential t-tests, Monte Carlo simulation indicates that their actual α and β are usually quite divergent from the nominal α and β.

We were led to obtain boundaries for one-sided truncated sequential t-tests by Monte Carlo procedures because of these conditions: the high degree of approximation inherent in current sequential procedures, the undesirable possibility of large sample sizes, the emphasis on two-sided tests, and the dependence of the truncation point (n_0) on α and β. The decision boundaries of a specific test are constructed for a given α, n_0, and specific probability boundary pattern. The value of β at a particular alternative depends on the probability boundary pattern for given values of α and n_0. We do not set a nominal value of β at a particular alternative. However, Monte Carlo approximations to the OC and ASN functions are presented.

This paper describes a procedure for constructing a one-sided truncated sequential t-test, constructs a series of tests for a given α with different n_0's and probability boundary patterns, compares a specific test with the fixed sample size t-test and Barnard's one-sided sequential t-test, considers possible applications of the test to natural resources, and outlines field procedures for the new test.

TEST PROCEDURES

The decision boundaries of a specific one-sided truncated sequential t-test are constructed with the prior knowledge of α, n_0, and a specific pattern of acceptance and rejection probabilities (probability boundary pattern) that yield the given value of α. The OC and ASN functions of such a test are controlled by varying α, n_0, and the probability boundary pattern.

In developing the test,[1] we consider the following problem:

Test

$$H_0 : E(X) = \mu_0 \text{ or } \delta = \delta_0 = 0$$

against

$$H_1 : E(X) > \mu_0 \text{ or } \delta = \delta_1 (\delta_1 > 0)$$

$$X \rightarrow \text{NIID}\ (\mu, \sigma^2)$$

in which $\delta = (\mu - \mu_0)/\sigma$ (non-centrality parameter), and σ is unknown.

We would like to choose

- d_s the decision statistic at stage s, $s = 1, \ldots, S$
- d_s^r the rejection point in the distribution of d_s
- d_s^a the acceptance point in the distribution of d_s
- n_s the number of observations at stage s
- S the upper limit in the number of stages so that the OC and ASN functions of the test have specified qualities and such that

$$n_0 \geq \sum_{s=1}^{S} n_s$$

with n_0, the truncation point or maximum number of possible observations, being specified in advance.

We have been unable to obtain an analytical solution to this problem. However, we have obtained a test based on Monte Carlo procedures.

The test is developed as follows. We define

α_s = probability of rejecting H_0 at stage s, given $\mu = \mu_0$

γ_s = probability of accepting H_0 at stage s, given $\mu = \mu_0$

α = overall probability of rejecting H_0, given $\mu = \mu_0$

and set

$$\gamma_s = \frac{\gamma_S}{\alpha_S} \alpha_s \text{ with } \alpha_s < \alpha_S, \text{ for } s = 1, \ldots, S-1$$

Because the test is truncated at stage S, we know that

$$\gamma_S = 1 - \alpha_S \text{ and } \gamma_s = \frac{1 - \alpha_S}{\alpha_S} \alpha_s$$

We let

$$D_s = \alpha_s + \gamma_s = \frac{\alpha_s}{\alpha_S} \quad \text{probability of a terminating decision at stage s}$$

$$C_s = 1 - D_s = 1 - \frac{\alpha_s}{\alpha_S} = \frac{\alpha_S - \alpha_s}{\alpha_S} \quad \text{probability of continuing at stage s}$$

$$P_s = \prod_{j=0}^{s-1} C_j \quad \text{probability of reaching stage s}$$

$$C_0 = 1$$

and note that

$$\alpha = \sum_{s=1}^{S} P_s \alpha_s$$

Since $\alpha_s = D_s \alpha_S$ from above,

$$\alpha = \sum_{s=1}^{S} P_s D_s \alpha_S = \alpha_S \sum_{s=1}^{S} P_s D_s$$

and, as the test is closed at S, we have

$$\sum_{s=1}^{S} P_s D_s = 1 \text{ and } \alpha = \alpha_S$$

[1] In the process we had frequent and helpful reference to: Alexander and Suich (1973), Alling (1966), Anderson (1960), Armitage (1957), Aroian (1968), Barnard (1952), Davies (1954), Ghosh (1970), Hall (1962), Jackson (1960), Johnson (1961), Meyers, Schneiderman, and Armitage (1966), Rushton (1950, 1952), Samuelson (1948), Schneiderman and Armitage (1962a, 1962b), Stockman and Armitage (1946), Suich and Iglewicz (1970), U. S. Department of Commerce (1951), Wald (1947), and Wetherill (1966).

Thus, any probability boundary pattern that satisfies the above criteria can be used to develop the exact acceptance and rejection probabilities at each stage for a test with a given α and n_0.

However, given S and the probability boundary pattern, we have neither a decision statistic with known probability distribution nor an analytical procedure for setting n_s. We proceed arbitrarily along the following lines:

Set $n_1 = 2$ and $n_s = 1$ for s = 2, 3, . . . , S, and let

$$d_s = \frac{(\bar{x}_s - \mu_0)}{\sqrt{\sum_{j=1}^{s}\sum_{i=1}^{n}(x_{ij} - \bar{x}_s)^2 \Big/ (\sum_{j=1}^{s} n_j)(\sum_{j=1}^{s} n_j - 1)}}$$

in which

$$\bar{x}_s = \frac{\sum_{j=1}^{s}\sum_{i=1}^{n_j} x_{ij}}{\sum_{j=1}^{s} n_j}$$

The statistic d_1 has a t-distribution with one degree of freedom, which allows us to set the points d_1^a and d_1^r where the probabilities of accepting and rejecting H_0 are

$$\gamma_1 = P(d_1 \leq d_1^a)$$

and

$$\alpha_1 = P(d_1 \geq d_1^r)$$

The statistic d_s $(s > 1)$ has an unknown conditional distribution. The conditional probabilities of accepting and rejecting H_0 are

$$\gamma_s = P(d_s \leq d_s^a \mid d_1^a < d_1 < d_1^r, \ldots, d_{s-1}^a < d_{s-1} < d_{s-1}^r)$$

and

$$\alpha_s = P(d_s \geq d_s^r \mid d_1^a < d_1 < d_1^r, \ldots, d_{s-1}^a < d_{s-1} < d_{s-1}^r)$$

For the values of n_s considered, the statistic d_s reduces to the statistic d_n where

$$d_n = (\bar{x}_n - \mu_0) \Big/ \sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2/(n)(n-1)}$$

and

$$\bar{x}_n = \sum_{i=1}^{n} x_i/n,\ n = s + 1, \text{ and } n_0 = S + 1$$

Interpretation of the acceptance and rejection probabilities using the statistic d_n can be facilitated graphically *(fig. 1)*. Even though we have developed our test for n_1=2 and n_s=1 for $s > 1$, the procedure can easily be modified to handle the more general case where $n_s > 1$ for all s.

We have approximated the decision points d_n^a and d_n^r $(n > 2)$ for several cases by Monte Carlo procedures.

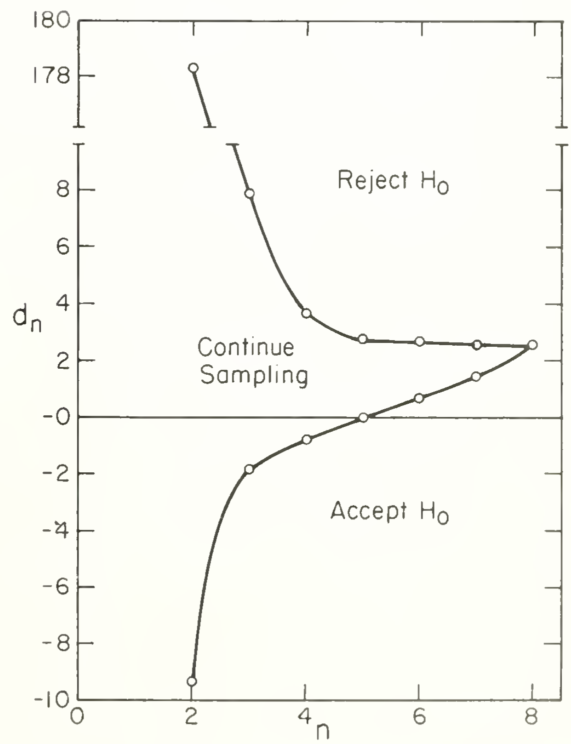

Figure 1—Acceptance and rejection boundaries in terms of d_n for a Pattern 3 test with S = 7, n_0 = 8, n_1 = 2, n_s = 1 (s > 1), and α = 0.05.

Examples of Proposed Test

In constructing examples of the proposed test, we utilized three probability boundary patterns. Each is intuitively appealing.

Pattern 1 sets $\alpha_s = \alpha\left[\sum_{i=1}^{s}(S+1-i)/\sum_{i=1}^{S} i\right]$ (probabilities increase at a constantly decreasing rate), Pattern 2 sets $\alpha_s = \alpha[s/S]$ (probabilities increase at a constant rate), and Pattern 3 sets $\alpha_s = \alpha\left[\sum_{i=1}^{s} i \Big/ \sum_{i=1}^{S} i\right]$ (probabilities increase at a constantly increasing rate).[2] In each case, $\gamma_s = \frac{1-\alpha_S}{\alpha_S}\alpha_s$.

Five examples are presented. Each has α set at 0.05. Three have $n_0 = 10$, each with a different probability boundary pattern. One boundary pattern has two additional examples with n_0=4 and n_0=7. The decision points at each stage of a given test were obtained by approximating the unknown probability distribution of d_n with 1000 iterations of the statistic $d_n(n = 2, 3, \ldots, n_0)$.

Computer program CALPRO[3] calculates the acceptance and rejection probabilities for Patterns 1, 2, and 3 and for any combination of α and n_0. Computer program STTEST approximates the decision boundary (acceptance and rejection points) for any test with α, n_0, and probability boundary pattern satisfying the specified criteria.

The probability boundary patterns and decision boundaries of tests with n_0 = 4, 7, and 10 for Pattern 1 and for Patterns 1, 2, and 3 with n_0 = 10 are given in *tables 1* and *2*.

The OC and ASN functions of each test were approximated by sampling normal distributions 1000 times each for δ = 0.0(0.5)4.0. Computer program OCASN approximates the OC and ASN points of a given test for any range of and interval between values of δ. The approximate OC and ASN functions for the tests described in *table 1* and *table 2* are given in *table 3* and *fig. 2.*

It should be recalled that the proposed test is constructed given α, n_0, and a probability boundary pattern—a particular value of β at a chosen value of δ is not specified in advance as in other sequential t-procedures. In other words, for n_0 given, the OC function depends on the probability boundary pattern.

Once the OC function of a given test has been obtained, a value of β can be approximated for any desired value of δ. If δ = 2.0 represents a critical alternative in hypothesis testing, *table 3* will yield the approximate value of δ for a given n_0 and probability boundary pattern. By using a much more expanded set of tables, the researcher could choose that test

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[2] Fowler, G. W. *An investigation of some new sequential procedures for use in forest sampling.* 1969. (Unpublished Ph.D. thesis on file at University of California, Berkeley)

[3] All computer programs are on file at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California 94701.

Table 1—*Probabilities of acceptance* (γ_n) *and rejection* (α_n) *at all possible sample points* (n) *for boundary patterns 1, 2, and 3 and indicated truncation points* (n_0), α = 0.05.

	Pattern 1						Pattern 2		Pattern 3	
	n_0									
	4		7		10		10		10	
n	γ_n	α_n	γ_n	α_n	γ_n	α_n	γ_n	α_n	γ_n	α_n
2	0.475	0.025	0.271	0.014	0.190	0.010	0.106	0.006	0.021	0.001
3	.792	.042	.498	.026	.359	.019	.211	.011	.063	.003
4	.950	.050	.679	.036	.507	.027	.317	.017	.127	.007
5			.814	.043	.633	.033	.422	.022	.211	.011
6			.905	.048	.739	.039	.528	.028	.317	.017
7			.950	.050	.823	.043	.633	.033	.443	.023
8					.887	.047	.739	.039	.591	.031
9					.929	.049	.844	.044	.760	.040
10					.950	.050	.950	.050	.950	.050

Table 2—*Decision values* (d_n^a, d_n^r) *at all possible sample points* (n) *for boundary patterns 1, 2, and 3 and indicated truncation points* (n_0), $\alpha = 0.05$.

	Pattern 1						Pattern 2		Pattern 3	
	n_0									
	4		7		10		10		10	
n	d_n^a	d_n^r	d_n^a	d_n^r	d_n^a	d_n^r	d_n^a	d_n^r	d_n^a	d_n^r
2	-0.079	12.706	-0.874	22.266	-1.472	31.820	-2.904	57.295	-15.057	286.506
3	1.705	4.289	.300	4.550	-.142	5.006	-.822	8.085	-2.410	16.416
4	4.243	4.243	1.414	3.194	.630	3.570	-.067	4.105	-1.048	5.164
5			2.556	3.391	1.470	3.259	.531	3.044	-.425	3.453
6			3.645	3.869	2.255	3.301	1.158	2.810	.041	2.883
7			4.681	4.681	3.108	3.510	1.743	2.707	.583	2.506
8					4.000	4.167	2.354	2.926	1.260	2.518
9					4.942	5.011	3.006	3.236	1.906	2.503
10					5.945	5.945	3.731	3.731	2.742	2.742

which was "best" in terms of α, n_0, OC function, and ASN function for a given problem.

The Monte Carlo estimates of α ($\hat{\alpha}$) are close to the nominal α; for, $0.046 \leq \hat{\alpha} \leq 0.051$ *(table 3)*. The Monte Carlo estimates of β at $\delta = 2.0$ are 0.368 for n_0=4, 0.122 for n_0=7, and 0.052 for n_0=10 with Pattern 1 and 0.052 for Pattern 1, 0.008 for Pattern 2, and 0.000 for Pattern 3 with n_0 = 10.

The Monte Carlo estimates of α at $\delta = 0$ and β at the chosen value of δ for all other sequential procedures (Alexander and Suich 1973; Meyers, Schneiderman, and Armitage 1966; Schneiderman and Armitage 1962b; Suich and Iglewicz 1970; Wetherill 1966) are distinctly different from the respective nominal values due to the approximations involved in their development. Our research indicates

Table 3—*Monte Carlo approximations of the probability of acceptance* (OC) *and the average sample number* (ASN) *as a function of the non-centrality parameter* (δ) *for Pattern 1 with* n_0 = 4, 7, 10, *and for Patterns 2 and 3 with* n_0 = 10, $\alpha = 0.05$.

	OC					ASN				
	Pattern					Pattern				
	1			2	3	1			2	3
	n_0					n_0				
δ	4	7	10	10	10	4	7	10	10	10
0.0	0.949	0.954	0.951	0.952	0.950	2.57	3.11	3.57	4.52	6.05
.5	.878	.829	.817	.767	.687	2.94	3.84	4.59	5.74	7.37
1.0	.730	.594	.539	.369	.217	3.21	4.20	5.08	5.94	6.84
1.5	.553	.325	.211	.077	.020	3.32	4.14	4.67	5.14	5.54
2.0	.368	.122	.052	.008	0	3.26	3.74	4.06	4.36	4.78
2.5	.203	.033	.007	0	0	3.12	3.40	3.58	3.94	4.42
3.0	.097	.008	0	0	0	2.97	3.16	3.29	3.68	4.19
3.5	.046	0	0	0	0	2.84	3.02	3.12	3.54	4.02
4.0	.018	0	0	0	0	2.74	2.94	3.01	3.44	3.88

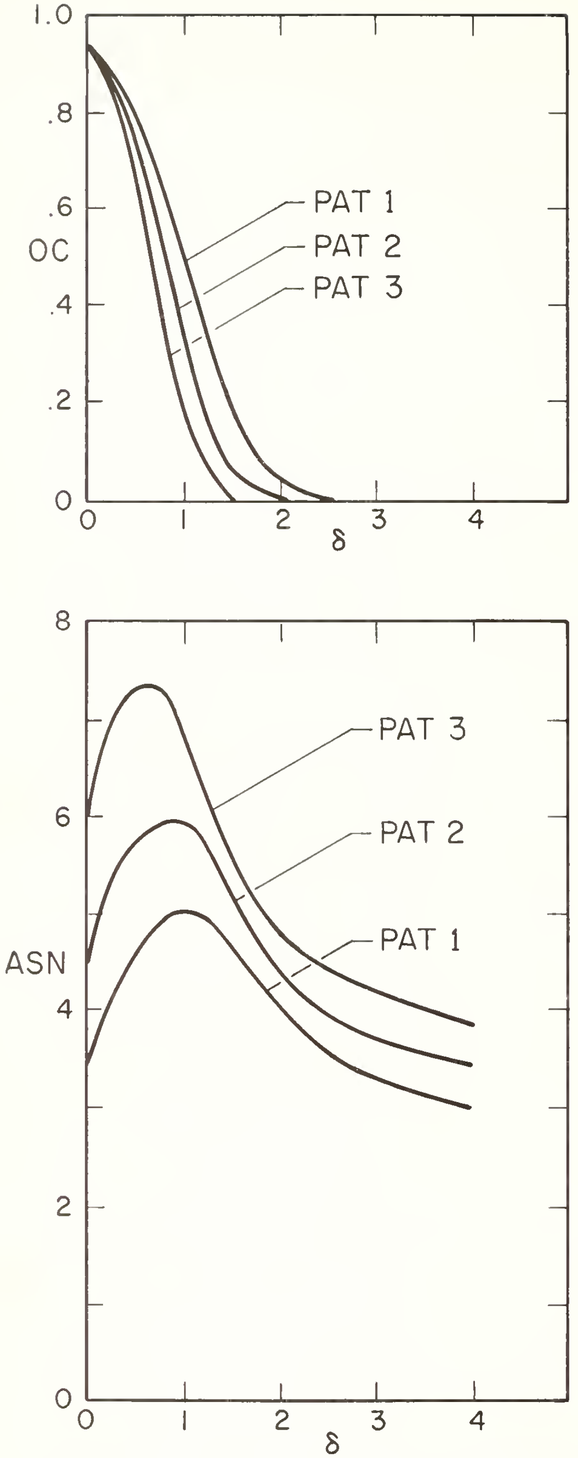

Figure 2—With n_0 = 10, the approximate probabilities of acceptance of H_0(OC), *top*, and the approximate average sample numbers (ASN), *bottom*, as functions of the non-centrality parameter (δ) are illustrated for three specified boundary patterns, α = 0.05.

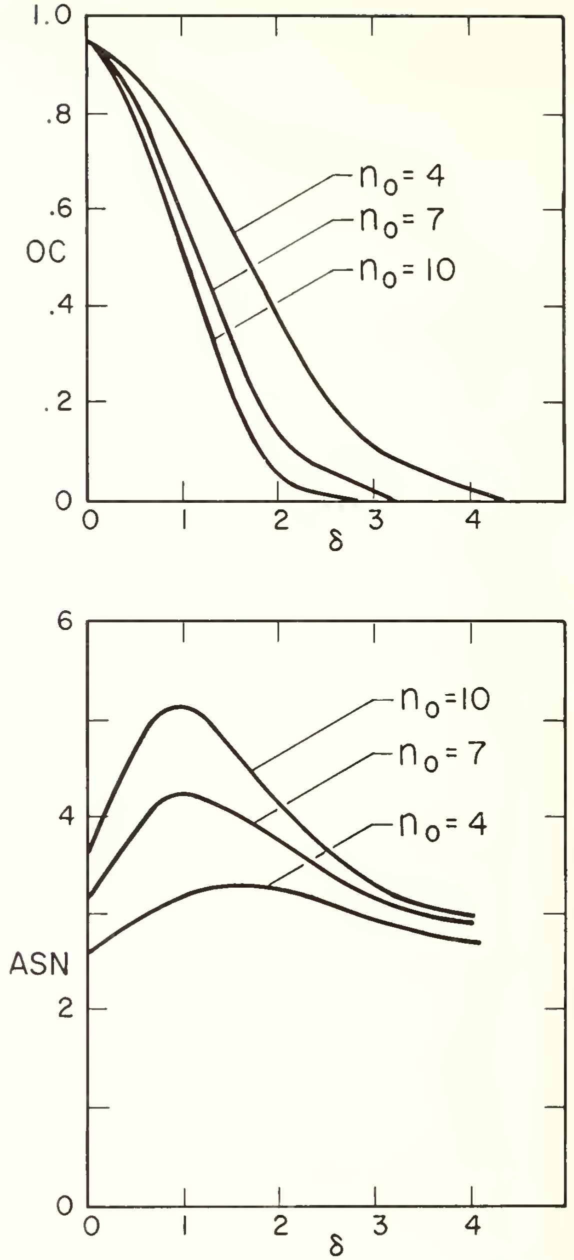

Figure 3—For Pattern 1, the approximate probabilities of acceptance of H_0(OC), *top*, and the approximate average sample numbers (ASN), *bottom*, as functions of the non-centrality parameter (δ) are illustrated for chosen values of n_0 (4, 7, 10), α = 0.05.

Table 4—*Probability boundary pattern and decision points for a Pattern 3 test with* S = 7, n_0 = 8, n_1 = 2, n_s = 1 (s > 1) *and* α = 0.05.

S	n	α_n P(R|$\mu=\mu_0$)	γ_n P(A|$\mu=\mu_0$)	d_n^r Rejection Point	d_n^a Acceptance Point
1	2	0.0018	0.0339	178.223	-9.345
2	3	.0054	.1018	7.949	-1.828
3	4	.0108	.2036	3.646	-.777
4	5	.0179	.3393	2.966	.001
5	6	.0268	.5089	2.683	.712
6	7	.0375	.7125	2.500	1.482
7	8	.0500	.9500	2.588	2.588

that our Monte Carlo estimates of α and β are quite close to the true unknown values of α and β. The differences are strictly due to the sampling errors involved in the Monte Carlo procedure.

The ASN function increases and the peak of the ASN function increases and becomes closer to $\delta = 0$ as n_0 increases for a given probability boundary pattern *(table 3* and *fig. 3)*. The ASN function tapers slowly from the peak as δ increases for a given n_0. The ASN function also increases as the peak increases and becomes closer to $\delta = 0$ as the probability boundary pattern goes from Pattern 1 to Pattern 2 to Pattern 3. The variances of the Monte Carlo estimates of the ASN and OC points indicate that these estimates are highly reliable and probably very close to the unknown parametric values.

All examples of the new test are upper one-sided tests. Lower one-sided tests can easily be developed from boundaries of the upper one-sided tests. Approximate two-sided tests can also be developed.

Examination of Given Test

Table 4 gives α_n, γ_n, d_n^r, and d_n^a for a test with S = 7, n_0 = 8, α = 0.05, and Pattern 3, with n_s, d_s, and d_n as defined earlier. d_n^r and d_n^a (n > 2) were based on 1000 computed d_n at each stage. *Fig. 1* shows the acceptance and rejection boundaries of the test.

The true average decision stage (ADS), average sample number (ASN), and the level of significance at H_0 of the test listed in *table 4* are:

$$\text{ADS} = 4.180$$
$$\text{ASN} = 4.180 + 1.000 = 5.180$$
$$\alpha = P(R \mid \mu = \mu_0) = 0.050$$

Table 5 presents the results of 20,000 simulated tests from a $N(\mu_0, \sigma^2)$ distribution.

Table 5—*Probabilities observed in 20,000 Monte Carlo trials compared to exact probabilities for a Pattern 3 test with* S = 7, n_0 = 8, n_1 = 2, n_s = 1 (s > 1) *and* α = 0.05.

S	n	α_n P(R|$\mu=\mu_0$)		γ_n P(A|$\mu=\mu_0$)	
		Exact	Observed	Exact	Observed
1	2	0.0018	0.0010	0.0339	0.0318
2	3	.0054	.0065	.1018	.1016
3	4	.0108	.0122	.2036	.2072
4	5	.0179	.0150	.3393	.3479
5	6	.0268	.0200	.5089	.5096
6	7	.0375	.0433	.7125	.7039
7	8	.0500	.0529	.9500	.9471

The observed probabilities of *table 5* allow us to calculate the Monte Carlo estimates

$$\widehat{ADS} = 4.185$$
$$\widehat{ASN} = 5.185$$
$$\hat{\alpha} = 0.047$$

Some discrepancies between the observed and exact probabilities at each stage are evident, but the Monte Carlo estimates of α and ASN are in relatively close agreement with the true values. These discrepancies are due to (a) the Monte Carlo procedures used in estimating the decision points at each stage of the test, and (b) the Monte Carlo procedures used to obtain the observed probabilities themselves. The exact OC and ASN functions of the test are predetermined (but unknown) as a function of α, n_0, and the probability boundary pattern. The actual OC and ASN functions are determined by the estimated decision points, and are unknown but different from the exact functions. The observed OC and ASN functions are estimates of the actual OC and ASN functions. The differences between the exact and actual test and related OC and ASN functions are due to (a) above, while the differences between the actual and observed OC and ASN functions are due to (b) above. The observed OC and ASN functions are used to approximate the OC and ASN functions of the exact test.

Comparison of New Procedure

To evaluate the properties and the possible applicability of the new test (TSTT), we compared it with the fixed sample size t-test (RAND) and Barnard's one-sided sequential t-test (BSTT) for the following problem:

$$H_0: E(X) = \mu = \mu_0$$
$$H_1: \mu > \mu_0$$
$$X \sim NIID(\mu, \sigma^2)$$
$$\sigma^2 \text{ unknown}$$

Our truncated test with $\alpha = 0.05$, $n_0 = 8$, and Pattern 3 probability boundary *(table 4, fig. 1)* yielded a Monte Carlo estimate of β of 0.057 at $\delta = 1.5$, so we compared it with these tests: (a) Barnard's test with nominal $\alpha = 0.05$, $\beta = 0.05$ at $\delta = 1.5$; and (b) fixed sample size t-test with nominal $\alpha = 0.05$ and $\beta = 0.039$ at $\delta = 1.5$ (sample size of 7).

The upper and lower decision boundaries of Barnard's tests were obtained with the aid of special tables (Davies 1967). The test statistic at each stage is

$$U_n = \sum_{i=1}^{n}(x_i - \mu_0) \Big/ \sqrt{\sum_{i=1}^{n}(x_i - \mu_0)^2}$$

The decision boundaries for Barnard's test are illustrated in *fig. 4*. Barnard's test is open in that the decision boundaries never meet.

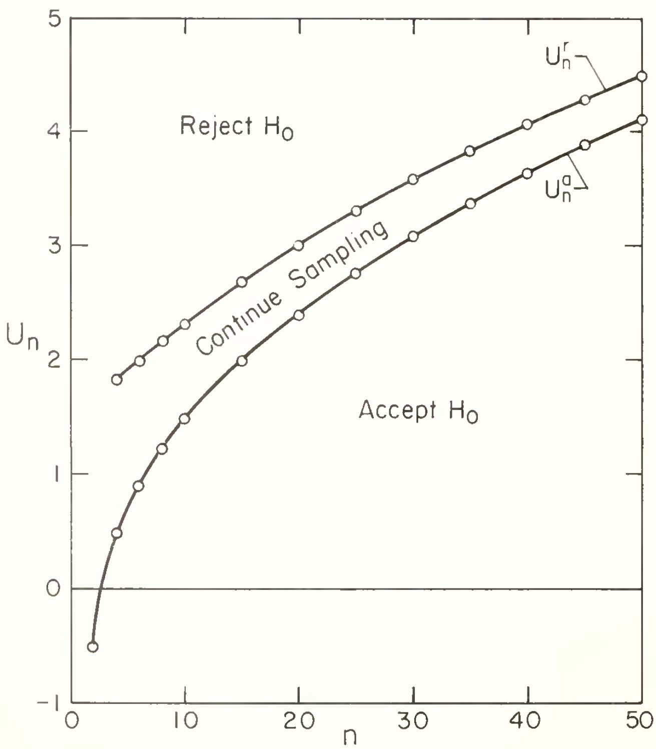

Figure 4—Upper rejection (U_n^r) and lower acceptance (U_n^a) boundaries of Barnard's one-sided sequential t-test (α = 0.05 and β = 0.05 at δ = 1.5). Encircled values are from Davies (1967, Table L-6).

Table 6—OC *and* ASN *values as a function of the non-centrality parameter* (δ) *for a TSTT (Pattern 3,* S = 7, n_0 = 8, n_1 = 2, n_s = 1 (s > 1) *and* α = 0.05*), a fixed sample t-test* (n = 7)*, and Barnard's one-sided open test* (α = 0.05, β = 0.05 *at* δ = 1.5).

δ	OC			ASN		
	Truncated	Fixed	Barnard	Truncated	Fixed	Barnard
-3.0	1.000	1.000	1.000	2.64	7.00	2.00
-2.0	1.000	1.000	1.000	2.83	7.00	2.01
-1.0	1.000	1.000	1.000	3.41	7.00	2.17
.0	.949	.952	.968	5.28	7.00	3.86
.5	.712	.655	.733	6.14	7.00	6.98
1.0	.308	.232	.188	5.95	7.00	8.04
1.5	.057	.041	.016	4.97	7.00	5.74
2.0	.002	.001	.001	4.29	7.00	4.68
3.0	.000	.000	.000	3.69	7.00	3.96
4.0	.000	.000	.000	3.48	7.00	3.75
5.0	.000	.000	.000	3.35	7.00	3.60
6.0	.000	.000	.000	3.21	7.00	3.46

The fixed sample t-test with a sample size of 7 is based on the test statistic

$$t_6 = (\bar{x} - \mu_0) \Big/ \sqrt{\sum_{i=1}^{7} (x_i - \bar{x})^2 / 42}$$

which is compared with $t_{0.05,6}$ = 1.943 in making the appropriate decision for the conventional fixed sample size test.

Each of 12 normal distributions with δ varying from -3 to 6 were sampled a thousand times *(table 6, fig. 5)* with each of the three tests. Both OC and ASN functions are presented as functions of δ.

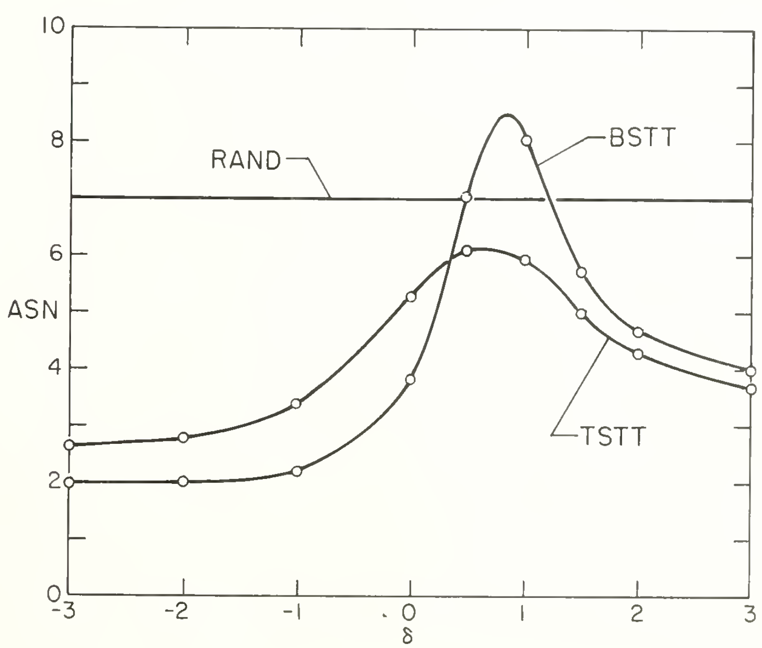

Figure 5—ASN as a function of the non-centrality parameter (δ) for TSTT (Pattern 3, S = 7, n_0 = 8, n_1 = 2, n_s = 1 (s > 1), and α = 0.05), RAND (n = 7), and BSTT (α = 0.05, β = 0.05 at δ = 1.5). Computed points are encircled. Curves are fitted by eye.

Table 7—*Observed probabilities of sample numbers* (SN) *as a function of the non-centrality parameter* (δ) *for TSTT (Pattern 3,* $S = 7$, $n_1 = 2$, $n_s = 1$ $(s > 1)$ *and* $\alpha = 0.05$*) and BSTT* ($\alpha = 0.05$, $\beta = 0.05$ *at* $\delta = 1.5$). *Observed* ASN *and its standard error* $s_{\widehat{ASN}}$ *are given.*

SN	δ=-1.0		δ=0.0		δ=1.0		δ=2.0	
	Truncated	Barnard	Truncated	Barnard	Truncated	Barnard	Truncated	Barnard
2	0.1025	0.8665	0.0310	0.3590	0.0115	0.0465	0.0145	0.0030
3	.4835	.1030	.1050	.2295	.0485	.0565	.1515	.0775
4	.3345	.0225	.1900	.1355	.1500	.1720	.4265	.5075
5	.0695	.0055	.2390	.0830	.1630	.1455	.2750	.2550
6	.0100	.0015	.2295	.0600	.1710	.1070	.0945	.0755
7	0	.0010	.1475	.0415	.2180	.0900	.0300	.0405
8	0	0	.0580	.0290	.2380	.0510	.0080	.0210
9	0	0	0	.0225	0	.0495	0	.0095
10	0	0	0	.0105	0	.0435	0	.0065
11-20	0	0	0	.0280	0	.1930	0	.0040
21-30	0	0	0	.0015	0	.0375	0	0
31-40	0	0	0	0	0	.0065	0	0
41-50	0	0	0	0	0	.0015	0	0
$\widehat{ASN}$	3.4010	2.1755	5.2055	4.0110	6.0395	8.3660	4.4055	4.6565
$s_{\widehat{ASN}}$	.0180	.0114	.0331	.0625	.0279	.1320	.0234	.0306

The results of a comparison of the distribution of sample sizes for four normal distributions, each sampled 2000 times, for TSTT and BSTT are given in *table 7*. Given the absolute guarantee of a limiting sample size, TSTT compares favorably with RAND and BSTT.

The Monte Carlo estimates of α at $\delta = 0$ are quite close to the nominal α for TSTT and RAND and distinctly less than the nominal α for BSTT *(table 6)*. The estimate of β at $\delta = 1.5$ is relatively close to the nominal β for RAND and distinctly less than the nominal β at $\delta = 1.5$ for BSTT. TSTT was chosen such that the Monte Carlo estimate of β at 1.5 was 0.057. The standard deviation ($s_{\widehat{oc}}$) for the estimate of the OC point is 0.007 and indicates that β is quite close to the true unknown β at $\delta = 1.5$.

The Monte Carlo estimate of the ASN function for TSTT is uniformly lower than the ASN function for RAND and uniformly lower than the ASN function for BSTT for $\delta > 0.3$ *(fig. 5)*.

The range of sample sizes is considerably larger for BSTT than for TSTT because of the open nature of the decision boundaries of BSTT *(table 7)*. The sample size for TSTT can be no larger than n_0=8 for the above example. The standard errors of the Monte Carlo estimates of the ASN points ($s_{\widehat{ASN}}$) indicate that $\widehat{ASN}$ is quite close to ASN for both TSTT and BSTT. Fowler[4] found this to be true for other examples of TSTT.

These results indicate the possible applicability of TSTT to many problems for which fixed sample size or other sequential t-tests have been used in the past.

APPLICATIONS IN FORESTRY

We know of no applications of sequential t-tests in the field of forestry. The application of sequential procedures has been largely limited to Wald's SPRT. We offer two examples where the SPRT has been used but where sequential t-tests may be more efficient.

Sequential procedures based on Wald's SPRT have been developed for (a) sampling of ribes populations

[4]Fowler, G. W. *An investigation of some new sequential procedures for use in forest sampling.* 1969. (Unpublished Ph.D. thesis on file at University of California, Berkeley)

in the control of white pine blister rust (*Cronartium ribicola* Fisher) in California (Offord 1966); and (b) sampling of brood densities of the Engelmann spruce beetle (*Dendroctonus engelmanni* Hopk.) in standing trees to determine infestation trends (Knight 1960). In each case, preliminary field studies indicated that real-world distribution of the pertinent variable was best described by the negative binomial distribution.

In the ribes work, the problem is to test whether the average number of feet of live stem (FLS) per acre of *Ribes* spp. (native currants or gooseberries) on a forest area meets a certain standard (μ_0) after a private contractor has completed eradication work on that area. Ribes eradication is carried out in order to eliminate the alternate host (ribes plants) of white pine blister rust and thereby break the weakest link in the life cycle of this forest disease.

An SPRT is constructed to determine whether or not the contractor met the standard. This standard is set according to the blister rust hazard of the area. The null hypothesis H_0: $\mu \leq \mu_0$ FLS/plot is tested against the alternative hypothesis H_1: $\mu > \mu_0$ with α and β set at μ_0 and μ_1, respectively, and a "pooled" estimate of K (the non-test parameter of the negative binomial distribution) being determined. The sequential procedure is to compare the cumulative FLS/plot, at each stage of the test, with the appropriate decision boundaries.

In the beetle work, in late June in stands of Engelmann spruce, the problem is to ascertain whether or not immediate control work is needed. An SPRT is constructed to determine if brood densities are high or low. The null hypothesis H_0: $\mu = 4$ beetles per 6- by 6-inch bark sample (no control necessary) is tested against the alternative hypothesis H_1: $\mu = 5$ beetles per bark sample (treatment necessary) with α (set at μ_0) and β (set at μ_1) and a "pooled" estimate of K being determined. The sequential procedure is to compare the cumulative number of beetles per bark sample, at each stage of the test, with the appropriate decision boundaries.

It would seem that sequential t-procedures and, in particular, the truncated sequential t-test would compare quite favorably to the SPRT in each of the above two examples. The SPRT, besides being an open test, assumes prior knowledge of the underlying distribution and that the "pooled" estimate of K is approximately equal to the K of the population being sampled. In a preliminary study, Fowler[5] found that the truncated sequential t-test compared favorably with the SPRT—even for distributions that were other than normal and highly irregular. These results plus the economic desirability of an upper limit to the number of observations in a given sample seem to indicate that the proposed test should be considered in certain forest sampling problems.

FIELD APPLICATION

To find out if the new procedure is operationally feasible in the field, we investigated the field procedure necessary to sample real-world forestry populations.

Since d_n is a rather difficult statistic to calculate in the field at each stage of the test, d_n can be transformed to U_n in which

$$U_n = nd_n \Big/ \sqrt{n(n-1+d_n^2)^2} = \sum_{i=1}^{n}(x_i - \mu_0) \Big/ \sqrt{\sum_{i=1}^{n}(x_i - \mu_0)^2}$$

This formulation is a monotone function of d_n and considerably easier to calculate. The OC and ASN functions that describe a particular test based on d_n will, of course, also describe the related test based on U_n. It is a simple procedure to convert the decision boundaries of a one-sided truncated sequential t-test from values of d_n to U_n.

When discrete distributions are sampled, the possibility of a series of observations starting with the first observation having the same value, say x^0, arises. Therefore, we have

$$U_n = \sum_{i=1}^{n}(x^0 - \mu_0) \Big/ \sqrt{\sum_{i=1}^{n}(x^0 - \mu_0)^2}$$

$$= n(x^0 - \mu_0) \Big/ \sqrt{n(x^0 - \mu_0)^2}$$

which reduces to $\sqrt{n}$ or $-\sqrt{n}$ depending on whether $x^0 > \mu_0$ or $x^0 < \mu_0$. The statistic U_n is set at zero when $x^0 = \mu_0$. U_n is superior to d_n for this case since

$$d_n = (\bar{x} - \mu_0) \Big/ \sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2/n(n-1)}$$

$$= (x^0 - \mu_0) \Big/ \sqrt{(x^0 - x^0)^2/(n-1)}$$

[5] Fowler, G. W. *An investigation of some new sequential procedures for use in forest sampling.* 1969. (Unpublished Ph.D. thesis on file at University of California, Berkeley)

which reduces to $(x^0-\mu_0)/0$. d_n can be set at zero when $x^0 = \mu_0$ but no meaningful value of d_n can be obtained when $x^0 \neq \mu_0$. In such cases, observations would have to be taken until the first observation with a different value occurred before starting the decision process. This would greatly affect the OC and ASN functions of the test.

The ribes example considered earlier will be used to illustrate the field application of the new test. Assume that the forest sampler has chosen the truncated test considered earlier, with $n_0 = 8$, $\alpha = 0.05$, and Pattern 3. Assume that this test yields the combination of OC and ASN that the forest sampler considers desirable for this problem with appropriate decision boundaries in terms of the statistic U_n *(fig. 6)*.

Assume $H_0: \mu \leq 15$ FLS/acre is tested against $H_1: \mu > 15$. A Field Tabulation Sheet *(fig. 7)* can be used in the application of the proposed truncated test to a simulated ribes population using the statistic U_n. The sampling procedure is as follows:

1. Take two observations at random from the population, yielding observations 10 and 15 FLS for our example.
2. Subtract $\mu_0 = 15$ from $x_1 = 10$ and $x_2 = 15$, calculate $(x_1 - \mu_0)^2$ and $(x_2 - \mu_0)^2$ (can be accomplished with a pocket electronic calculator), and then calculate $\sum_{i=1}^{2}(x_i - \mu_0)$ and $\sum_{i=1}^{2}(x_i - \mu_0)^2$.
3. Calculate $\sqrt{\sum_{i=1}^{n}(x_i - \mu_0)^2}$ (can be accomplished using a pocket electronic calculator), calculate $U_2 = \sum_{i=1}^{2}(x_i - \mu_0) \Big/ \sqrt{\sum_{i=1}^{2}(x_i - \mu_0)^2}$ on the Field Tabulation Sheet *(fig. 7)* and compare $U_2 = -1.00$ with U_2^a and U_2^r. Since $U_2^a < U_2 < U_2^r$, take another observation.
4. Repeat steps 2 and 3 for $n = 3$. This yields $U_3 = -1.27$, and since $U_3^a < U_3 < U_3^r$, take another observation.
5. Repeat steps 2 and 4 for $n = 4$. This yields $U_4 < U_4^a$, stop and accept H_0.

The results of the above example can be followed graphically in *fig. 6*.

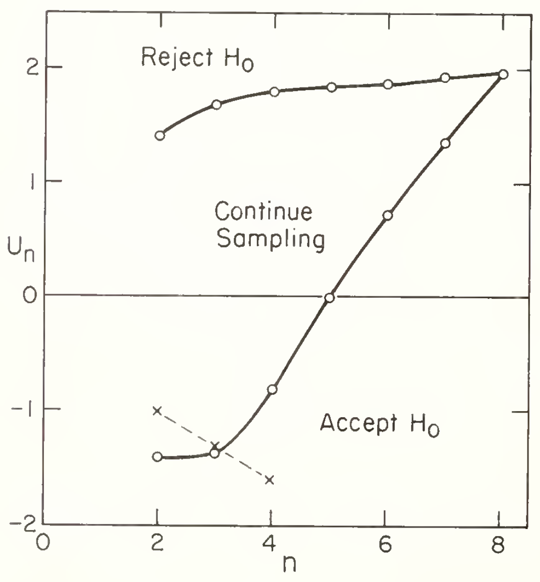

Figure 6—Acceptance and rejection boundaries in terms of U_n for a Pattern 3 test with $S = 7$, $n_0 = 8$, $n_1 = 2$, $n_s = 1$ ($s > 1$), and $\alpha = 0.05$. Computed points are encircled. Curves are fitted by eye. Dashed lines connecting points (x) illustrate a field application (see Fig. 7).

The field operation of the new procedure seems to be feasible and straightforward. The use of the transformation U_n simplifies the operation considerably. Some sample calculations must be made in the field at each stage of the test, but with the aid of a small pocket-size electronic calculator, such calculations are not too difficult.

We suggest that researchers consider the use of the new procedure instead of the usual fixed sample size test for all sampling problems where acceptance or rejection of some standard (μ_0) is desired. The new procedure would be particularly applicable where observations are time-consuming, expensive, and/or destructive, as on the average, only 40% to 60% as many observations are needed as for equally reliable fixed sample-size procedures.

To choose a specific one-sided truncated sequential t-test, the researcher would have to choose meaningful values of α and β for the specific problem and decide on a truncation point. The sampling frame for the population to be sampled should be constructed so as to minimize the difficulty of taking a sequential random sample in the field. A procedure for supplying random numbers to the sampler one at a time should be implemented to insure independence of observations. Field personnel should be thoroughly trained in the operation and decision process and in the calculation procedure for the new test. Field tabulation sheets should be waterproof and bound in a field book with a water-proof hard cover.

FIELD TABULATION SHEET FOR A ONE-SIDED TRUNCATED SEQUENTIAL t-TEST (PAT 3): $n_0 = 8$, $\alpha = 0.05$, $\beta = 0.05$ @ $\delta \approx 1.5$.

n	ACCEPT H_0	ACCEPTANCE BOUNDARY	U_n	REJECTION BOUNDARY	REJECT H_0
2		-1.4062	-1.00	1.4142	
3		-1.3699	-1.27	1.7053	
4	X	-0.8186	-1.61	1.8065	
5		0.0011		1.8540	
6		0.7432		1.8817	
7		1.3696		1.8898	
8		1.9778		1.9778	

n	X_i	μ_0	$X_i-\mu_0$	$\sum_1^n(X_i-\mu_0)$	$(X_i-\mu_0)^2$	$\sum_1^n(X_i-\mu_0)^2$	$\sqrt{\sum_1^n(X_i-\mu_0)^2}$	U_n
1	10	15	-5	-5	25	25		
2	15	15	0	-5	0	25	5.00	-1.00
3	0	15	-15	-20	225	250	15.81	-1.27
4	1	15	-14	-34	196	446	21.12	-1.61
5								
6								
7								
8								

COMMENTS OR CALCULATIONS:

Figure 7—Suggested field tabulation sheet for a one-sided truncated sequential t-test (Pattern 3, S = 7, $n_0 = 8$, $n_1 = 2$, $n_s = 1$ (s > 1), and $\alpha = 0.05$).

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A new procedure for constructing one-sided truncated sequential t-tests and its application to natural resource sampling are described. Monte Carlo procedures were used to develop a series of one-sided truncated sequential t-tests and the associated approximations to the operating characteristic and average sample number functions. Different truncation points and decision boundary patterns were examined. The fixed sample size t-test and Barnard's open one-sided sequential t-test were compared with the new procedure. The upper one-sided test described can easily be modified to a lower one-sided test.

Oxford: 524.63–015.5.
Retrieval Terms: biometrics; sampling; sequential sampling; t-test.

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PACIFIC SOUTHWEST Forest and Range Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701

PONDEROSA PINE PROGENIES: differential response to ultramafic and granitic soils

James L. Jenkinson

USDA FOREST SERVICE RESEARCH PAPER PSW-101/1974

CONTENTS

The Author

JAMES L. JENKINSON is a research plant physiologist investigating the genetics of western forest trees, with headquarters in Berkeley, California. He earned a bachelor of science degree in forestry (1957) and a doctorate in plant physiology (1966) at the University of California, Berkeley. He joined the Station staff in 1966, after working as an Assistant Specialist in the University's School of Forestry and Conservation.

SUMMARY

Jenkinson, James L.
1974. **Ponderosa pine progenies: differential response to ultramafic and granitic soils.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif., 14 p., illus. (USDA Forest Serv. Res. Paper PSW-101)

Oxford: 174. 7 *Pinus ponderosa* (794): 232.13: 181.342
Retrieval Terms: Pinus ponderosa; genetic variation; progeny trials, nutrient uptake; serpentine soils; California.

Ponderosa pine *(Pinus ponderosa* Laws.*)* in Oregon and California typically grows on a wide variety of nutritionally contrasting soils ranging from highly fertile granitic to very infertile ultramafic types. Its presence on such diverse soils suggests edaphic adaptations in this widely distributed, commercially important forest tree.

Ultramafic soils are commonly deficient in calcium (Ca), nitrogen (N), phosphorus (P), potassium (K), and high in magnesium (Mg), but are also highly variable. Thus, ponderosa pines on these soils vary in growth and associated vegetation, yet contrast with those on adjacent, more fertile soils in their slower growth and different species associates.

This paper reports a study to explore inherent differences between trees in the capacities of their progenies to grow on granitic and ultramafic soils, and to determine whether differences are related to the nutritional conditions of soils supporting the seed parents.

Wind-pollinated progenies from selected ponderosa pines in northern California were grown on a granitic soil and on a range of soils derived from ultramafic rocks. Seed was collected from nine trees in six stands in the northern Sierra Nevada. Two trees were sampled on a granitic soil (Holland series); the other seven grew on soils (Henneke, Dubakella, Cornutt series are examples) that represent the full range of ultramafic parent materials. Survival, first-year growth, and nutrient uptake of selected progenies were compared in four greenhouse tests. The granitic test soil was chosen for its high fertility; the infertile ultramafic test soils were chosen for their range of parent rocks and chemical differences.

The progenies showed inherent differences in growth, nutrient uptake, and mycorrhizae formation, depending on the test soil. Growth differences between granitic and ultramafic progenies, and between ultramafic progenies, were mainly related to differences in Ca uptake. Progenies with the better growth consistently had higher Ca concentrations in the seedling roots, tops, or both. Large growth differences between progenies on some ultramafic soils, and smaller or no differences on other ultramafics and the granitic soil, were explained by progeny differences in the capacity to take up Ca and by differences in Ca availability among soils. Growth differences were greatest at moderate-to-low levels of Ca availability, and least at very low and high levels. Growth differences between progenies were not closely related to differences in mycorrhizae formation.

On the granitic and more common ultramafic soils, top growth was associated with shoot Ca concentration in the granitic progenies, and with Ca and N in ultramafic progenies. Root growth was related to root P (and possibly N) concentration in granitic progenies, but to N and K in the ultramafic progenies.

On a localized, extremely infertile ultramafic soil, all seedlings from granitic progenies died in less than 3 months, while about 20 percent of those from two ultramafic progenies were alive at 6 months.

When a severe water stress was imposed and rates of seedling mortality were noted, no difference in drought tolerance was found between progenies on either granitic or ultramafic soils.

The inherent variation in first-year growth and survival of these ponderosa pine progenies shows that some of the parent trees chosen for this study are better adapted than others to the nutritional conditions found in ultramafic soils. Although the possibility of hybridization or introgression with Jeffrey pine – which grows extensively on ultramafic soils – existed for several of the ultramafic progenies, the more likely explanation of the adaptive capacity observed is simply variability within ponderosa pine.

The inherent variation in growth and nutrient uptake of the progenies on ultramafic soils implies that similar variation may exist in adaptedness to other forest soils. Growth differences between the progenies were large enough to suggest selection for specific soil types by progeny-testing seed parents.

One of the most widely distributed trees in western North America, ponderosa pine *(Pinus ponderosa* Laws.*)* shows geographic and elevational variation that reflects climatic adaptations.[1] Its presence on a wide range of nutritionally contrasting soils – especially in Oregon and California – suggests there may also be edaphic adaptations in this forest tree.

Among the most infertile forest soils are those derived from ultramafic rocks. Such rocks consist mainly of ferromagnesian minerals, and soils formed on them are usually deficient in nitrogen, phosphorus, potassium, and calcium and high in magnesium (Krause 1958, Kruckeberg 1969, Walker 1954). Ponderosa pine occurs sparingly on these soils in a wide variety of climates in the Wenatchee Mountains of central Washington (Kruckeberg 1969), in the Strawberry Range of east-central Oregon, and in the North Coast Ranges, Klamath Mountains, and from below 2,000 to nearly 6,000 feet in the northern Sierra Nevada of California.

Ponderosa pine is known on soils formed on peridotites, serpentinites, slickentite -- a highly-sheared serpentinite (Walker and Griggs 1953) – and other ultramafic rocks showing various degrees of alteration from peridotite to altered serpentinite. Because of such diversity in soil parent material, the stands vary greatly in tree growth, spacing, and associated species. Most of them are in sharp contrast with stands on adjacent fertile soils by their remarkably different vegetation, slower growth, and generally more open character.

Surprisingly few studies have dealt with edaphic adaptations in woody plants: Habeck (1958) compared the growth of white cedar *(Thuja occidentalis* L.*)* seedlings from upland (drained) and lowland (swampy) stands on both well-drained and poorly-drained soils; roots of upland seedlings were twice as long in well-drained, but only half as long in poorly-drained soil as roots of lowland seedlings. Griffin (1965) found no obvious differential response in first-year growth of seedlings from 17 Digger pine *(P. sabiniana* Dougl.*)* stands, including five on ultramafic soils, when the seedlings were grown on both an extremely infertile serpentinite (slickentite) and a fertile granitic soil. Kruckeberg (1967) outplanted lodgepole pine *(P. contorta* Dougl.*)* seedlings from three ultramafic and two non-ultramafic sources on an ultramafic soil, and found the ultramafic sources eventually showed much better top growth. Such apparently nutritional adaptations are common among the many investigated herbaceous species with ultramafic and non-ultramafic populations; plants from the former frequently show the better growth on ultramafic soil (Kruckeberg 1951, 1954, 1967).

This paper reports a study of wind-pollinated progenies from ponderosa pine trees growing on granitic and ultramafic soils in the northern Sierra Nevada of California. The study considered two questions: Are there inherent differences between trees in the capacities of their progenies to grow on ultramafic and granitic soils? If differences exist, are they related to the nutritional conditions of soils supporting the seed parents?

METHODS AND MATERIALS

The performances of the progenies were compared in four greenhouse tests:

Test A: Survival and growth of granite and slickentite progenies were compared on granitic and peridotite soils, both with and without water stress.

Test B: Survival of granite, serpentinite, and slickentite progenies were compared on granitic and slickentite soils, while growth and nutrient uptake of the same progenies were compared on granitic and serpentinite-peridotite soils.

Test C: Growth and nutrient uptake of granite and serpentinite progenies were compared on soil supporting the serpentinite parents and on granitic soil.

Test D: Growth and nutrient uptake of peridotite and serpentinite-peridotite progenies were compared on soil supporting the serpentinite-peridotite parent, and on granitic and peridotite soils.

Cones were collected from nine trees in six stands *(table 1)*; the seeds were extracted in sunlight, cleaned, and stored at 1° C. The ultramafic test soils represented the full range in parent materials *(table 1)*. To obtain additional chemical differences, soil was taken from both the A and B horizons *(table 2)*. The granitic test soil was known to be fertile. Each soil

[1] See Callaham 1962; Callaham and Liddicoet 1961; Conkle 1973; Mirov, Duffield, and Liddicoet 1952; Squillace and Silen 1962; Weidman 1939; Wells 1964a,b.

Table 1—*Origins of wind-pollinated ponderosa pine progenies and of ultramafic and granitic soils employed in the tests*

Item	Locality and California county	Elevation	Soil series
		Ft.; and m.	
Progeny:			
Granite[1]	Sand Mountain, El Dorado	4,300; 1,311	Holland
Slickentite a, b[2]	Brush Creek, Sierra	4,600; 1,402	(a lithosol)
Serpentinite	Ramshorn Creek, Sierra	2,800; 853	Henneke-like
Serpentinite a, b[2]	Johntown Creek, El Dorado	1,920; 585	Henneke
Peridotite	Rocky Point, Plumas	5,040; 1,536	Cornutt
Serpentinite-peridotite	Meadow Valley Creek, Plumas	3,750; 1,143	Weitchpec- or Dubakella-like
Soil:			
Granitic (quartz monzonite)	Ben Lomond Mountain, Santa Cruz	2,500; 762	Sheridan
Peridotite A, B[3]	Little Red Mountain, Mendocino	2,700; 823	Cornutt
Serpentinite A, B[3]	Johntown Creek, El Dorado	1,920; 585	Henneke
Serpentinite-peridotite A, B[3]	Meadow Valley Creek, Plumas	3,700; 1,128	Weitchpec- or Dubakella-like
Slickentite	Clear Creek, San Benito	3,200; 975	(a lithosol)

[1]Pooled collection from two trees.
[2]Two single-tree collections.
[3]Two horizons sampled.

was sifted with a 5-mm. screen, blended, and transferred to containers 28 cm. diameter by 30 cm. deep. To insure that germination vigor did not confound the growth comparisons, only seeds with similar germination speeds were planted. For test A, 10 or 12 germinants per progeny were sown in each container; for each of the other tests, seven or eight were sown. The tests were replicated two (A, D), three (B), or four (C) times.

Seeds were stratified 10 weeks at 5° C. and germinated at 23° C. During seedling establishment, the soils were surface-watered as needed and damping-off fungi were controlled with Captan fungicide. Thereafter soils were surface- and deep-watered weekly. Deionized water was used throughout to avoid the addition of essential elements. To eliminate greenhouse position effects, I randomized all containers and rotated them frequently.

Test A extended from early May to mid-December; B, C, and D extended from early May to late October in the following year. After growth ceased, the seedlings were lifted by washing out the roots and

Table 2—*Chemical analyses of ultramafic and granitic soils employed in greenhouse tests of ponderosa pine progenies*

Test soil	Profile sample depth	pH	Total N	Total P	Replaceable K^+	Replaceable Ca^{++}	Replaceable Mg^{++}	Cation exchange capacity	Ca^{++} saturation
	Cm.		*Percent*	*Percent*	*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Pct.*
Granitic	0-60	4.8	0.138	0.130	0.80	1.56	0.72	3.45	45.2
Peridotite A	0-30	6.3	.056	.081	.11	1.28	.59	2.63	48.6
Peridotite B	60-90	6.6	.002	.024	.03	.12	.45	1.50	8.0
Serpentinite A	0-15	6.3	.073	.016	.08	3.64	12.7	17.3	21.0
Serpentinite B	20-45	6.4	.046	.011	.06	1.92	20.2	21.0	9.1
Serpentinite-peridotite A	0-20	6.2	.063	.044	.15	1.70	23.1	24.2	7.0
Serpentinite-peridotite B	40-60	6.4	.015	.025	.13	1.12	44.7	43.7	2.6
Slickentite	0-15	8.8	.001	.000	.02	.22	42.0	6.83	3.2

rinsed in de-ionized water. In test A, the lengths of the tap root and each lateral root longer than 0.5 cm. were measured for each seedling. To estimate mycorrhizae, I recorded the number of coralloid structures – short roots with multiple dichotomies covered with fungal mycelium (Slankis 1958). To evaluate total growth, the shoot and roots were separated 1 mm. below the cotyledon node and weighed after oven-drying 48 hours at 70° C.

To evaluate nutrient uptake, the shoots and roots were separately combined by progeny and container, milled to pass a 40-mesh screen, and analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in duplicate 100-mg. samples. Nitrogen was determined by a micro-Kjeldahl method (Jackson 1958). P, K, Ca, and Mg were determined on samples wet-ashed in nitric-perchloric acid (Johnson and Ulrich 1959): P was determined by a molybdenum blue colorimetric method, K by flame emission, and Ca and Mg by atomic absorption. Growth and element concentration data were analyzed by variance and multiple regression analyses, and means were compared by t-tests (Steel and Torrie 1960).

To evaluate the test soils, replaceable K^+, Ca^{++}, and Mg^{++}, total N and P, cation exchange capacity, and pH were determined on duplicate samples passed through a 2-mm. screen *(table 2)*. Nitrogen was determined by a micro-Kjeldahl method, and P by nitric-perchloric acid digestion and a modified molybdenum blue method (Jackson 1958). The cations were extracted with neutral 1N ammonium acetate and determined as noted above. The cation exchange capacity was estimated by Ca^{++} saturation of the exchange complex (Rich 1961, 1962) and pH was determined on a saturation paste.

Table 3–*Growth of 35-day-old granite (G) and slickentite progenies (Sk) on granitic and peridotite soils (test A)*[1]

Soil and progeny	Shoot weight	Root weight	Lateral root length
	Gram	Gram	Cm.
Granitic:			
G	0.034	0.050	61
Sk a	.039	.048	53
Peridotite A:			
G	.028 b	.048 b	61 b
Sk a, b	.035 a	.063 a	91 a
Peridotite B:			
G	.021 b	.042 b	64 b
Sk a, b	.028 a	.050 a	91 a

[1]Means followed by unlike letters differ significantly at the 5 percent level.

Survival, Growth, Nutrient Uptake

Test A: At 35 days after sowing, the slickentite progenies showed better growth than granite progenies on the peridotite soils, but not on granitic soil *(table 3)*. On peridotite, the slickentite progenies had 25 to 33 percent greater shoot weight, 19 to 31 percent greater root weight, and 42 to 50 percent longer roots. All tap roots were down 28 to 30 cm., and no mycorrhizae were evident at this stage.

Many ultramafic soil sites are thinly vegetated, and unusually hot and dry during the summer. In such circumstances, seedling establishment probably requires adaptation to extended periods of high water stress as well as to nutritional deficiency. To check this possibility, I discontinued watering half of the seedlings when they were 2 months old.

No difference in drought tolerance between progenies was found. After 8 weeks of water stress, all seedlings on granitic soil (a loamy sand) were dead *(table 4)*, and rates of mortality were similar. After 15 weeks of stress – when watering was resumed – all seedlings on the peridotite soils (sandy clay loam, clay loam) still appeared healthy, though subsequent losses on peridotite-B soil were probably related to the stress period.

At 7 months, slickentite progenies continued to show better growth than the granite progenies on both peridotite soils *(table 4)*. Growth differences were large on peridotite-A, relatively small on the very infertile peridotite-B, and – except for shoot weight – not significant on the fertile granitic soil. On peridotite-A soil with no water stress, slickentite progenies averaged 60 percent more shoot weight, 55 percent more root weight, 53 percent more root elongation, and 81 percent more mycorrhizae. Severe water stress reduced the differences, but the slickentite progenies still showed 29 percent more shoot weight, 40 percent more root weight, and 32 percent more root elongation. On peridotite-B soil the watering regime exerted little, if any, influence on progeny differences. With or without water stress, slickentite progenies had higher shoot and root weights and greater root elongation than the granite progenies.

While root elongation was the same for progenies on granitic soil, it was consistently greater for the slickentite progenies on peridotite soil, suggesting an adaptation for improving nutrient uptake from nutri-

Table 4—*Survival and growth of granite (G) and slickentite progenies (Sk) on granitic and peridotite soils under two watering regimes (test A)*[1]

Soil and progeny	Survival	Shoot weight	Root weight	Lateral root length	Coral-loid structures
	Pct.	—— *Gram*	——	*Cm.*	
		Water adequate			
Granitic:					
G	100	0.74 b	0.93	545	0.4
Sk a, b	100	.92 a	1.07	546	1.2
Peridotite A:					
G	100	.30 b	.38 b	204 b	16 b
Sk a, b	100	.48 a	.59 a	312 a	29 a
Peridotite B:					
G	100	.19 b	.33 b	256 b	14
Sk a, b	100	.22 a	.40 a	303 a	16
		Water limiting			
Granitic:					
G	0	–	–	–	–
Sk a, b	0	–	–	–	–
Peridotite A:					
G	100	.14 b	.20 b	152 b	1.5
Sk a, b	100	.18 a	.28 a	201 a	3.0
Peridotite B:					
G	80	.092	.17 b	183	.7
Sk a, b	85	.11	.21 a	207	2.4

[1]Means followed by unlike letters differ significantly at the 5 percent level.

ent-deficient soil. Regression coefficients for root length on weight in peridotite soil were 0.94 with 35-day-old seedlings and 0.78 with 7-month-old seedlings. Since root elongation could be estimated by root weight, length measurements were discontinued.

Test B: During this test, water was never limiting, and no seedlings died on either the granitic or serpentinite-peridotite soils. On slickentite soil, however, all of the granite seedlings died within 3 months and roughly 20 percent of the ultramafic seedlings survived 6 months *(fig. 1)*. Eight days after planting, all seedlings were in the expanded-cotyledon stage and appeared healthy, but their subsequent epicotyl growth was severely stunted. Ten weeks later, when the last granite seedling was dead, 37 percent of the slickentite and 27 percent of the serpentinite seedlings were still living.

On the granitic and serpentinite-peridotite (SP) soils, both ultramafic progenies showed better root growth than the granite progenies, averaging 16 percent more growth in granitic and SP-B, and 21 percent more in SP-A soil *(table 5)*. The slickentite progeny consistently had the highest shoot Ca concentrations, and on SP-A soil both ultramafic progenies had higher root Ca concentrations.

Test C: On granitic soil, the granite progenies averaged slightly more growth than the serpentinite-b progeny, while the serpentinite-a progeny showed about 15 percent more shoot and root growth and 50 percent higher shoot Ca concentrations than the granite progenies *(table 6)*. The granite progenies had higher P and K concentrations in the shoots, and higher P in the roots.

Both serpentinite progenies clearly showed a greater capacity to grow on the serpentinite soils than did the granite progenies. On A-horizon soil, the serpentinite progenies had 27 and 37 percent more shoot growth, 36 and 58 percent more root growth, and about 25 percent higher shoot Ca concentrations. The serpentinite-b progeny also had about 46 percent high root Mg concentrations and roughly 60 percent more mycorrhizae than the serpentinite-a and granite progenies. On B-horizon soil the serpentinite progenies had 36 and 45 percent more shoot growth, 43 and 51 percent more root growth, and about 70 percent more mycorrhizae. The serpentinite-b progeny again had much higher root Mg concentrations than the

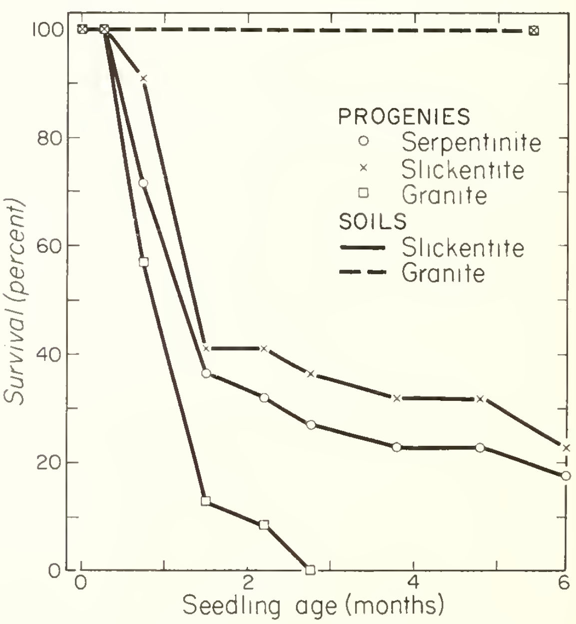

Figure 1—Survival of ponderosa pine on granitic and slickentite soils (test B).

Table 5—*Growth and element uptake of granite (G), serpentinite (S), and slickentite progenies (Sk) on granitic and serpentinite-peridotite soils (test B).*[1]

Soil and progeny	Shoot						Root						Coral-loid struc-tures
	Weight	N	P	K	Ca	Mg	Weight	N	P	K	Ca	Mg	
	Gram	*Mmole/g.*	*µmole/g.*	—— *Meq./g.* ——			*Gram*	*Mmole/g.*	*µmole/g.*	—— *Meq./g.* ——			
Granitic:													
G	0.36	1.34	50	0.35	0.18 b	0.11	0.50 b	0.63	32	0.22	0.18	0.18	3.7
S	.41	1.48	45	.29	.18 b	.13	.57 a	.67	27	.22	.20	.20	7.3
Sk b	.41	1.50	47	.32	.25 a	.16	.59 a	.67	29	.23	.19	.21	7.0
Serpentinite-peridotite A:													
G	.22	1.50	42	.20	.061 ab	.42	.33 b	.57	24	.13	.09 b	.39	28
S	.24	1.50	39	.20	.052 b	.42	.38 a	.58	22	.12	.16 a	.36	28
Sk b	.25	1.57	37	.18	.066 a	.44	.42 a	.57	19	.11	.17 a	.39	27
Serpentinite-peridotite B:													
G	.16	.98	36	.15	.046 b	.35	.28 b	.47	19	.099	.13	.30	19
S	.16	.93	35	.14	.052 ab	.37	.32 a	.44	20	.084	.13	.31	26
Sk b	.18	.98	36	.17	.061 a	.38	.33 a	.44	19	.086	.14	.30	27

[1] Means followed by unlike letters differ significantly at the 5 percent level.

Table 6—*Growth and element uptake of granite (G) and serpentinite progenies (S) on granitic and serpentinite soils (test C)*[1]

Soil and progeny	Shoot						Root						Coral-loid struc-tures
	Weight	N	P	K	Ca	Mg	Weight	N	P	K	Ca	Mg	
	Gram	*Mmole/g.*	*µmole/g.*	—— *Meq./g.* ——			*Gram*	*Mmole/g.*	*µmole/g.*	—— *Meq./g.* ——			
Granitic:													
G	0.44 ab	1.49 ab	46 a	0.32 a	0.20 b	0.14	0.59 ab	0.76	35 a	0.31	0.23	0.14	1.2
S a	.51 a	1.61 a	39 b	.27 b	.30 a	.17	.68 a	.82	27 b	.32	.24	.14	2.3
S b	.42 b	1.42 b	38 b	.26 b	.22 b	.16	.55 b	.78	28 b	.26	.23	.15	9.2
Serpentinite A:													
G	.32 b	1.55	37	.18	.072 b	.35	.36 b	.64	22	.15	.25	1.02 b	26 b
S a	.43 a	1.58	38	.18	.093 a	.41	.57 a	.63	22	.15	.22	.98 b	28 b
S b	.40 a	1.47	35	.17	.088 a	.39	.49 a	.65	19	.14	.23	1.46 a	43 a
Serpentinite B:													
G	.26 b	1.38	32	.18	.064	.34	.33 b	.59	22	.12	.27	1.30 b	37 b
S a	.37 a	1.31	30	.15	.066	.39	.50 a	.56	20	.12	.27	1.31 b	62 a
S b	.35 a	1.36	35	.16	.060	.37	.48 a	.55	20	.12	.30	2.54 a	63 a

[1] Means followed by unlike letters differ significantly at the 5 percent level.

others (95 percent more than the granite progenies), and evidently was an inherent magnesium accumulator.

Test D: The two ultramafic progenies used in this test displayed equal shoot growth on granitic soil *(table 7)*. However, the serpentinite-peridotite (SP) progeny had 32 percent more root growth, and about 30 percent higher shoot Ca and K concentrations than the peridotite progeny. On the peridotite soils, growth differences were not significant, although the SP progeny had slightly better growth and 30 percent higher shoot Ca concentrations on peridotite-A soil.

On SP-A soil, the SP progeny showed 45 percent more shoot growth, 49 percent more root growth, and 43 percent higher shoot Ca concentrations, while the peridotite progency had higher root P and Mg concentrations. On SP-B, the SP progeny showed 22 percent more root growth and 85 percent higher shoot Ca concentrations, while the peridotite progeny had higher root P concentrations and 62 percent more mycorrhizae.

Nutrients Limiting Growth

Interpretation of the relationship between plant growth and element concentrations in plant tissues normally depends on a knowledge of the critical concentration curves developed for the species. A typical curve has a near-vertical arm (element deficient) and a near-horizontal arm (element adequate). The smooth transition between the arms includes the critical concentration, a value associated with growth 5 to 10 percent below maximum (Ulrich 1961).

In the present study, scatter diagrams relating growth to element concentration showed relationships comparable to those in critical concentration curves *(fig. 2)*. Ca showed a typical curve for the shoots, and K for the shoots and roots. N and P showed only the vertical arm of the curve for the roots. Established forms of such curves were used to describe the relationships between seedling growth and element concentrations, and to identify those elements which probably limited growth of the granite and ultramafic progenies.

Table 7–*Growth and element uptake of peridotite (P) and serpentinite-peridotite progenies (SP) on granitic, peridotite, and serpentinite-peridotite soils (test D)*[1]

Soil and progeny	Shoot						Root						Coral-loid struc-tures
	Weight	N	P	K	Ca	Mg	Weight	N	P	K	Ca	Mg	
	Gram	*Mmole/g.*	*µmole/g.*	*Meq./g.*	*Meq./g.*	*Meq./g.*	*Gram*	*Mmole/g.*	*µmole/g.*	*Meq./g.*	*Meq./g.*	*Meq./g.*	
Granitic:													
P	0.37	1.78	44	0.27 b	0.23 b	0.15	0.53 b	0.82	34	0.28	0.24	0.21	8.7
SP	.38	1.94	50	.36 a	.30 a	.16	.70 a	.81	28	.30	.21	.19	1.6
Peridotite A:													
P	.20	1.85	40	.19	.10 b	.12	.41	.71	29	.14	.16	.12	23
SP	.23	1.98	50	.19	.13 a	.11	.47	.74	26	.12	.16	.10	15
Peridotite B:													
P	.14	1.38	39	.13	.071	.18	.40	.53	20	.076	.10	.10	15
SP	.15	1.53	48	.15	.077	.19	.45	.55	20	.071	.11	.10	15
Serpentinite-peridotite A:													
P	.20 b	1.56	51	.20	.051 b	.38	.35 b	.59	30 a	.15	.25	.38 a	59
SP	.29 a	1.60	44	.21	.073 a	.41	.52 a	.61	22 b	.14	.19	.30 b	54
Serpentinite-peridotite B:													
P	.16	1.09	32	.14	.034 b	.32	.31 b	.48	23 a	.11	.17	.23	39 a
SP	.17	1.17	36	.16	.063 a	.38	.38 a	.46	17 b	.10	.14	.22	24 b

[1]Means followed by unlike letters differ significantly at the 5 percent level.

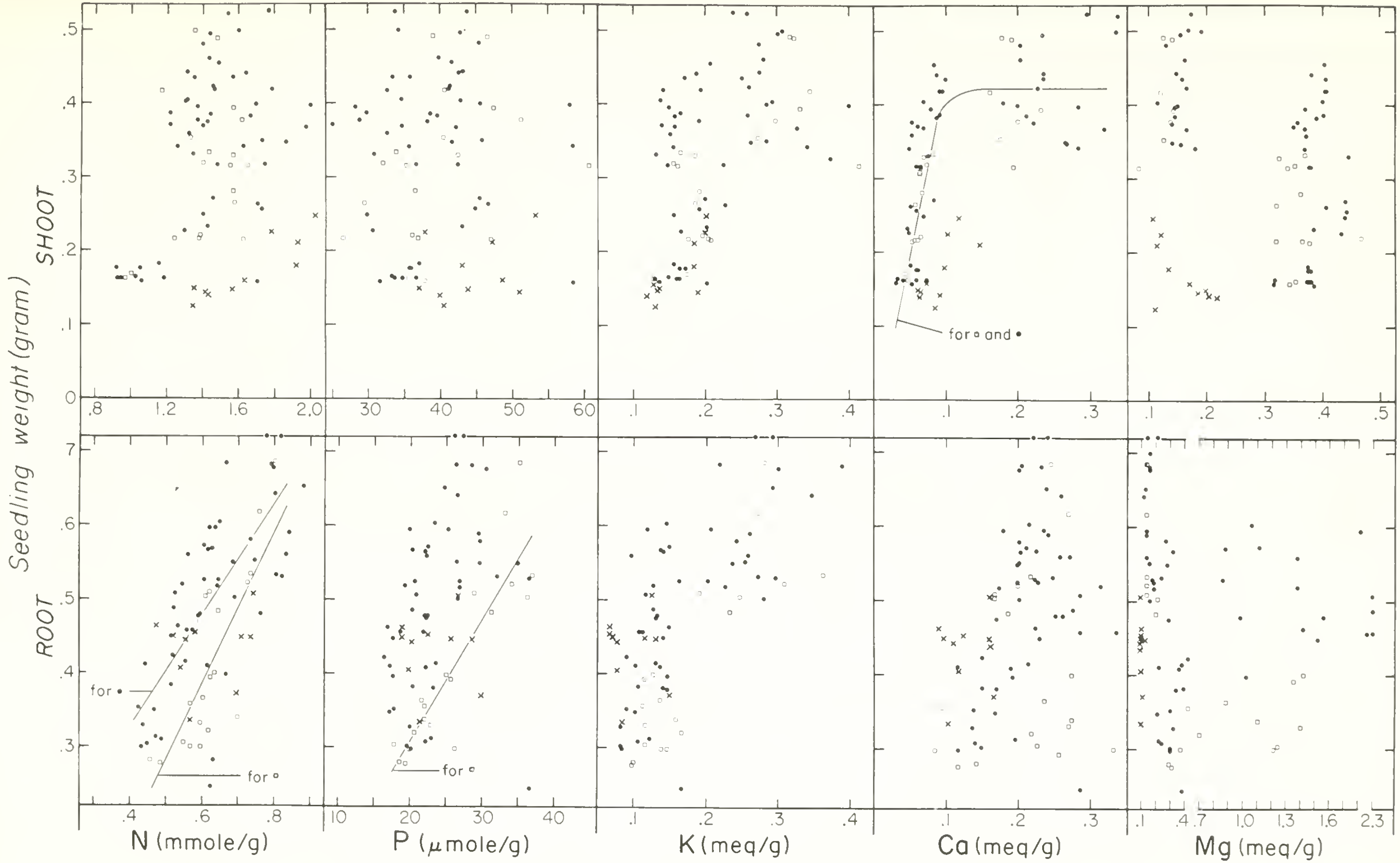

Figure 2—Growth and nutrient concentrations of ponderosa pine. □ shows granite and ● ultramafic progenies tested on granitic, serpentinite, and serpentinite-peridotite soils. X shows progenies grown on peridotite soils.

Curves were fitted to the shoot and root weights and corresponding N, P, K, Ca, and Mg concentrations by using stepwise multiple regression analysis. For seedlings on granitic, serpentinite, and serpentinite-peridotite soils, there were 50 observation sets for six ultramafic and 19 for two granite progenies. Each set included the mean shoot or root weight and the corresponding element concentrations for a given progeny and container. On peridotite soils 10 sets of data for two ultramafic progenies were analyzed separately because their patterns generally differed from those obtained on other soils *(fig. 2)*. Log transformations – $\log_e Y = a + b(\log_e X)$ and $\log_e Y = a + b(\log_e X) + c(\log_e X)^2$ – showed the best fit of the data, i.e., consistently higher coefficients of multiple determination (R^2), and were used throughout.

Simple regressions showed growth to be either positively or not correlated with N, P, K, and Ca concentrations. With Mg they showed growth to be mainly negatively correlated, although many of the larger ultramafic shoots and roots had very high Mg concentrations *(fig. 2)*. Because its inclusion did not alter the outcome, Mg was dropped from the multiple regressions.

For the granite and ultramafic progenies tested on granitic, serpentinite, and serpentinite-peridotite soils, multiple regression showed that shoot growth was significantly positively correlated with N and Ca, but not P and K *(table 8)*. Comparison of standard partial regression coefficients showed that Ca was only 1.4 times more important than N for explaining variation in shoot growth of ultramafic progenies, but 3.7 times more important for granite progenies. Moreover, inclusion of the quadratic for Ca (to obtain a better fit for shoot weight and Ca concentration data) dropped N from significance in the granite progenies, and the R^2 with N, P, K, and Ca in the regression was no greater than that with Ca alone *(table 8)*. Calcium seemingly was more limiting for shoot growth of granite than ultramafic progenies. Since the calcium deficiency was less severe in ultramafic progenies, the element in next shortest supply, N, was also limiting their shoot growth.

Table 8–*Coefficients of multiple determination (R^2) for growth and nutrient concentrations in ponderosa pine progenies tested on granitic, serpentinite, and serpentinite-peridotite soil*[1]

Progeny and dependent variable (wt., g.)	Independent variables (conc.)	R^2
Granite:		
Shoot	N*, P, K, Ca**	0.78
	N, P, K, Ca, Ca^2	.81
	Ca, Ca^2	.82
Root	N, P**, K, Ca	.84
	N*, P**	.86
Ultramafic:		
Shoot	N**, P, K, Ca**	.63
	N**, P, K, Ca, Ca^2	.69
	Ca, Ca^2	.55
Root	N*, P, K*, Ca	.62

[1]All values of R^2 were significant at the 1 percent level. Asterisks designate significant positive correlations at the 5 (*) and 1 (**) percent levels.

Using this same approach, I found different relationships for the roots. For the granite progenies, root growth was significantly positively correlated with P alone when N, P, K, and Ca were included in the regression. When just N and P were included, R^2 was slightly higher and root growth was correlated with both N and P. Comparison of the standard partial regression coefficients indicated P was twice as important as N for explaining the variation in growth. For the ultramafic progenies, root growth was significantly positively correlated with N and K, but not P. Comparison of the standard partial regression coefficients suggested N and K were equally important for explaining the variation in growth.

For ultramafic progenies on peridotite soils, the only significant standard partial regression coefficient was obtained for shoot N concentration. Since these N concentrations were not especially low, no element could really be singled out as limiting. It may be significant, however, that in all tests the lowest shoot and root K and Mg concentrations were found in seedlings on peridotite soils *(fig. 2)*.

DISCUSSION AND CONCLUSIONS

Ponderosa pine trees clearly differ in the inherent capacities of their wind-pollinated progenies to grow on ultramafic soils. Their progenies also differ in amount of mycorrhizae formation, but this variation does not explain the growth differences between progenies: In test A, slickentite and granite progenies differed significantly in mycorrhizae formation on only one peridotite soil, and then only when water was not limiting. But on both peridotite soils the progenies differed in growth whether or not water was limiting. All of the test B progenies had similar amounts of mycorrhizae on ultramafic soils, but the ultramafic progenies showed better root growth than the granite progenies on both serpentinite-peridotite soils. In test C, serpentinite and granite progenies different in mycorrhizae formation on only one serpentinite soil, even though the serpentinite progenies showed much greater growth on both serpentinite soils. And in test D, the serpentinite-peridotite progeny had greater root growth on both serpentinite-peridotite soils, but much less mycorrhizae formation on one of them than the peridotite progeny. On the fertile granitic soil, where mycorrhizae formation was always minimal, several progenies differed significantly in growth but not in mycorrhizae formation. Apparently, growth differences between progenies are not closely related to differences in mycorrhizae formation.

Growth differences between ultramafic and granitic progenies (tests B, C) and between ultramafic progenies (test D) were consistently associated only with differences in tissue Ca concentration: progenies with better growth had higher Ca concentrations in the roots, shoots, or both. The large differences between progenies in the capacity to grow on some ultramafic soils, and smaller or no differences on other ultramafic and granitic soils, can be explained by differences in capacity to take up Ca – especially from soil low in available calcium – and by differences in calcium availability among soils.

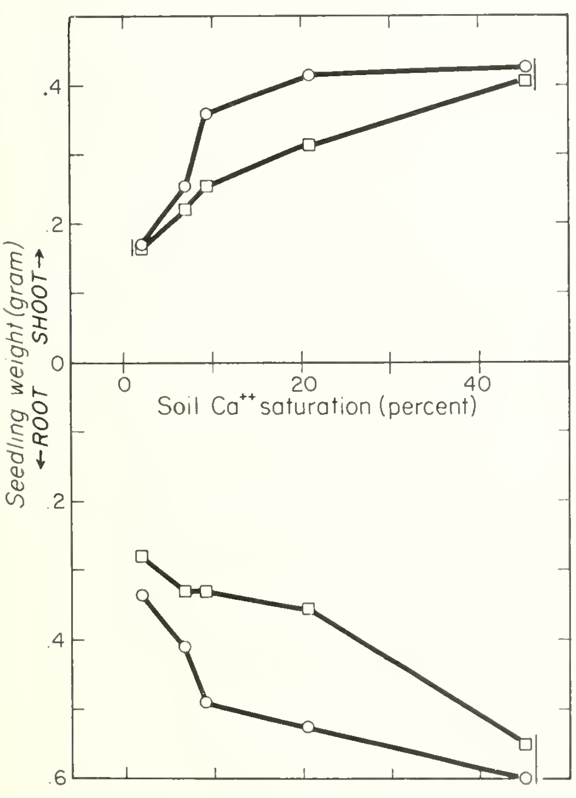

Figure 3—Influence of soil calcium availability on the growth of ponderosa pine. □ shows granite and ○ ultramafic progenies. Means not common to a vertical bar differ significantly at the 5 percent level.

Seedling growth on granitic and the more common ultramafic soils (serpentinite and serpentinite-peridotite) was closely related to soil Ca^{++} saturation, an index to soil calcium availability *(fig. 3)*. All progenies showed about equally good growth when calcium availability was high, and poor growth when it was very low.

The consistently better growth of ultramafic progenies in the 5 to 25 percent Ca^{++}-saturation range suggests they were the more efficient calcium absorbers. And comparison of seedling Ca contents shows that ultramafic progenies did take up more Ca than did the granite progenies *(fig. 4)*. With increases in Ca^{++} saturation above 7 percent, shoot Ca content – roughly proportional to Ca^{++} saturation from 2.5 to 45 percent – increased at greater rates in ultramafic progenies. Root Ca content of ultramafic progenies increased sharply with increase in Ca^{++} saturation from 2.5 to 9 percent and was essentially unchanged thereafter; in granite progenies root Ca content increased sharply with increase in Ca^{++} saturation from 7 to 9 percent, and continued to increase to the 45 percent level. With calcium availability between 2.5 and 25 percent, ultramafic progenies always showed more root growth (tests A-C) and higher root Ca contents than did the granite progenies.

On soil with very low Ca^{++} saturation *(fig. 3)*, differences in both growth and calcium uptake between granite and ultramafic progenies were greatly diminished. The cause may have been the near-zero calcium availability for all progenies, a relatively greater deficiency of some other essential element, and/or incipient magnesium toxicity. Lack of appreciable growth differences on soil with 45 percent Ca^{++} saturation simply reflects a level of calcium availability sufficient for maximum growth of both granite and ultramafic progenies, and several of the latter undoubtedly absorbed Ca in luxury amounts.

Relationships between seedling shoot growth and Ca concentration are direct evidence that the granite and ultramafic progenies responded differentially to calcium availability. Variation in shoot Ca concentration explained 82 percent of the variation in shoot growth of granite progenies, but only 55 percent in

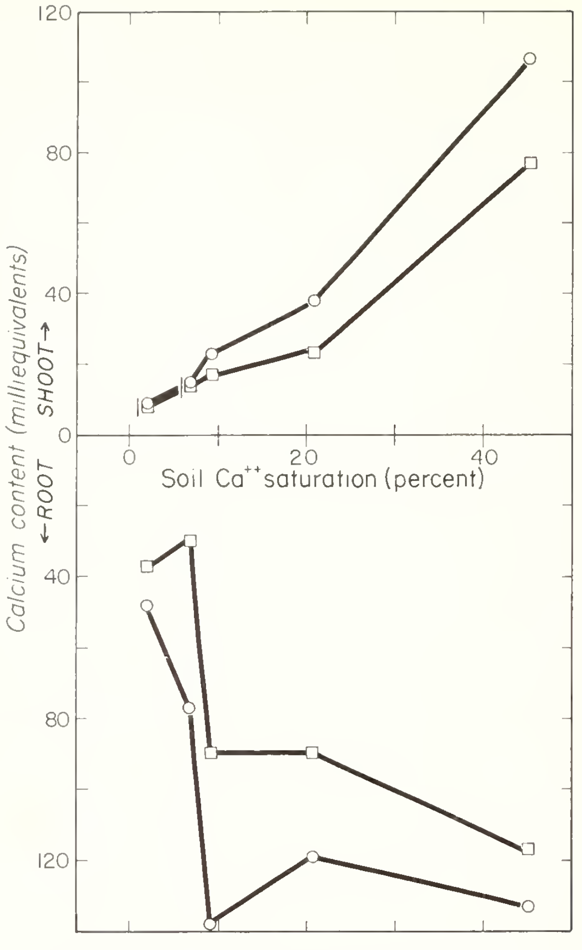

Figure 4—Influence of soil calcium availability on the calcium uptake of ponderosa pine. □ shows granite and ○ ultramafic progenies. Means not common to a vertical bar differ significantly at the 5 percent level.

ultramafic progenies. Ultramafic progenies absorbed more Ca, and translocated more Ca to seedling tops. Because Ca generally was more limiting for shoot growth of the granite progenies, their growth was the more closely related to shoot Ca concentration.

Differences between the granite and ultramafic progenies with respect to their N relationships were probably related to the differential uptake of Ca. Some ultramafic progenies appear to have absorbed and translocated sufficient Ca to cause N – apparently the element in next shortest supply – to become limiting for shoot growth. Nitrogen probably did not effectively limit shoot growth of the granite progenies because Ca, the element in shortest supply, was always translocated in too-small amounts.

At least in part, differences between element concentrations in the shoots and roots reflected differences between tissues in their relative requirements for nutrients, and in relative mobilities of elements in the seedlings. Thus nitrogen, which is highly mobile in plants, was generally in much higher concentration in the shoots. In contrast, Ca, the least mobile element, was in roughly three times greater concentration in the roots, where it apparently even accumulated to excess. The low mobility of Ca helps to explain why Ca was deficient in shoots but not in roots. Conversely, the high mobilities of N, P, and K may partly account for their seeming deficiencies in roots.

The most extreme nutritional condition was found on slickentite, a more localized soil than serpentinite and serpentinite-peridotite. No granite and only 20 percent of the ultramafic progenies even survived on this soil. The survival of some ultramafic seedlings was probably related to their better root growth and greater capacity to take up Ca, and perhaps other elements, at extremely low soil calcium availability. The slickentite soil was nutritionally sterile. Its very low Ca^{++} saturation, alkaline pH, and Mg/Ca ratio (190) all indicate a severe calcium deficiency. Another striking feature of the slickentite soil was its seemingly absolute phosphorus deficiency, but it was not determined whether ultramafic seedlings survived because the seeds contained more P than those from granite parents. Finally, the very high amount of replaceable Mg^{++}, six times the capacity of the exchange complex, indicates magnesium toxicity (Proctor 1970) as the lethal agent. In this root environment, progenies with an inherently great capacity to take up Ca would be expected to show tolerance because Ca exerts a protective action against toxic effects of other cations (Bonds and O'Kelley 1969; LaHaye and Epstein 1969; Wyn Jones and Lunt 1967).

Soil calcium availability was evidently of primary importance for determining amounts of pine seedling growth on the more common ultramafic soils (serpentinite, serpentinite-peridotite) and possibly slickentite. Numerous investigations have already implicated low calcium availability as the general "serpentine factor" affecting growth of herbaceous plants (Krause 1958; Kruckeberg 1954; Martin, Vlamis, and Stice 1953; Walker 1954; Walker, Walker, and Ashworth 1955; Vlamis 1949; Vlamis and Jenny 1948).

Peridotite soils differed from all of the other soils in seedling growth and nutrient uptake *(fig. 2)*. Growth was much less throughout a wide range of Ca^{++} saturation than it was at similar saturations on other soils *(table 2)*. There are several possible explanations for this response. The very low amounts of Ca in the peridotite soils may restrict plant growth even though Ca^{++} saturation of the exchange complex is high (Jenny and Cowan 1933; Key, Kurtz, and Tucker 1962). Errors in determining cation exchange capacity, caused by clay fractions high in amorphous or poorly-crystalline sesquioxides (Rich 1962), could produce erroneously high Ca^{++} saturation percents. Also, as noted earlier, essential elements other than Ca – K and even Mg – may limit seedling growth on peridotite soils.

The first-year survival and growth differences of the ponderosa pine progenies show that some of the parent trees chosen for this study are much better adapted than others to the nutritional conditions found in ultramafic soils. Two explanations of this adaptive capacity are possible. The first is simply variability within this species. The second is Jeffrey pine *(P. jeffreyi* Grev. & Balf.*)*, which grows extensively on ultramafic soils and is known to hybridize with ponderosa pine (Haller 1962; Righter and Duffield 1951). Several of the ponderosa pine seed parents were growing within a few hundred feet of Jeffrey pine, so the possibility of hybridization or introgression exists. However, these species differ in flowering time (Duffield 1953), cross with difficulty (Critchfield 1966) and only occasionally hybridize in nature (Haller 1962). Since both the seed parents and the seedlings were typically ponderosa pine in morphology, the more likely explanation of adaptive capacity is variability within the species.

The inherent variation in growth and nutrient uptake of these progenies on ultramafic soil implies that similar variation may exist in adaptation to other forest soils. Growth differences were large enough to suggest that selection for specific soil types by progeny-testing seed parents may have merit. Field studies in progress should determine whether edaphic ecotypes exist in ponderosa pine.

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1974. **Ponderosa pine progenies: differential response to ultramafic and granitic soils.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 14 p., illus. (USDA Forest Serv. Res. Paper PSW-101)

Progenies of nine ponderosa pines native to one granitic and several ultramafic soils in the northern Sierra Nevada were grown on both soil types in a greenhouse. The progenies differed markedly in first-year growth on infertile ultramafic soils, but not on a fertile granitic soil. Growth differences between progenies were primarily related to differences in calcium uptake from soils low in available calcium. On an extremely infertile ultramafic soil, progenies differed in survival. The results suggest that some ponderosa pines are better adapted than others to the nutritional conditions of ultramafic soil.

Oxford: 174.7 *Pinus ponderosa* (794): 232.13: 181.342.
Retrieval Terms: Pinus ponderosa; genetic variation; progeny trials, nutrient uptake; serpentine soils; California.

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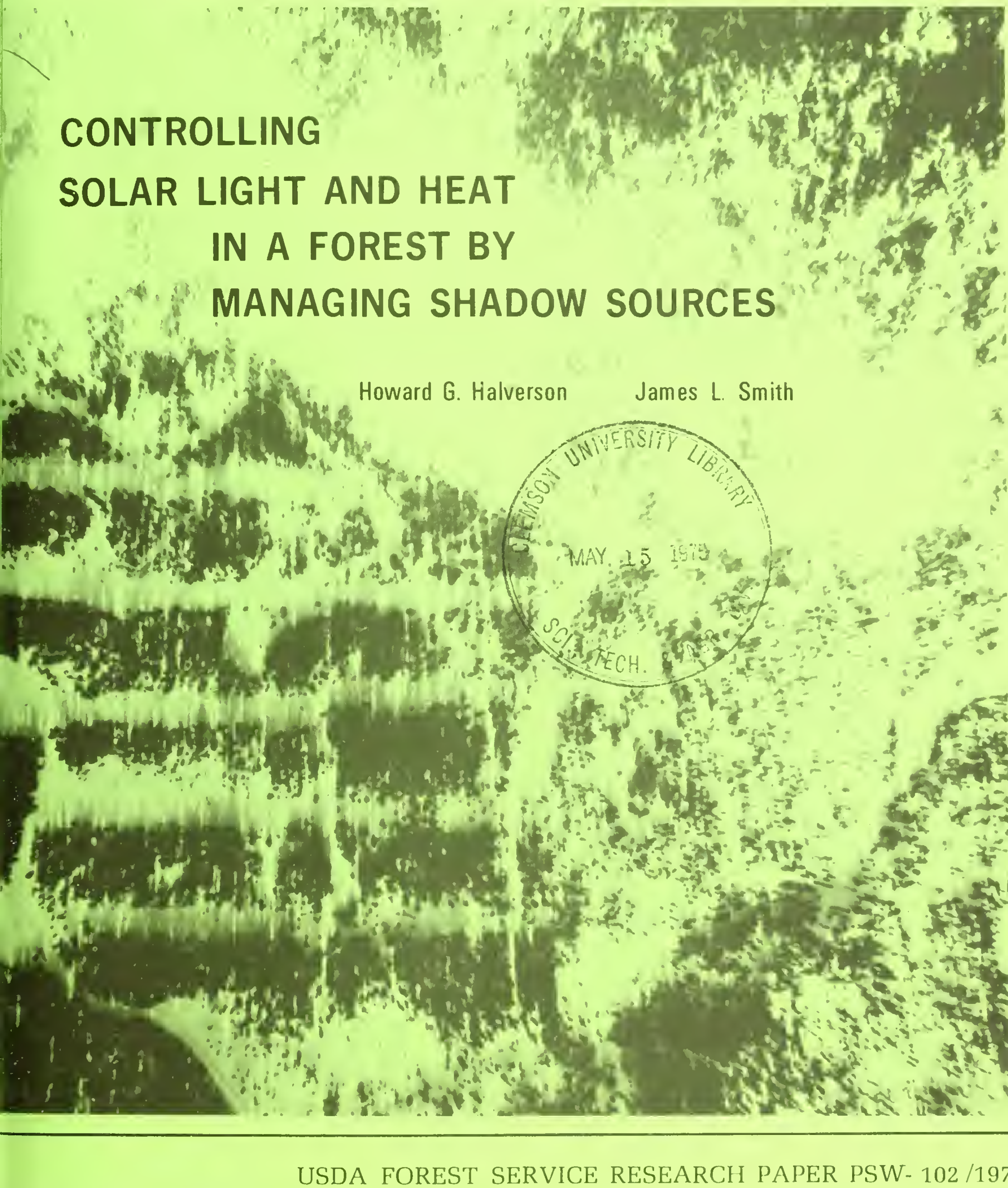
PACIFIC SOUTHWEST Forest and Range Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701



CONTROLLING SOLAR LIGHT AND HEAT IN A FOREST BY MANAGING SHADOW SOURCES

Howard G. Halverson James L. Smith

USDA FOREST SERVICE RESEARCH PAPER PSW-102/1974

CONTENTS

The Authors

are assigned to the Station's research unit on water yield improvement in the conifer zone, with headquarters in Berkeley, California. **HOWARD G. HALVERSON** earned a bachelor of science degree in forest management at Iowa State University (1960), and master's and doctor's degrees in watershed management at the University of Arizona (1962, 1971). He joined the Station staff in 1965. **JAMES L. SMITH**, in charge of the unit, earned undergraduate degrees in forest management and general agriculture (1949, 1951) and a master's degree in soils and silviculture (1950) at the University of Georgia. He received a doctorate from Michigan State University in 1954, and a year later joined the Forest Service. He became a member of the Station staff in 1963.

SUMMARY

Halverson, Howard G., and James L. Smith
1974. **Controlling solar light and heat in a forest by managing shadow sources.** USDA Forest Serv. Res. Paper PSW-102, 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 116.2:111.211:614
Retrieval Terms: insolation; reproduction; snow management; environmental planning.

Solar radiation incident to the soil, snow surface, or boles of border trees in a timber harvest area is an important environmental factor. Incident solar radiation creates a secondary form of radiation which affects the forest. Objects, even air, which are warmed by absorbing solar radiation, emit longwave radiation at increasing intensity as their temperature rises. Since solar insolation is the primary energy source for processes such as forest development and snowmelt, controlling solar exposure is a realistic way to develop a desirable environment within the forest. Timber harvests can be designed to exert some control over insolation within a forest opening. By managing forests, we can control the presence or absence of shadows at a site during critical time periods. The shadow patterns developed provide a direct means of reducing or increasing solar insolation.

The forest manager must determine what level of solar insolation is necessary to reach the management objectives. The season or dates that are critical must also be determined. The shadow lengths can be integrated with site information to help develop a management scheme. By the computer method presented here, the shadow extent in an opening can be determined using readily available data. Inputs are the latitude, east and south slope components of the site, date expressed as day number, and the desired time interval between shadow calculations. Outputs include shadow lengths, given as totals and as east-west and north-south components for each time interval, as well as the azimuth of the sun. With this information the shadow pattern from a residual stand can be determined before the harvest.

Examination of snow accumulation and ablation patterns in a group of cut strips in California illustrates how shadows can be used in snow management. Two-chain wide cut strips extending north-south and east-west were compared during a snow season. Accumulation patterns were similar. Snow and tree boles at the north boundary were exposed to solar radiation throughout the day on the east-west strips. The exposure to shortwave and reradiated longwave resulted in accelerated snowmelt along the north boundary. On the strips oriented north-south, the snowmelt pattern across the strip was more even, with less melt near the borders than was evident near the north border of the east-west strip. When the snow water content was reduced to 2 inches concentrated along the south boundary of the east-west strip, there were 10 inches of water evenly distributed on the north-south opening. The snow study showed that the energy regime was more uniform across the openings oriented north-south, and that the reduced radiation level delayed snowmelt.

Snow management is only one of several applications of shadow information. The size, shape, and orientation of openings can be designed to encourage reproduction, prevent changes in stream temperature, control soil surface temperature, and control other processes dependent on solar light and heat.

Shadow length tables can be developed for a specific site by the resource manager. A series of eight sets of shadow length tables is available as a supplement to this report. The tables are issued for even latitudes between 36° and 50° N. Slope inclinations up to 40° in both north-south and east-west directions are covered for each latitude. Interpolation for intermediate latitudes and slopes will make these tables applicable to most forest situations.

For optimum growth, a forest needs the right amount of solar light and heat. Solar radiation affects transpiration, evaporation, temperature, soil moisture, oxidation of organic matter, plant growth, and snow ablation. If the forest manager could control solar light and heat, he might be able to develop a more favorable growth environment. Through silvicultural practices, he could favor certain tree species over others. Available browse could be increased for wildlife. Fish habitat could be enhanced by regulating stream temperatures. Soil moisture and snow accumulation or ablation could be altered by cultural patterns.

The amount of direct sunlight allowed to reach the soil or snow surface and tree boles will vary according to the timber harvest method used. Clearcutting large areas results in maximum exposure to shortwave radiation. Selection cutting results in minimum increase in solar energy below the remaining canopy. Strip or small-patch cutting can be designed to control light exposure and subsequent heat exposure in the openings and near the border. Size and shape of cuttings can be varied so as to fully expose or fully shade the soil or snow surface in an opening and tree boles on the sides of the opening.

Timber harvests of various forms, sizes, and orientations have been proposed to meet snow management needs (Anderson 1963, Berndt 1965, Church 1933, Kittredge 1953). But most harvests are designed without full consideration of how the resultant opening will affect the radiation level in the opening and in the forest near the borders.

Shadows cast by surrounding trees partially control the amount of heat and light reaching the surface or tree boles. Length of shadows at the time maximum control is desired largely determines the size of a harvest opening. Shadow length and direction for trees of the same height vary according to aspect, slope, latitude, time of day, and time of year. By knowing in advance the shading patterns and light conditions in openings, the forest manager can plan more effectively for reaching a specific management objective.

This paper describes a computerized technique for determining the shadow length and direction for a tree of any height in any location between 23.45° N. latitude and 50° N. latitude. The method is applicable to any aspect, slope, time of day, and time of year.

For those who do not wish to develop their own, a set of eight tables has been prepared. These "Shadow Length Tables for Environmental Planning" are available for individual latitudes – 36, 38, 40, 42, 44, 46, 48, and 50 – or as a complete set and may be secured upon request to: Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701, Attention: Publications. The tables cover the contiguous United States from 36° N. latitude to 50° N. latitude in 2-degree increments.

Each set of the eight tables consists of 175 individual tables. By extrapolation, they can be used from the Mexican to the Canadian border. Each table lists shadow lengths for latitude by seven monthly intervals – beginning on December 22 (shortest day of the year) and ending June 22 (longest day of the year). The tables can also be used to determine shadow lengths for the period June 22 to December 22 by reversing the dates, because the sun paths are the same moving south in summer and moving north in winter. Slopes covered in the tables are 0°, 20°, and 40° in 25 combinations of north-south and east-west aspects for each date.

SOLAR RADIATION

Several conditions regulate the amount of direct solar radiation and the reradiated longwave energy from tree boles. These include latitude of the site, date translated into position of the sun, aspect, slope angle, and vegetation present. Four conditions are fixed: latitude, date, aspect, and slope angle. The vegetation can be managed to control partially the amount of radiation reaching the soil or snow surface and to alter the microclimate in a desired direction.

The radiation reaching the soil or snow surface is a combination of direct and scattered shortwave radiation from the sun, atmospherically diffused shortwave radiation, and longwave radiation from tree boles or other nearby objects. When exposed to radiant solar energy, these objects are warmed and emit longwave radiation. The greater the mass of trees or other objects heated, the greater the radiation. Effects of accelerated snowmelt from this form of radiation have been observed as far as 200 feet south of a wall of timber.

Longwave radiation is an important energy source in the early melt season because snow is a black body in long wavelengths. Shortwave radiation is less important owing to the high reflectivity (albedo) of the snow surface -- especially at low sun elevations.

Later in the melt season, albedo decreases as the snow structure changes, and as airborne detritus and plant debris accumulate on the surface. At that time, shortwave radiation also assumes a major role in snowmelt. Since the amount of light and heat reaching the forest floor or snow surface under forest cover is directly related to the amount of cover, changes in cover pattern and amount alter the heat-light regime.

PROCEDURE

The equations for calculating the total shadow length, north and east length components, and the sun azimuth were programed in FORTRAN IV language. The computer program (Appendix) determines the time of sunrise, then begins listing three shadow components and sun azimuth. Computations continue at time intervals specified by the operator until sunset. Southerly vectors of the shadows (between March 22 and September 21) are listed as negative, and northerly shadow vectors are positive. Likewise, westerly shadow vectors (before noon) are positive and easterly shadow vectors are negative. A reversal of either sign convention means the sun is not visible from the site at the time, and all shadows should be considered infinite. The times listed on the program output are true solar times; the Appendix includes a procedure to convert to local standard time.

The program and three data cards are required to generate shadow information for any combination of date, aspect, and latitude within the program limits. Aspect is used here for a value that combines aspect and slope. The first data card transmits the following information:

Columns:	
1-10	Latitude of the site in degrees
11-20	Day number of the year (Julian date)
21-30	South slope angle in degrees
31-40	East slope angle in degrees
41-50	Time interval between shadow computations in hours

The time interval, in hours and decimal fractions, determines how frequently during the day the shadow length will be computed. The time interval must be listed, and although it is unlimited, intervals of one-half or 1 hour appear most useful. In every case, a decimal point must be included or the data punched in fields of 10.4.

The second data card – a title card – is printed directly on the output sheet. Up to 80 alphanumeric characters may be keypunched and will appear at the top of the output. This card may be left blank if desired, but a card must be in the deck. If more than one computation is to be made at the same time, several pairs of data cards in the proper order may be inserted.

The last data card lists an impossible latitude, 95°, to terminate calculations.

The latitude of the observer or site is listed in degrees and decimal fractions. The program is limited to 23.45° to 50° N. This coverage includes all of the United States except Alaska and Hawaii. The day number of the year (Julian date) follows and may range from 1 to 365. (The dates have been fitted to a mean year within each leap year cycle.) The year 1950 is used for general meteorological purposes (List 1958).

Any slope and aspect can be described by two angles, one in the north-south direction and the other in an east-west direction. The south slope angle, in degrees and decimal fractions, corrects for the north or south component of aspect. A positive angle is a northerly component; a negative angle is a southerly component. A similar angle system exists to correct for east and west components; a positive angle is a west component; a negative angle is an east component. Slope angles are limited to 90°.

The slope angles can be estimated from topographic maps or measured on the site. However, if estimating is not practical and general slope and aspect data are on hand, the information in the Appendix can be used to convert slope inclinations in percent to slope in degrees. A method is included to convert the azimuth and inclination for the slope into the south and east vectors that will describe the slope and aspect of the site in the proper form for the shadow length program.

PROGRAM OUTPUT

The program output is a series of tables listing shadow length of objects for varying aspects, latitudes, and seasons of the year. The shadow lengths in the tables are a percent of the height, *above the soil or snow surface* of the shadow source. North-south and east-west shadows are calculated, as well as the total shadow length and the azimuth of the sun measured eastward from the south. The direction of the shadow is the reverse of the azimuth.

To illustrate the utility of these shadow lengths, let us consider the shading effect of trees along the borders of timber harvests.

Only on extreme northern aspects (*fig. 1*) does the shadow extend beyond the north boundary of an east-west oriented cut strip 2 chains (132 feet) wide. On southerly aspects, during early spring, from 100 percent to approximately 65 percent of the surface of such a strip and all tree boles at the north boundary are not shaded at any time.

Coupled with direct insolation is the effect of longwave radiation from the trees bordering the northern boundary of the cut strip. Their combined effects may increase the net radiation received inside the opening. Snow is a black body for longwave radia-

```
SHADOW LENGTH   NORTH ASPECT 20 DEG, WEST ASPECT  0 DEG  APR 1  LAT 40

SUN RISES AT       5.78 HOURS
SUN  SETS AT      18.22 HOURS

SUN SOUTH OF EAST AT       6.33 HOURS
SUN SOUTH OF WEST UNTIL      17.67 HOURS
SHADOW POINTS NORTH BETWEEN THESE TIMES

SHADOWS AS A PERCENT OF BORDER TREE HEIGHT.
WEST AND NORTH SHADOWS POSITIVE, OTHERS NEGATIVE. A REVERSAL OF CONVENTION
MEANS THE SUN IS BELOW THE HORIZON.  IF ONE OF THE TWO CONVENTIONS IS REVERSED
BOTH THE DIRECTIONAL AND TOTAL SHADOW LENGTHS ARE MEANINGLESS.
```

TIME SOLAR	SHADOW LENGTH EAST OR WEST	SHADOW LENGTH NORTH OR SOUTH	AZIMUTH OF SUN	TOTAL SHADOW LENGTH
5.78	53783.40	-277.15	95.25	53784.11
6.28	977.22	-7.81	90.44	977.25
6.78	486.46	46.29	85.59	488.65
7.28	317.03	69.20	80.58	324.50
7.78	228.98	81.68	75.32	243.11
8.28	173.56	89.38	69.66	195.23
8.78	134.40	94.51	63.46	164.30
9.28	104.41	98.05	56.54	143.23
9.78	80.01	100.56	48.69	128.50
10.28	59.16	102.32	39.72	118.20
10.78	40.61	103.52	29.48	111.20
11.28	23.47	104.27	18.00	106.87
11.78	7.10	104.61	5.60	104.85
12.28	-9.04	104.59	-7.12	104.98
12.78	-25.47	104.20	-19.44	107.27
13.28	-42.74	103.40	-30.77	111.89
13.78	-61.52	102.14	-40.86	119.24
14.28	-82.72	100.30	-49.69	130.01
14.78	-107.66	97.69	-57.42	145.38
15.28	-138.52	93.99	-64.24	167.40
15.78	-179.16	88.62	-70.37	199.88
16.28	-237.33	80.50	-75.97	250.61
16.78	-331.42	67.19	-81.19	338.16
17.28	-518.41	42.22	-86.17	520.13
17.78	-1108.84	-19.59	-91.02	1109.01

Figure 1—The relation of the shadow length of border trees on a cut strip to the strip width can be determined from these tables. They show shadow lengths as a percent of source height for a north aspect, 20° slope on April 1 at latitude 40° N.

tion and so shading tree boles would reduce the net radiation to the snow and delay melt.

Shadow-length effects can be evaluated by estimating the incident solar radiation received by a surface. At 40° N. latitude on a level site on April 1, the shadow extent is a maximum of 72.4 percent of the bordering tree height on an east-west clearcut strip (*fig. 2*). If bordering trees tower 100 feet above the snow and the strip is 2 chains wide, then 60 feet of the snowpack and the wall of timber at the north border of the strip are exposed for the 11.34 hours between the east-west crossings of the sun. The snow and the north boundary trees exposed to direct solar radiation could receive as much as 786.3 Langleys/day according to potential solar radiation tabulations (Frank and Lee 1966). The radiation becomes progressively greater as the aspect becomes more southerly and shadows become shorter. Solar radiation increases to 890 ly/day on a 45° S. slope. A 45° N. slope receives 225.8 ly/day. East and west slope components change the time of sunrise and sunset, but affect direct solar radiation only slightly. A 45° E. or 45° W. aspect reduces the potential solar radiation from 786.3 to 721.6 ly/day.

Data from a snow study serve to illustrate the effects of orientation upon the microclimate and subsequent melt of snow in 2-chains-wide openings created by a strip cut timber harvest pattern. The site

```
SHADOW LENGTH   NORTH ASPECT  0 DEG, WEST ASPECT  0 DEG  APR 1  LAT 40

SUN RISES AT       5.78 HOURS
SUN  SETS AT      18.22 HOURS

SUN SOUTH OF EAST AT        6.33 HOURS
SUN SOUTH OF WEST UNTIL      17.67 HOURS
SHADOW POINTS NORTH BETWEEN THESE TIMES

SHADOWS AS A PERCENT OF BORDER TREE HEIGHT.
WEST AND NORTH SHADOWS POSITIVE, OTHERS NEGATIVE. A REVERSAL OF CONVENTION
MEANS THE SUN IS BELOW THE HORIZON.  IF ONE OF THE TWO CONVENTIONS IS REVERSED
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```

TIME SOLAR	SHADOW LENGTH EAST OR WEST	SHADOW LENGTH NORTH OR SOUTH	AZIMUTH OF SUN	TOTAL SHADOW LENGTH
5.78	53783.40	-4965.41	95.25	54012.12
6.28	977.22	-7.54	90.44	977.25
6.78	486.46	37.55	85.59	487.90
7.28	317.03	52.58	80.58	321.36
7.78	228.98	59.99	75.32	236.71
8.28	173.56	64.33	69.66	185.10
8.78	134.40	67.11	63.46	150.22
9.28	104.41	69.00	56.54	125.15
9.78	80.01	70.31	48.69	106.51
10.28	59.16	71.22	39.72	92.59
10.78	40.61	71.84	29.48	82.52
11.28	23.47	72.22	18.00	75.94
11.78	7.10	72.40	5.60	72.75
12.28	-9.04	72.39	-7.12	72.95
12.78	-25.47	72.19	-19.44	76.55
13.28	-42.74	71.78	-30.77	83.54
13.78	-61.52	71.13	-40.86	94.05
14.28	-82.72	70.18	-49.69	108.48
14.78	-107.66	68.81	-57.42	127.77
15.28	-138.52	66.83	-64.24	153.80
15.78	-179.16	63.91	-70.37	190.22
16.28	-237.33	59.31	-75.97	244.63
16.78	-331.42	51.34	-81.19	335.37
17.28	-518.41	34.66	-86.17	519.57
17.78	-1108.84	-19.73	-91.02	1109.02

Figure 2—Shadow length effects on a cut strip can be evaluated from the appropriate tables. These show shadow lengths for a north aspect, level plain, on April 1 at latitude 40° N.

of the study was at about 40° N. latitude, on a 9° N. slope at 7,000 feet elevation in the Sierra Nevada of California. Border timber was about 100 feet above the snow on April 1.

The effect of the lack of tree shadow was evident (*fig. 3*). Snow water equivalent measured across an east-west-oriented cut strip at several times during a snow season showed wide fluctuations. Each part of the opening received about the same amount of precipitation, but the ablation pattern varied across the opening. Ablation rate increased toward the north boundary. Late in the season snow was retained only at the south boundary. The snow and then the soil near the north border were exposed to both direct solar radiation and energy reradiated from exposed tree trunks.

These effects show how the environment changes progressively across the opening in relation to shadow length (*fig. 4*). Toward the north boundary, the microclimate includes more energy and becomes hotter and drier. The changing microclimate accelerates snowmelt in selected areas.

Conversely, in 2-chain strips cut north and south through timber 100 feet tall, the opening is exposed to the sun for about 7 hours before shadows falling eastward or westward again cover the entire strip (*fig. 4*). In such cuts, any one point within the cut strip is exposed to direct solar radiation for only half this time before shadows again cover it. Direct solar radiation may fall below 240 ly/day upon the surface. Easterly and westerly aspects receive about the same radiation; only the times of sunrise and sunset change. North and south aspects change the direct solar radiation as received on a plain in a range from 89 ly/day on 45° N. aspects to 290 ly/day on 45° S. aspects.

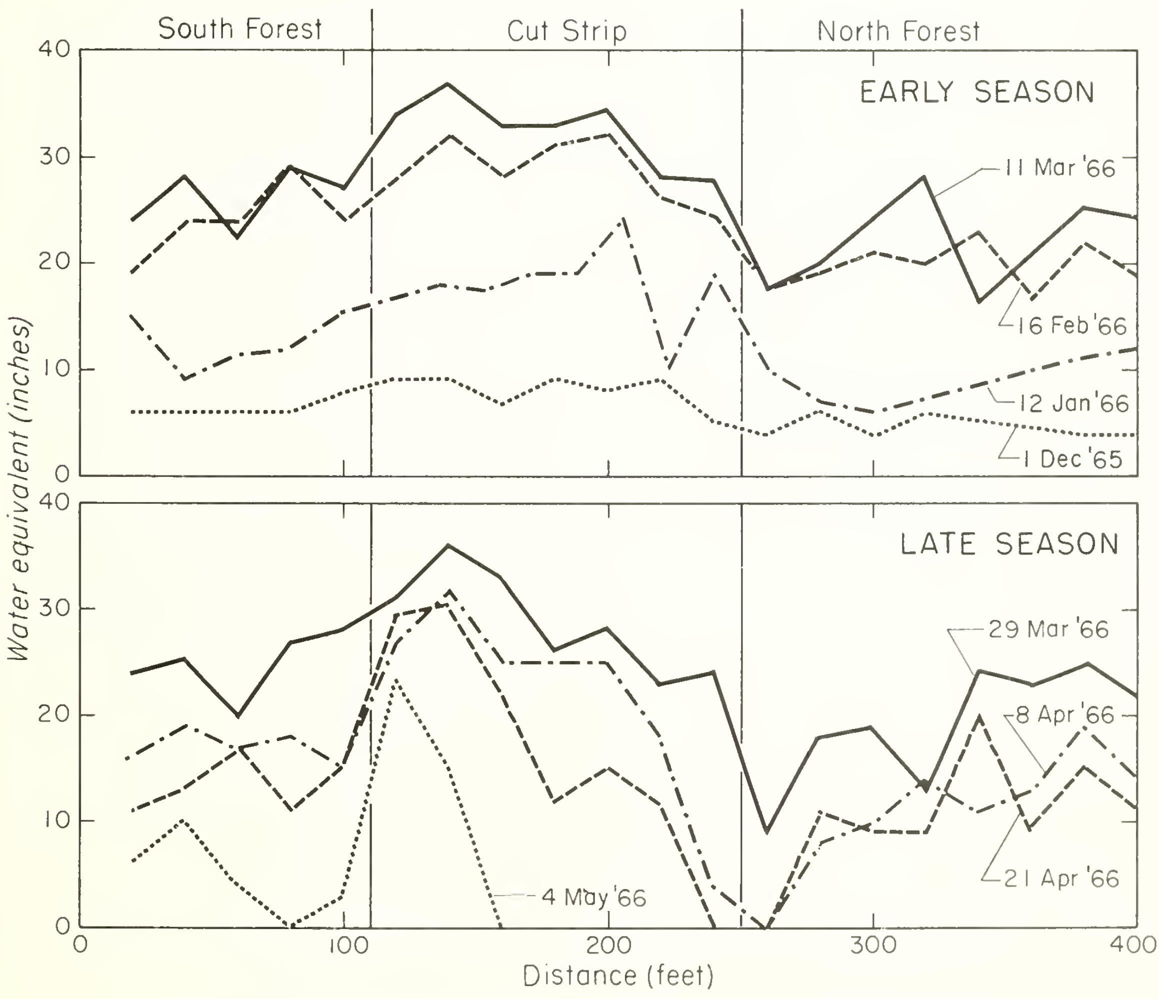

Figure 3—Snow water equivalent recorded during the early and late periods of a snow season, in a harvest area oriented east to west, showed an increase in ablation toward the north boundary.

The study data for accumulation in an open area oriented north-to-south showed that the pattern was uniform across the strip (*fig. 5*). The late season surveys showed that ablation was also uniform. Only a small differential increase appeared at either boundary. Ten inches of water remained in the snow across the north-south oriented strip at a time when only 2 inches remained on the east-west oriented strip. The snow information showed that the environment was more uniform across the opening. The strip received less energy and therefore was cooler.

The study illustrates that on strips oriented in a north-south direction, the cut area receives more shade, and the boundary trees themselves are more shaded than on strips oriented east-west. The shaded trees reradiate less energy to the snowpack, thus delaying the date and reducing the rate of snowmelt, and producing a generally milder microclimate. Only on extreme north exposures does the boundary orientation fail to affect the radiation to the opening.

Although the utility of shadow length information has been illustrated with data from snow water equivalent, applications could be drawn from other types of management data. The silvicultural requirements of different species dictate whether an opening should be designed to admit maximum or minimum solar radiation and reradiation. Roads and other

SHADOW LENGTH NORTH ASPECT 9 DEG, WEST ASPECT 0 DEG APR 1 LAT 40

SUN RISES AT 5.78 HOURS
SUN SETS AT 18.22 HOURS

SUN SOUTH OF EAST AT 6.33 HOURS
SUN SOUTH OF WEST UNTIL 17.67 HOURS
SHADOW POINTS NORTH BETWEEN THESE TIMES

SHADOWS AS A PERCENT OF BORDER TREE HEIGHT.
WEST AND NORTH SHADOWS POSITIVE, OTHERS NEGATIVE. A REVERSAL OF CONVENTION MEANS THE SUN IS BELOW THE HORIZON. IF ONE OF THE TWO CONVENTIONS IS REVERSED BOTH THE DIRECTIONAL AND TOTAL SHADOW LENGTHS ARE MEANINGLESS.

TIME SOLAR	SHADOW LENGTH EAST OR WEST	SHADOW LENGTH NORTH OR SOUTH	AZIMUTH OF SUN	TOTAL SHADOW LENGTH
5.78	53783.40	-567.31	95.25	53786.39
6.28	977.22	-7.54	90.44	977.25
6.78	486.46	40.42	85.59	488.13
7.28	317.03	58.08	80.58	322.31
7.78	228.98	67.12	75.32	238.62
8.28	173.56	72.52	69.66	188.10
8.78	134.40	76.03	63.46	154.41
9.28	104.41	78.43	56.54	130.58
9.78	80.01	80.11	48.69	113.22
10.28	59.16	81.28	39.72	100.53
10.78	40.61	82.08	29.48	91.57
11.28	23.47	82.57	18.00	85.84
11.78	7.10	82.80	5.60	83.10
12.28	-9.04	82.78	-7.12	83.27
12.78	-25.47	82.52	-19.44	86.37
13.28	-42.74	82.00	-30.77	92.47
13.78	-61.52	81.16	-40.86	101.85
14.28	-82.72	79.94	-49.69	115.03
14.78	-107.66	78.19	-57.42	133.06
15.28	-138.52	75.68	-64.24	157.84
15.78	-179.16	71.99	-70.37	193.08
16.28	-237.33	66.28	-75.97	246.42
16.78	-331.42	56.58	-81.19	336.22
17.28	-518.41	37.14	-86.17	519.74
17.78	-1108.84	-19.37	-91.02	1109.01

Figure 4—Shadow length effects on the cut strip studied are evident from these tables for a north aspect, 9° slope, on April 1 at latitude 40° N.

physical facilities can be cleared of snow earlier than normal by increasing heat into a location, or kept closed later into the season by maintaining a heavy total cover or by removing back-radiating vegetation on the border. Stream temperatures can be regulated – increased by removal of vegetation on the south bank or held relatively constant by removal of vegetation from the north bank. In each case, the management goal may be attained more readily by evaluation of the effect of changed solar radiation before the harvest begins. Many other uses can be made of this type of information.

APPLICATION

Before the resource manager can use this technique, he must develop a series of tables for the major combinations of slope, aspect, sun angle, and times of year that are of interest to him. In a timber harvest, for example, he would determine the basic objective of his timber manipulation, and then the desirable shadow length for each combination of slope-aspect conditions at the date he most desires to exercise control. These decisions determine the width and length of the opening to be harvested. The actual harvest pattern width will vary, depending on slope angle and aspect. Thus if timber is harvested in a cut

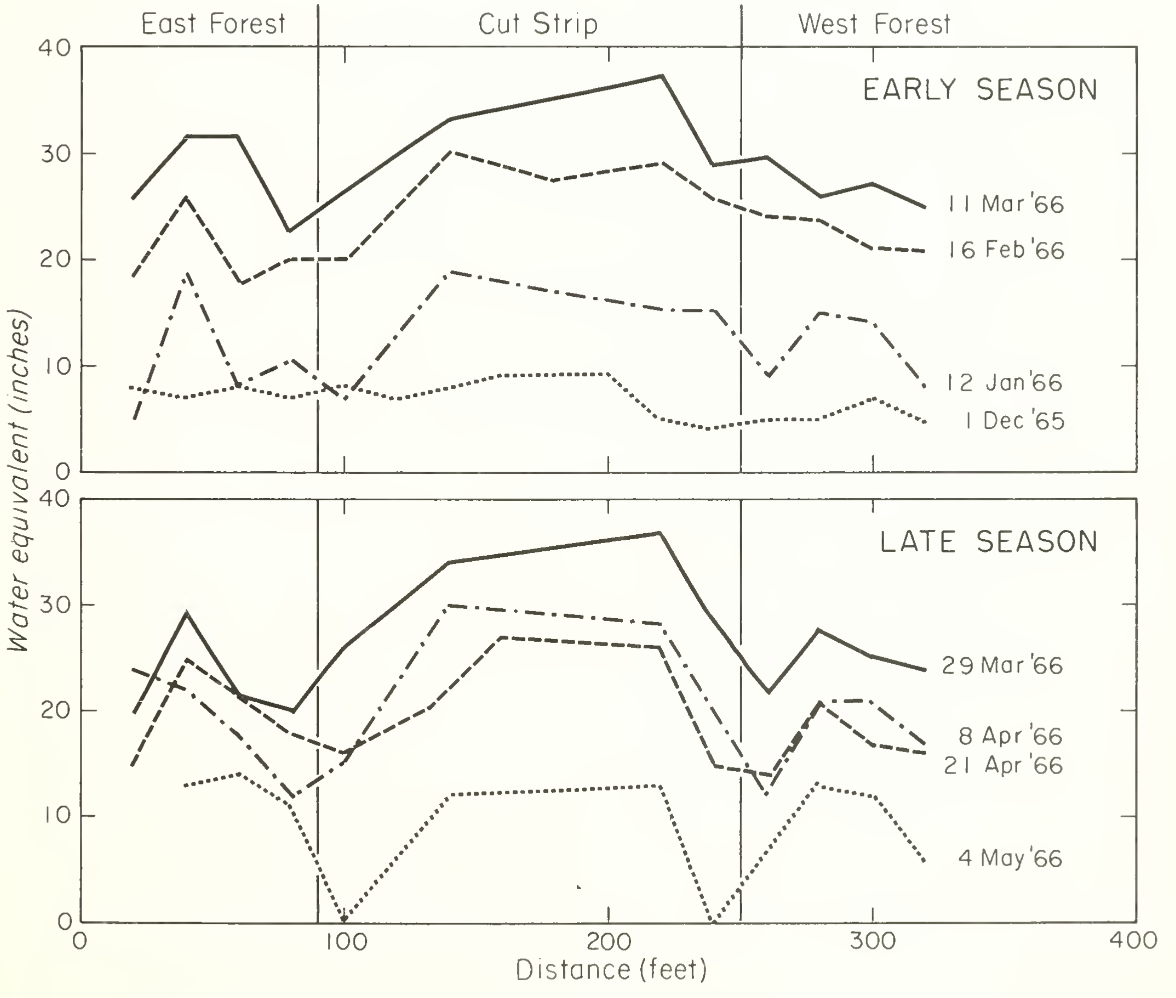

Figure 5—Snow water equivalent data for a harvest area oriented north to south showed a uniform pattern across the opening.

strip, width of the cut strip will vary, as cutting proceeds across a slope. This pattern relieves the monotonous visual effect of a strip having straight sides. In a patch harvest, the opening size will also vary with slope angle and aspect changes.

From the direction of the shadow and the length of shadow cast by the boundary trees at any given time of year, it is possible to estimate the increase or decrease in heat and light to the snow surface resulting from management. By shadow length manipulation, maximum control over the forest environment can be achieved. However, good planning and application on the ground is required to achieve the desired results.

APPENDIX

Shadow Length Program

```
              PROGRAM SHDW (INPUT,OUTPUT)
        C     THIS PROGRAM COMPUTES THE LENGTH OF A TREE SHADOW AS A PERCENT
        C     OF TREE HEIGHT.  THE SHADOW IS GIVEN IN EACH OF THE CARDINAL
        C     DIRECTIONS.  THE LENGTH IN TOTAL IS ALSO CALCULATED.  THE
        C     AZIMUTH OF THE SUN AT EACH TIME IS GIVEN.   INPUT DATA REQUIRED
        C     INCLUDE THE LATITUDE, DATE NUMBER, SOUTH SLOPE COMPONENT IN
        C     DEGREES, EAST SLOPE COMPONENT IN DEGREES, AND THE TIME INTERVAL
        C     BETWEEN CALCULATIONS DESIRED.  ALL DATA ARE ENTERED IN FIELDS OF
        C     10.4.  THE SECOND DATA CARD IS A TITLE CARD FOR IDENTIFICATION.
              DIMENSION TITLE(14)
              REAL NSHAD
            1 READ 1000,XLAT,DTNO,SSLP,ESLP,DLTT
  20          IF(XLAT.GE.90.) GO TO 6000
  23          READ 1001,(TITLE(J),J=1,14)
        C     COMPUTERS USE RADIANS, NOT DEGREES.  THIS SEQUENCE CONVERTS.
  31          CDR=6.2832/360.
  32          XLTR=XLAT*CDR
  33          DTR=(DTNO+10.5)*CDR*360./365.25
  36          SSLP=SSLP*CDR
  40          ESLP=ESLP*CDR
  41          DECL=-23.45*COS(DTR)*CDR
  45       10 T=4.0
        C      CALCULATE THE TIME OF SUNRISE.
  47       11 DO 13 I=1,450
  51          H=(12.-T)*15.*CDR
  54          SINA=SIN(XLTR)*SIN(DECL)+COS(XLTR)*COS(DECL)*COS(H)
  72          IF(SINA)12,14,14
  74       12 T=T+.01
  76       13 CONTINUE
 100       14 TSR=T
        C     CALCULATE WHEN SUN IS DUE EAST OF SITE.
 102       20 SINAPL=0.0
 103       21 H=(12.-T)*15.*CDR
 106          SINA=SIN(XLTR)*SIN(DECL)+COS(XLTR)*COS(DECL)*COS(H)
 124          A= ASIN(SINA)
 126          SINAP=COS(DECL)*SIN(H)/COS(A)
 136          IF(SINAPL.GE.SINAP)GO TO 22
 141          SINAPL=SINAP
 142          T=T+.01
 144          GO TO 21
        C     CALCULATE WHEN SUN IS DUE WEST AND SUNSET.
 145       22 TSHDW=T-.01
 146          TEND=24.-TSR
 150          TQT=24.-TSHDW
 152          TDW=24.-TSHDW
 153          T=TSR
 154          PRINT 1002,(TITLE(J),J=1,14)
 161          PRINT 1003,TSR
 167          PRINT 1004,TEND
 175          PRINT 1005,TSHDW
```

```
203          PRINT 1006,TDW
211          PRINT 1007
215          PRINT 1008
221          PRINT 1009
225          PRINT 1010
231          PRINT 1011
235       31 IF(T.GE.12.)GO TO 60
240          H=(12.-T)*15.*CDR
242          SINA=SIN(XLTR)*SIN(DECL)+COS(XLTR)*COS(DECL)*COS(H)
260          A= ASIN(SINA)
262          SINAP=COS(DECL)*SIN(H)/COS(A)
272          AP= ASIN(SINAP)
274          XLOS=100./TAN(A)
277          XKLL=XLOS*SIN(AP)
302          Y=ATAN(100./XKLL)
306          IF(ESLP.GE.0.0)GO TO 68
310          SHAD=XKLL*SIN(Y)/SIN(3.1416-Y+ESLP)
321          GO TO 70
321       60 IF(T.GE.TEND)GO TO 1
324          H=(12.-T)*15.*CDR
326          SINA=SIN(XLTR)*SIN(DECL)+COS(XLTR)*COS(DECL)*COS(H)
344          A= ASIN(SINA)
346          SINAP=COS(DECL)*SIN(H)/COS(A)
356          AP= ASIN(SINAP)
360          XLOS=100./TAN(A)
363          XKLL=XLOS*SIN(AP)
366          Y=ATAN(-100./XKLL)
372          IF(ESLP.GE.0.0) GO TO 69
374          SHAD=XKLL*SIN(3.1416-Y)/SIN(Y+ESLP)
406          GO TO 70
406       68 SHAD=XKLL*SIN(3.1416-Y)/SIN(Y-ESLP)
421          GO TO 70
421       69 SHAD=XKLL*SIN(Y)/SIN(3.1416-Y-ESLP)
433       70 IF(T.LE.TSHDW) GO TO 59
436          IF(T.LE.TQT) GO TO 61
440          AP=0.0-3.1416-AP
443          GO TO 61
443       59 AP=3.1416-AP
445       61 XKL=XLOS*COS(AP)
450          Z=ATAN(100./XKL)
454          IF(SSLP.GE.0.0) GO TO 41
456          NSHAD=XKL*SIN(Z)/SIN(3.1416-Z+SSLP)
467          GO TO 90
467       41 NSHAD=XKL*SIN(3.1416-Z)/SIN(Z-SSLP)
502       90 TSHAD=SQRT(SHAD**2 + NSHAD**2)
506          AP=AP*57.296
510       93 PRINT 1012,T,SHAD,NSHAD,AP,TSHAD
526          T=T+DLTT
530          GO TO 31
        1000 FORMAT(5F10.4)
        1001 FORMAT(13A6,A2)
        1002 FORMAT(1H1,///,13A6,A2)
        1003 FORMAT(/,5X13HSUN RISES AT ,F10.2,6H HOURS)
        1004 FORMAT(5X13HSUN  SETS AT ,F10.2,6H HOURS)
        1005 FORMAT(/,5X21HSUN SOUTH OF EAST AT ,F10.2,6H HOURS)
        1006 FORMAT(5X,24HSUN SOUTH OF WEST UNTIL ,F10.2,6H HOURS)
        1007 FORMAT(5X,*SHADOW POINTS NORTH BETWEEN THESE TIMES*)
        1008 FORMAT(/5X*SHADOWS AS A PERCENT OF BORDER TREE HEIGHT.*)
        1009 FORMAT(5X,*WEST AND NORTH SHADOWS POSITIVE, OTHERS NEGATIVE. A REV
            1ERSAL OF CONVENTION*,/,5X,*MEANS THE SUN IS BELOW THE HORIZON.  IF
            2 ONE OF THE TWO CONVENTIONS IS REVERSED*,/,5X,*BOTH THE DIRECTIONA
            3L AND TOTAL SHADOW LENGTHS ARE MEANINGLESS.*)
        1010 FORMAT(///,6X4HTIME,6X13HSHADOW LENGTH,7X13HSHADOW LENGTH,6X7HAZIM
            2UTH,6X13HTOTAL SHADOW )
        1011 FORMAT(5X5HSOLAR,7X12HEAST OR WEST,6X14HNORTH OR SOUTH,6X6HOF SUN,
            210X6HLENGTH,/)
        1012 FORMAT(F10.2,4F17.2)
531     6000 CONTINUE
531          RETURN
533          END
```

Calculations of Shadows, Time, and Aspect

Computer Calculations of Shadows

The shading pattern created by trees on the edges of openings cut through the forest in a north-south or east-west direction is calculated in the program from standard formulas. They may be expressed as:

$$\sin \alpha = \frac{\cos \sigma \ \sin h}{\cos a} \qquad (1)$$

$$\sin a = \sin \delta \ \sin \sigma + \cos \delta \ \cos h \cos \sigma \qquad (2)$$

$$s = \frac{100}{\tan a} \qquad (3)$$

in which

a = altitude of the sun (angular elevation above the horizon)
δ = latitude of the observer
σ = declination of the sun
h = hour angle of the sun (angular distance from the meridian of the observer)
α = azimuth of the sun (measured eastward from south)
s = horizontal shadow length as a percentage of tree height above the snow

The altitude and azimuth of the sun are functions of the latitude of the observer, time of day or hour angle, and the date expressed as declination of the sun. Hour angle is the difference between time of observation and true solar noon; 1 hour is equivalent to 15°.

The program first calculates the sun azimuth and altitude of the sun above a horizontal plane through the site. Equation 3 is used to calculate the horizontal shadow length. To convert the horizontal shadow length into a south or east vector, an additional calculation is performed. The north component, NV, is computed from the cosine of the sun azimuth and the shadow length, s, from equation 3. The east vector EV, is computed from sine function:

$$NV = s \cos \alpha \qquad (4)$$
$$EV = s \sin \alpha \qquad (5)$$

To correct for slope, the total length and the south and east vectors are projected upon the plane of the slope as supplied on the first input data card. The projection is made along a path governed by the altitude and azimuth of the sun, and the three shadow lengths on the slope are then computed with the sine law.

Time Conversion

The time values used are true solar time. The true solar day is defined as the interval between two consecutive transits of the sun across any given meridian. True solar time is based on true solar noon, when the geometric center of the sun crosses the longitude of the observer. However, the revolution of the earth around the sun and the rotation of the earth on its axis are not precisely synchronous.

The mean solar day was adopted to gain the advantage of regularity. Mean solar time assumes a sun moving on the equatorial plane with a uniform velocity equivalent to the average velocity of the sun. The equation of time, which is obtained from a solar ephemeris (List 1958) is the difference between true and mean solar time and equals zero at four times during the year:

Date:	*Minutes*	*Hours*
Jan. 10	− 7.2	− 0.12
24	− 12.0	− .20
Feb. 7	− 14.2	− .24
20	− 13.9	− .23
Mar. 7	− 11.3	− .19
21	− 7.5	− .13
Apr. 4	− 3.3	− .05
19	+ 0.5	+ .01
May 3	+ 3.1	+ .05
18	+ 3.7	+ .06
June 1	+ 2.4	+ .04
22	− 1.6	− .03
July 12	− 5.4	− .09
27	− 6.4	− .11
Aug. 10	− 5.4	− .09
25	− 2.3	− .04
Sept. 9	+ 2.4	+ .04
23	+ 7.3	+ .12
Oct. 8	+ 12.1	+ .20
22	+ 15 3	+ .26
Nov. 5	+ 16.4	+ .27
19	+ 14.7	+ .25
Dec. 3	+ 10.5	+ .18
22	+ 1.8	+ .03

Local standard time (LST) is based on 15° longitudinal time zones. Noon in local standard time occurs when the sun in a mean solar day crosses the time zone meridian. To determine true solar time, add 4 minutes to the local standard time (not daylight saving time) for each degree of longitude the station is east of the standard meridian, or subtract 4 minutes for each degree west of the standard meridian.

This first calculation results in local mean solar time. True solar time is then obtained by adding algebraically the equation of time from the table.

Local standard time can be determined from true solar time through the reverse of the procedure just described. That is, the appropriate equation of time is algebraically subtracted from any time value given by the shadow length program. Then 4 minutes is subtracted (added) for each degree of longitude the station is east (west) of a standard meridian. Standard meridians for the 48 contiguous States, by time zones, are:

	Standard meridian degrees west longitude
Time zone:	
Eastern	75°
Central	90°
Mountain	105°
Pacific	120°

Standard meridians for the world can be determined from a time zone map as published by the U.S. Navy (1960).

Slope and Aspect Corrections

Site aspect is often described as the direction perpendicular to the contour, and slope by the inclination in percent. These data can be converted to the form required by the shadow program, although measurement on the site is desirable.

To convert to aspect, the azimuth of the perpendicular to the contour, measured eastward from south, must be determined. With this method, a south aspect has an azimuth of 0°, east has an azimuth of 90°, north is 180°, and west is 270°. Then:

$$\text{ESLP} = \text{-arc sin}\left[\frac{\sin\phi\ \sin\theta}{+\sqrt{\cos^2\phi + \sin^2\phi\ \sin^2\theta}}\right] \qquad (6)$$

$$\text{SSLP} = \text{-arc sin}\left[\frac{\sin\phi\ \cos\theta}{+\sqrt{\cos^2\phi + \sin^2\phi\ \cos^2\theta}}\right] \qquad (7)$$

in which

ESLP = east slope vector in degrees
ϕ = slope in degrees
θ = azimuth from south toward east in degrees
SSLP = south slope vector in degrees

Note that the absolute value for slope is used in these calculations. The algebraic sign for azimuth, when carried in the numerator, gives the correct sign for the south slope and east slope values for use on the input data card. Signs of the functions are:

	Range in degrees			
	0–90	*90–180*	*180–270*	*270–360*
Function:				
Sine	+	+	–	–
Cosine	+	–	–	+

To convert percent slope to degrees and decimal parts required by the program, this tabulation is useful:

	Slope inclination
	Degrees
Slope (percent):	
0	0.00
10	5.72
20	11.32
30	16.70
40	21.80
50	26.57
60	30.97
70	35.00
80	38.67
90	41.98
100	45.00

Alternatively, more precise degree values for a percent slope can be calculated by the relation:

$$\tan\phi = \frac{x}{100} \qquad (8)$$

in which ϕ = slope angle in degrees and minutes and x = percent slope (elevational difference between two points 100 feet apart in horizontal distance).

Any minutes of angle must be converted to decimal form for program use by dividing by 60′/°. For example, a 20 percent slope may be expressed as $\tan\phi = 20/100 = 0.20$. From a table of trigonometric functions, the angle ϕ is 11°19′ or 11° plus 19′ divided by 60′/°, or 11.32°.

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Halverson, Howard G., and James L. Smith
1974. **Controlling solar light and heat in a forest by managing shadow sources.** USDA Forest Serv. Res. Paper PSW-102, 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Control of solar light and heat to develop the proper growth environment is a desirable goal in forest management. The amount of sunlight and heat reaching the surface is affected by shadows cast by nearby objects, including trees. In timbered areas, the type of forest management practiced can help develop desired microclimates. The results depend on the size and orientation of openings created and on the shade cast by surrounding vegetation. A computerized method to calculate the extent of boundary shading for any combination of date, slope, and aspect between 23.45° N. latitude and 50° N. latitude is described. For those who do not wish to develop their own, a set of shadow-length tables is available upon request. These may be secured as an entire set or by individual latitudes. They provide coverage for the contiguous United States in increments of 2° from 36° N. latitude to 50° N. latitude. By extrapolation, the tables can be used from the Mexican to the Canadian border.

Oxford: 116.2:111.211:614.
Retrieval Terms: insolation; reproduction; snow management; environmental planning.

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PACIFIC SOUTHWEST Forest and Range Experiment Station

FOREST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701

PLANTING TRIALS OF 10 MEXICAN PINE SPECIES IN HAWAII

Craig D. Whitesell

USDA FOREST SERVICE RESEARCH PAPER PSW-103 /1974

CONTENTS

The Author

CRAIG D. WHITESELL is assigned to the Station's Institute of Pacific Islands Forestry, headquartered in Honolulu, Hawaii. He is doing research on the silviculture of native and planted forests in Hawaii and Guam. He received his bachelor's degree (1951) from West Virginia University, and his master's degree (1954) from Duke University—both in forestry. He has been with the Station's Hawaii staff since 1962.

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U.S. Forest Service research in Hawaii
is conducted in cooperation with
Division of Forestry
Hawaii Department of Land and Natural Resources

SUMMARY

Whitesell, Craig D.
1974. **Planting trials of 10 Mexican pine species in Hawaii.** USDA Forest Serv. Res. Paper PSW-103, 8 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 174.7 *Pinus* spp.–(72):(969):232.11
Retrieval Terms: Pinus spp., Mexican pines; species trials; mortality; life form; Hawaii

Because Hawaii has no native conifers, tree planters began introducing species of the *Pinus* genus to the islands. These introductions were started in the 1890's. Not until the 1960's did foresters include pines from Mexico. Rich in *Pinus* species, Mexico resembles Hawaii in latitude, elevation, rainfall, and soils. In 1962, pine seeds were made available to the U.S. Forest Service for planting trials in Hawaii. The seeds had been collected by the North Carolina State University-Industry Tree Improvement Program in central Mexico.

The seeds were planted on two islands: 10 species representing 70 families were outplanted on Maui; five species, representing 28 families, were outplanted in Molokai. A *family* refers to all seedlings propagated from seeds collected from one specific mother tree growing in Mexico.

The planting site on Maui is on the leeward slope of Mt. Haleakala, a dormant volcano, at 6450 feet (1970 m) elevation. The Molokai site is on a narrow upland ridge at 3200 feet (975 m) elevation. Annual rainfall averages 40 inches (1000 mm) or more at both locations, but this amount varies greatly from year to year.

The experimental plantings were laid out in a randomized block design, with four replications and 15-tree row plots. Each row plot consists of the progeny of one mother tree. Survival, growth measurements, vigor, and stem form of the trees were recorded at the end of the first, third, and fifth years after outplanting.

Nine species planted on Maui and five species on Molokai showed promise at age 5. Average annual height growth ranged from 1 to 3 feet (0.3 to 1 m) on Maui and from 1 to 2 feet (0.3 to 0.6 m) on Molokai. Average height growth varied greatly among families within species, and this was also true for survival.

Average diameters at breast height at age 5 ranged from 1.7 to 2.7 inches (4 to 7 cm) for all species with 10 or more measurable trees except *Pinus michoacana* var. *cornuta.* On Molokai, this variety averaged 3.7 inches (9 cm) d.b.h.

Low initial survival was primarily related to poor planting stock and adverse site conditions. Less than 5 percent of any one species died during the last 2 years.

Most of the surviving trees on both islands were vigorous, healthy plants 5 years after outplanting. *P. oocarpa,* planted on Maui, was an exception; two-thirds of the trees showed poor vigor and had dieback that was related to frost damage.

Strong winds caused broken stems, windthrow, or damaged leaders, chiefly in *P. leiophylla* on both islands, and in *P. patula* on Maui. Wild pigs partially or completely girdled some of the largest trees on Molokai. They were particularly attracted to *P. montezumae* and *P. pseudostrobus.* The only serious insect infestations occurred on Maui, where two species of aphids attacked all 10 species planted. No diseases were observed on any of the pines.

The success of most of the species in these trials is attributed to the similarities in latitude, elevation, and rainfall between the collection areas in Mexico and the planting sites in Hawaii. Species that are growing well on both Maui and Molokai are *P. montezumae, P. michoacana* var. *cornuta, P. pseudostrobus, P. tenuifolia,* and *P. leiophylla.* Potentially useful species planted only on Maui are *P. hartwegii, P. michoacana, P. rudis, P. patula,* and *P. teocote.* These species can be used to meet the need for erosion control, amenity plantings, and recreation forests where conifer species are desired.

To make up for the lack of native conifers, tree planters in Hawaii began introducing species of the *Pinus* genus in the early 1890's (Bryan 1947). Not until the 1960's, however, did they begin to try out the Mexican pines—even though Mexico and Hawaii have highly similar climates, and Mexico is perhaps the "richest pine-growing region in terms of number of species" (Din 1958).

A wide variety of pine species grow in Mexico at Hawaii's latitude (19° to 22° N.), some on soils of volcanic origin, and under temperatures and rainfall conditions similar to those found in the State. These Mexican species can grow under a broad range of site conditions. Several have been successfully introduced in Africa (Kriek 1970; Loock 1950; Mirov 1967), Australia, and elsewhere (Streets 1962).

One reason why Mexican pines have only recently been tried in Hawaii has been the difficulty in obtaining seeds from Mexico—and that difficulty still persists. It was partially overcome in 1962 when cooperators in the North Carolina State University-Industry Tree Improvement Program collected pine seeds in Mexico (Saylor and McElwee 1963; Zobel 1970). Their primary goal was to collect seeds of species that offered promise for commercial use on adverse sites in the Southern United States and elsewhere, where native species do not grow satisfactorily or where pines are not indigenous. They distributed seeds to cooperators throughout the Southeastern United States, Hawaii, and Brazil. Saylor (1969) reported third-year results of the planting trials.

This paper reports results of planting trials of 10 Mexican pine species on the islands of Maui and Molokai, Hawaii, and suggests their implications for reforestation work in the State.

METHODS

Seeds of 10 species, one variety, and one form were obtained from 23 locations in five states in Mexico: Jalisco, Mexico, Michoacan, Puebla, and Tlaxcala (*table 1*). They are situated between 19° and 20° North latitude and between 98° and 105° West longitude.

The parent trees were generally growing in open stands. The seed collectors tried to obtain the best phenotypes, but this was not always possible—primarily because pine seed yield was poor in 1962. Many stands were cut over, burned over, or grazed, and were understocked. Stands of *Pinus montezumae* and *P. patula* of superior form and height were located, however, and seeds collected (Saylor and McElwee 1963).

The collection sites ranged from 4520 to 12,000 feet (1380 to 3600 m) elevation. Soils varied in fertility from low to high, and soil textures included volcanic ash, ash over silt loams, loams, sands, silts, and clays.

Nursery Transplanting

The seeds were sown at a State tree nursery on the island of Hawaii in 1963. Germination success ranged from poor to good for the 100 seed lots sown. Rodents, birds, flooded seed beds, and damping off contributed to mortality, reducing the number of seedling lots available for outplanting to 70.

The seedlings were scheduled for outplanting during the rainy season (winter) of 1963-64. But the sites were too dry to plant that season because no winter storms occurred. And so the seedlings were transplanted in the nursery. Many seedlings died thereafter.

The surviving seedlings were lifted for shipment as 1-1 stock. Most had poor root systems. The quality and vigor of the seedlings were low. Therefore, the number available for many seed lots was fewer than that specified as desirable in the experimental design.

Planting Design

The experimental design prescribed for all participants in the North Carolina State University–Industry Tree Improvement Program was followed in Hawaii wherever possible. This randomized block design had four replications and 15-tree row plots. Initial spacing was 9 feet within and between rows. The number of plots for a given species in a block varied from 1 to 13. The seedlings in each plot represent a specific mother tree from which seeds were collected. All seedlings from one mother tree are collectively referred to as a *family*. In Hawaii, lack of planting material reduced the number of blocks to either two or three for some seed lots.

Ten species, represented by 70 families, were planted on Maui; because of the scarcity of material, only five species and 28 families were planted on Molokai (*table 2*).

Planting Sites

The planting site on Maui is on the Kula Forest Reserve, 6450 feet (1970 m) elevation, latitude 20° 42′ North, and longitude 156° 19′ West. The site is on the leeward slope of Mt. Haleakala, a dormant volcano. Rainfall averages 40 inches (1000 mm) annually but varies greatly from year to year. Major storms occur most frequently between October and March; the rest of the year may be extremely dry.

The estimated average annual temperature at the site, near Poli-poli Springs, is 53° F (12° C). Frosts occur occasionally during winter. Strong winds are a hazard to planted stands. Dense cloud cover or fog is almost a daily occurrence.

The soil is Laumaia loam, a member of the medial, isomesic family of Typic Dystrandepts (formerly classified as a Latosolic Brown Forest soil). It is a well-drained soil developed from volcanic ash and cinders,

Table 1–*Sources of pine seed from Mexico outplanted on Maui and Molokai, Hawaii*

Pinus species	State and numbers of collections	Elevation (meters)	Latitude (N.)	Longitude (W.)
P. hartwegii Lindl.	Mexico (1)	3660	19°06′	98°35′
P. michoacana Martinez	Michoacan (1)	1380	19°25′	101°50′
P. michoacana var. *cornuta* Martinez	Michoacan (3) Jalisco (1)	1800-2320	19°25′ to 20°	102° to 104°
P. montezumae Lamb.	Puebla (2) Michoacan (1) Mexico (1)	2270-2710	19°10′ to 19°30′	98° to 102°50′
P. montezumae forma *macrocarpa* Martinez	Michoacan (1)	2100	20°	102°
P. rudis Endl.	Tlaxcala (1)	2740	19°40′	98°30′
P. oocarpa Schiede	Michoacan (2)	1450-1680	19° to 19°20′	102° to 104°20′
P. patula Schiede & Deppe	Tlaxcala (1) Puebla (1)	2030-2680	19°40′ to 20°12′	98°20′ to 98°30′
P. pseudostrobus Lindl.	Puebla (1) Michoacan (1)	2040-2320	19°30′ to 19°50′	97° to 102°
P. tenuifolia Benth.	Michoacan (1)	2100	19°30′	102°
P. teocote Schiede & Deppe	Tlaxcala (1) Puebla (1)	2650-2830	19°	98°
P. leiophylla Schiede & Deppe	Michoacan (1) Puebla (1)	2100-2480	19°20′ to 19°30′	98°30′ to 102°

Table 2–*Survival, height, vigor, and form, at age 5, of Mexican pine species planted on Maui and Molokai, Hawaii*

Location and *Pinus* species	Number of families	Survival			Height			Good vigor	Good form
		Species average	Family range	Number of living trees	Species average	Species maximum	Family range		
		Percent			*Meters*			*Percent*	
Maui:									
P. hartwegii	2	63	58-67	34	1.5	2.4	1.3-1.5	94	79
P. michoacana	3	11	8-23	15	1.9	3.3	1.2-2.4	100	73
P. michoacana var. *cornuta*	9	21	7-38	102	2.3	4.3	1.5-2.4	99	67
P. montezumae	13	18	0-47	130	2.3	4.9	1.5-3.0	98	72
P. montezumae f. *macrocarpa*	1	18		8	3.8	4.9		100	75
P. rudis	3	59	48-70	89	1.9	3.7	1.8-2.0	100	57
P. oocarpa	5	16	9-20	38	1.4	2.4	1.2-1.5	34	24
P. patula	7	21	13-27	56	4.5	6.1	3.4-4.9	85	66
P. pseudostrobus	10	29	22-43	156	4.1	7.3	2.7-5.2	95	66
P. tenuifolia	4	22	17-34	48	4.4	7.0	3.3-5.2	93	67
P. teocote	4	39	15-57	58	2.4	3.7	2.1-2.7	100	64
P. leiophylla	9	46	29-70	245	2.5	5.2	1.8-3.0	87	45
Molokai:									
P. michoacana var. *cornuta*	5	25	11-40	69	2.7	5.5	1.5-4.0	100	41
P. montezumae	7	13	0-21	49	1.5	4.6	0.9-2.1	90	51
P. pseudostrobus	8	30	7-40	108	3.4	6.1	2.4-4.0	98	34
P. tenuifolia	2	69	33-78	86	3.4	6.7	3.4-3.7	94	49
P. leiophylla	6	60	41-85	216	2.9	5.2	1.8-3.7	93	14

and is 30 to 42 inches (76 to 107 cm) thick. The surface layer is mildly alkaline. The subsoil is either a clay loam or silty clay loam, and is neutral to medium acid (U.S. Soil Conserv. Serv. 1972). Aspect is west, with slopes of 1 to 25 percent.

Native vegetation consisted of grasses and scattered shrubs. The grass formed a tight sod over much of the area. The most common shrub present was pukiawe (*Styphelia taemeiameiae* [Cham.] F. Muell.) from 3 to 6 feet (1 to 2 m) tall. A few sandalwood (*Santalum* spp.) and mamane (*Sophora chrysophylla* [Salisb.] Seem.) shrubs were also present.

Site preparation consisted of clearing most of the shrub vegetation with a bulldozer, and scalping the sod at each planting spot with a mattock.

The planting site at Molokai is on the Molokai Forest Reserve, 3200 feet (975 m) elevation, latitude 21° 09′ North, and longitude 156° 56′ West. The site is on a narrow upland ridge on east Molokai. Some rain usually falls each month, with the wettest period between November and April. The average is about 50 inches (1270 cm) annually, but sometimes from twice this amount to less than half may be recorded in any given year. The mean temperature averages 71° F (22° C), the mean temperature for February is 66° F (19° C), and for August, 75° F (24° C).

The soil is Olelo silty clay, a member of the clayey, oxidic, isothermic family of Humoxic Tropohumults (formerly classified as a Humic Ferruginous Latosol). It is a well-drained soil, developed from basic igneous rocks weathered in place. The surface layer, a dark reddish-brown color, contains ironstone concretions. The subsoil is also a dark reddish-brown silty clay. This soil is strongly acid, the surface layer having a pH of 4.8 and the subsoil a pH of 4.6 to 4.8 (U.S. Soil Conserv. Serv. 1972). Aspect is east, with slopes of from 3 to 25 percent.

The native vegetation consisted chiefly of scrub ohia (*Metrosideros collina* [Forst.] Gray), 'a'ali'i (*Dodoneae* spp. Mill.), Hilo grass (*Paspalum conjugatum* Berg.), and pukiawe.

The site was prepared with a bulldozer, cleared either in strips one blade wide (12 feet or 3.5 m), or by creating larger openings with the scrub vegetation pushed into gullies or windrows.

Observations and Measurements

The age of trees was calculated from the date of outplanting, in 1965. Observations and measurements were recorded the first, third, and fifth succeeding years. At the end of the fifth year after outplanting, I checked the seedlings for survival, total height, diameter, vigor, and stem form. Individuals severely damaged by frost or winds, which produced multiple stems, broken tops, and windthrow, were excluded in height and diameter computations. To be rated as having good form, a tree had to have a straight single stem, i.e., no sweep, crooks, or forks. Tree vigor was rated as either good (healthy in appearance) or poor (sickly).

Stem diameters of all trees over 5 feet (1.5 m) tall were measured at breast height (d.b.h.).

RESULTS AND DISCUSSION

Survival

Poor initial survival, though disappointing, was not unexpected, because of poor quality planting stock and harsh site conditions. Survival by the fifth year of the 10 species planted on Maui ranged from 11 percent for *P. michoacana* to 63 percent for *P. hartwegii.* Among the five species planted on Molokai, it ranged from 13 percent for *P. montezumae* to 69 percent for *P. tenuifolia* (*table 2*). Most mortality occurred during the first year: in half of the species, less than one-third of the trees were still alive. Some sickly trees of each species (a maximum of 7 percent per species) died during the next 2 years. Subsequently, during the fourth and fifth years, no more than 4 percent of any one species died, and some of this loss was caused by severe winds. On Maui, half of the species had no mortality during this period, and mortality was nearly as low on Molokai. Within most species, considerable variation in survival occurred among families.

Three species, *P. patula, P. leiophylla,* and chiefly *P. oocarpa,* suffered frost damage on Maui. Thirty-seven percent of the *P. oocarpa* were top-killed or died back nearly to the ground. A few seedlings were killed outright.

Growth

The average fifth-year heights ranged from 4.5 feet (1.4 m) for *P. oocarpa* to 14.4 feet (4.4 m) for *P. tenuifolia,* and 14.6 feet (4.5 m) for *P. patula,* on Maui (*table 2*). *P. pseudostrobus* averaged 13.3 feet (4.1 m) and *P. montezumae* f. *macrocarpa* averaged 12.5 feet (3.8 m). The latter far exceeded its type (*P. montezumae*), which averaged 7.7 feet tall (2.3 m) during the 5-year period. *P. hartwegii* has been described by Loock (1950) as slow growing but of good form. Our seed source from the upper volcanic slopes of Mount Popocatepetl, Mexico, at 12,000 feet (3660 m), grew slowly on Maui, averaging 1 foot (0.3 m) a year, with good form. On Maui, differences in average total height growth of families within a species varied from 0 to 8 feet (2.4 m).

At the lower-elevation Molokai site, *P. montezumae* was the slowest growing, averaging 5 feet (1.5 m) in 5 years (*table 2*). The two fastest growing species, *P. pseudostrobus* and its close relative *P. tenuifolia,* each averaged slightly more than 11 feet (3.4 m). The somewhat poorer height growth of these two species on Molokai can be attributed to terminal dieback and forking among the tallest individuals more exposed to wind. This "mechanical" damage to the thin, tender shoots by wind is one of the several causes of forking in *P. pseudostrobus* that Loock (1950) observed in the Republic of South Africa. Differences in average height growth of families within a species ranged from 1 to 8 feet (0.3 to 2.4 m) on Molokai.

Where 10 or more trees of a species were measured, the average diameters were computed. These ranged from 1.7 to 2.7 inches (4 to 7 cm) with one exception: On Molokai, 33 *P. michoacana* var. *cornuta* trees averaged 3.7 inches in diameter (9 cm), and one individual measured 6.1 inches (15 cm) d.b.h.

Vigor

Most of the trees were robust, healthy plants 5 years after outplanting. Nine species on Maui had at least 93 percent of the trees showing good vigor (*table 2*). Eighty-seven percent of the *P. leiophylla* and 85 percent of the *P. patula* trees showed good vigor, whereas only 34 percent of the *P. oocarpa* were rated as vigorous.

On Molokai, the species with the highest percentage of vigorous trees was *P. michoacana* var. *cornuta* (100 percent); the lowest was *P. montezumae* (90 percent) (*table 2*).

Stem Form

Strong winds at both the Maui and Molokai sites damaged trees of some species more than those of others. On Maui the percentage of trees which were not measured because of severe wind damage (broken stems or windthrow) ranged from 0 to 4 percent for eight species. This loss increased to 7 percent for *P. leiophylla* and to 9 percent for *P. patula*. On Molokai, wind damage was less than 2 percent for each of four species, and was 7 percent for *P. leiophylla.*

Few species had a high percentage of straight, single-stem trees. Only about two-thirds of the trees on Maui and less than half of those on Molokai had single, straight stems (*table 2*). The species with the lowest percentage of straight unforked stems were *P. oocarpa* (24 percent) on Maui and *P. leiophylla* (14 percent) on Molokai.

Although local environmental factors accounted for poor form to some extent, genetic factors also played an important role. Examination of the seed collection data determined that most of the stems of the parent trees in Mexico were graded as fair or poor; that is, most had some crook or twist. Many of the stands had been cut over. Differences between sources are illustrated by the performance of two collections of *P. leiophylla,* one in Michoacan at 6900 feet (2100 m) elevation and the other in Pueblo at 8130 feet (2480 m) elevation. On Maui, the Pueblo source had 76 percent (of 102 trees) with straight single stems, compared with 22 percent (of 143 trees) for the Michoacan source. Loock (1950) reported: "In Michoacan . . . two distinct strains appear to exist. The one is usually very branchy, of poor form and rather short and crooked boled, while the other has a fairly good form and often reaches heights of up to 80 feet." The Michoacan source for the present study could be a representative of the branchy, poor form strain.

The families of three species, *P. patula, P. montezumae,* and *P. michoacana* var. *cornuta,* were also grouped by provenance, but no significant variation in form was found within these species.

A few individuals of three species developed "foxtails"—elongated stem growth with no lateral branches. This type of growth is common when pines are grown in the subtropics or tropics (Kozlowski and Greathouse 1970). Two percent of the *P. montezumae, P. pseudostrobus,* and *P. leiophylla* stems on Maui and the *P. pseudostrobus* on Molokai had this characteristic.

On Molokai, wild pigs seemed particularly attracted to *P. montezumae* and *P. pseudostrobus,* either partly or completely girdling the stems. They usually selected the best trees. The pigs completely ignored only one species, *P. michoacana* var. *cornuta.*

Insects and Disease

The only serious insect infestations occurred on Maui, where two species of aphids were observed on all of the pines tested except *P. michoacana* var. *cornuta.* The two aphids were identified by the State Entomologist as *Cinara carolina* Tissot and *Macrosiphum avenae* (Fabricius). Eventually, they were controlled by the ladybug beetle (*Hippodamia convergens* [Guerin-Mendville]).

No diseases were observed on any of the pines.

CONCLUSIONS

Early indications are that Mexico deserves increased attention as a source of conifer species for reforestation on adverse sites at higher elevations in Hawaii. The success of the planting trial can be attributed to the similarities in latitude, elevation, and rainfall between the seed sources in Mexico and the sites in Hawaii. Considering the site conditions, growth and vigor of these Mexican pines must be rated as excellent. Species that have performed well on both Maui and Molokai are *Pinus montezumae, P. michoacana* var. *cornuta, P. pseudostrobus, P. tenuifolia*, and *P. leiophylla*. Potentially useful species planted only on Maui are *P. hartwegii, P. michoacana, P. rudis, P. patula*, and *P. teocote*.

These Mexican pine species can be used to meet several of the State Division of Forestry's management objectives: the development of multiple-use forests for recreation, erosion control, and amenity plantings (Sager and Korte 1971). Mexican pines could be used on these sites for replanting understocked hardwood plantations and for controlling noxious plants. More time is needed before the value of these species for timber production can be determined.

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1974. **Planting trials of 10 Mexican pine species in Hawaii.** USDA Forest Serv. Res. Paper PSW-103, 8 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Ten species of Mexican pines were planted on adverse sites at 6450 feet (1970 m) elevation on Maui, and five species on similar sites at 3200 feet (975 m) elevation on Molokai, Hawaii. Initial survival was poor because of the low quality of the planting stock and harsh site conditions, but subsequent mortality was low. Growth and vigor has been satisfactory. Average annual height growth five years after outplanting ranged from 1 to 3 feet (0.3 to 1 m) on Maui and from 1 to 2 feet (0.3 to 0.6 m) on Molokai. Most trees showed good vigor. The results suggest that Mexican pines would be suitable for reforestation on adverse sites at the higher elevations in Hawaii.

Oxford: 174.7 *Pinus* spp.–(72):(969):232.11
Retrieval Terms: Pinus spp., Mexican pines, species trials, mortality, life form, Hawaii

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PACIFIC SOUTHWEST Forest and Range Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701

Growth and Mortality after Regeneration Cuttings in Old-Growth Redwood

Kenneth N. Boe

USDA FOREST SERVICE RESEARCH PAPER PSW-104 /1974

CONTENTS

The Author

KENNETH N. BOE was formerly in charge of the Station's research unit on the silviculture of redwood and associated species, with headquarters at Arcata, California. A native of Montana, he earned bachelor's (1946) and master's (1948) degrees in forestry at Montana State University. He joined the Station in 1956 and retired in March 1974 after more than 33 years in Federal service. He is currently engaged in teaching and consulting work.

SUMMARY

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Oxford: 174.7 *Sequoia sempervirens:*221.2:228
Retrieval Terms: Sequoia sempervirens; regeneration cuttings; stand development; logging damage; mortality.

Growth and mortality factors associated with three regeneration cutting methods—clearcutting, shelterwood, and selection cutting—were studied during an investigation of the most effective way to convert old-growth redwood (*Sequoia sempervirens* [D. Don] Endl.) into younger managed stands. Each method was tried twice on the Redwood Experimental Forest, Del Norte County, in north coastal California. The clearcuttings were in small blocks of 10 to 20 acres and alternated with reserve seed blocks about the same size. Like the shelterwood cuttings, they will result in even-aged stands. On each shelterwood, about 75 percent of the merchantable volume was harvested in the first cutting; on one half of each shelterwood all the overstory will be harvested after reproduction is established; on the other half the overstory will be removed in two cuts about 10 years apart. The selection method is aimed at producing and maintaining uneven-aged forests by recutting every 10 years for a planned rotation of 80 to 100 years.

In these old-growth stands, crown improvement to reserved redwood a few years after harvesting was highly variable. There was no consistent tendency of crowns to improve or decline more on the shelterwood than on the selection cuttings.

Mortality of reserved trees caused by logging was in direct proportion to the volume cut. Where about half the volume was harvested on selection cuttings, 20 percent of sawtimber, 70 percent of poletimber, and 80 percent of saplings were killed. But where 75 percent was cut on the shelterwood, the losses were 50 percent of sawtimber, 90 percent of poletimber, and 90 percent of saplings.

The implications of growth in basal area and cubic volume vary with the kind of regeneration cutting. On clearcuttings, since few if any residual trees remain, the basal area and cubic volume growth accrue on the new young stand 5 or more years after regeneration is established. For the shelterwood method, the reserved sawtimber stand is kept for a short period; therefore, growth on these trees is short-term gain. On selection cuttings, however, it is theoretically possible to have a continuous intermixed producing and regenerating forest—but proportions differ between old and young stands.

For sawtimber trees, the selection cuttings had a larger negative net basal area growth than did the shelterwood, because mortality was high on the selection. Even increment on surviving trees on both cuttings was only poor to fair, considering the voluminous growing stock. As expected, net growth on the uncut stand was near zero because of mortality.

On all the cuttings, net growth of poletimber was slightly positive or nearly so mainly because of ingrowth. Mortality was a significant amount.

For saplings, the increment and ingrowth were already one-half or more of that on the heavy sawtimber growing stock of corresponding shelterwood cuttings and one-eighth or more on selection cuttings, by the end of the second growth period. Because of well-stocked reproduction, increment and ingrowth were relatively large on the clearcuttings.

Growth of sawtimber in terms of cubic volume paralleled that for basal area. High mortality resulted in negative net growth; the largest was on the selection cuttings. Increment on surviving trees was fair on a per acre basis, but very poor as a percent of growing stock.

On poletimber, net cubic volume was largely the result of ingrowth from saplings. The largest amounts were measured on the two clearcuttings. And increases would probably be at an accelerating rate.

For redwood, the diameter was significantly correlated with age. Therefore, initial diameter was a principal independent variable for analyzing diameter growth after harvesting. Crown change and competition from other reserved trees as expressed by basal area were inadequate variables to account for diameter growth in multiple regression equations.

During the first postlogging period (about 5 years), diameter growth accelerated on redwood trees less than 100 inches (254 cm) d.b.h. and rate decreased as diameter increased on all but one cutting. The same acceleration pattern prevailed during the second postlogging period of 5 years and on all cuttings. The growth, by diameter class, however, was at a higher level on the uncut stands during the second than during the first period. This difference suggests a climatic effect; part of the higher level of growth on the regeneration cuttings was probably due to climate.

Since diameter was signficantly correlated with diameter increase on the individual cuttings, a single equation was computed for all cuttings and for both growth periods. This equation may be used on other cutover stands of site class I for redwood having similar stand characteristics to predict diameter growth by which the future stand volume may be computed:

$$Y = 4.009 - 0.026X$$

in which Y = diameter growth ratio for a 10-year period and X = initial d.b.h. (inches).

The forest manager responsible for harvesting stands of old-growth redwood (*Sequoia sempervirens* [D. Don] Endl.) has a choice of regeneration cutting methods. If he wants to develop and maintain an uneven-aged forest, he would choose the selection method. If his objective is even-aged management, then his choices would be shelterwood, seed tree, or clearcutting. To decide, he has to consider many factors. Among them are the growth and mortality of the reserve and new growing stock.

In the past, the timber industry varied its cutting practices in old-growth redwood from what was essentially clearcutting, adopted before 1930, to selective cutting, which was used until about 1960. Show (1932) proposed a deliberate saving of seed trees and documented that higher grades of lumber could be attained in the future from small trees reserved from cutting than from new young-growth. Furthermore these small trees had negative value when cut, and if left they would accelerate their growth. Person (1947) reported similar results supporting selective cuttings in which the financially immature trees were left. And Fritz (1951) developed additional evidence of the great potential for growth acceleration by the suppressed trees left after cutting old-growth redwood. In present industry operations, however, economic changes have made clearcutting feasible. Furthermore, artificial regeneration, and in the right situations, natural regeneration, are considered quick, sure means of starting new crops. Some industrial foresters, however, are continuing selective harvesting of old-growth to capitalize on growth of reserved trees and to obtain natural regeneration for the new crop.

To obtain information about growth of reserved stands, the Pacific Southwest Forest and Range Experiment Station started test regeneration cuttings on the Redwood Experimental Forest in northern California in 1959, and completed the first series in 1960 and the second series in 1964. Two remeasurement periods have now passed. During the first period after harvesting we usually expect heaviest mortality. In an earlier report I summarized findings on wind mortality (Boe 1965).

This paper documents logging mortality and damage and growth and mortality following three types of cuttings: clearcutting, selection, and shelterwood. Annual increment of the reduced sawtimber volume in selection and shelterwood cuttings was below that in the uncut stand. Average net growth—especially on the selection cuttings—was strongly negative because of high mortality. Net growth and increment of saplings and poles began to be a significant amount in the second period—particularly on clearcuttings—because of ingrowth.

THE STUDY

A major goal of the study was to analyze growth and mortality associated with regeneration cutting methods that could effectively convert old-growth redwood into younger managed stands. For the experiments, three methods were tried in each of two areas.

The first method was clearcutting (*fig. 1*) of all sawtimber in small blocks ranging in size from 10 to 20 acres and alternated with reserve seed blocks about the same size. This method results in future even-aged young stands.

The second method was a shelterwood cutting (*fig. 1*), which also results in even-aged new stands. About 75 percent of the sawtimber volume was harvested. Vigorous codominant trees were reserved to help protect the site, furnish seed, and add growth. After reproduction was satisfactorily established, all of the reserved overstory was to be removed on one half of each shelterwood cutting. On the other half, the overstory was to be removed in two equal cuts—the first after reproduction was established, and the second about 10 years later. Because regeneration was adequate, and windfalls required salvage, shelterwood cutting A was reharvested in 1965. Shelterwood cutting B was scheduled for reharvesting in 1974, the planned 10 years after the first cutting.

The third method, selection cutting (*fig. 1*), is aimed at producing and maintaining uneven-aged forests. The first harvest removed about 50 percent of the volume in sawtimber of all sizes. Selected larger older trees were cut on about 10 percent of the area and additional smaller trees were cut because they

Figure 1—Reserved growing stock after regeneration cuttings ranged from none on the clearcutting (upper left) and light on shelterwood (upper right) to moderate on the selection cutting (lower left). The uncut stand (lower right) illustrates full stocking.

were defective or dying, or had to be removed to provide space to fell the larger trees. The reserved trees of all sizes tend to be arranged either in groups or alone and are unevenly spaced throughout the stand. The selection cuttings were to be reharvested every 10 years with a planned rotation of 80 to 100 years. The windfalls were salvaged on selection cutting A in 1965 after 5 years, but selection cutting B was to be recut in 1974—10 years after the initial harvest.

METHODS

To study the growth and mortality on these series of cuttings, 0.4-acre (0.16-hectare) sample plots were randomly located on each of the cuttings. There are 10 plots on each of two shelterwood and two selection cuttings, five plots on each of four clearcuttings, and eight plots in the adjacent uncut reserve stands. On each of the growth plots, all redwood and Douglas-fir were measured. Other species were measured on a subsample of one-quarter of each growth plot. All plots were established before the cuttings to permit an evaluation of the impact of cutting on the reserve trees.

The initial information recorded consisted of measurements of diameter and of merchantable and total heights of a subsample of trees; descriptions of crown vigor and sizes; and estimates of the kind and amount of understory vegetation. From the crown estimates, made initially and after one remeasurement, I computed a crown index which is a numeric expression in whole numbers of the product of tree crown relative length, relative width, and density. Length and width were estimated as a percent of the total height of each sample tree. Arbitrarily, I assigned the value 3 to a dense foliage crown, 2 to medium, and 1 to thin and open. A typical crown index is 50 X 25 X 2 = 2500.

After logging was completed, we made several remeasurements. First, we recorded the kind and amount of logging damage before burning slash on the cuttings. Then after an interval of 4 or 5 years the diameters of trees were redetermined—by tape on trees generally 24 inches d.b.h. and less and by increment borings on the larger trees, with no allowance for bark growth. The crowns were reestimated for length, width, and vigor. Mortality was noted and new trees that exceeded the minimum measurable size, i.e., ingrowth, were recorded.

Growth was analyzed in two principal ways: (1) an evaluation of basal area and cubic volume growth on reserve and new trees in the cuttings, relative to each other and to growth in the uncut stands, and (2) an analysis of redwood diameter growth by regression.

For evaluation of basal area and cubic volume growth, the individual tree data were calculated by plots and all species were combined. The growth components are (a) increment on surviving trees, (b) mortality, and (c) ingrowth into the size group being considered. Cubic volume growth was calculated for sawtimber (trees 11 inches d.b.h. in size and larger) and for poletimber (trees 5 to 10.9 inches d.b.h.). Basal area growth was determined for saplings (1 to 5 inches d.b.h.), poletimber, and sawtimber.

RESULTS

Impact on Reserved Trees

Crown Change

The crown indexes after 5 or more years showed there was no consistent pattern of crown improvement (*fig. 2*). On shelterwood A there were general declines in crown areas; on shelterwood B, a slight improvement; on selection A, a definite improvement; and on selection B, a definite decline. These ratings are evidence that short-time change of old-growth redwood crowns by epicormic and other needle and branch growth is highly variable between cuttings and for all crown sizes.

Logging Damage

The principal logging damage was the immediate death of a sizeable portion of the intended sawtimber reserve—21 to 22 percent on selection and 49 to 57 percent on shelterwood cuttings (*table 1*). Logging also caused destruction of many smaller trees, much of it unavoidable: on selection cuttings about 70 percent of saplings and 62 percent of poletimber; on shelterwood about 82 percent of saplings and 80 percent of poletimber. Nearly all poletimber and saplings on clearcuttings were also killed, but they were usually considered unneeded or expendable during slash disposal. This damage is from felling, bucking, building tractor layout and skidroads, and skidding logs. This damage is instant loss of growing stock. And although most of the sawtimber trees were utilized, the reduction greatly changed the intended differences between cuttings. The level of losses was in direct proportion to the level of cut—heaviest for the 75 percent cut on the shelterwood and least for the 50 percent cut on the selection area. During a given season, the same crew worked on both selection and shelterwood cuttings; therefore, its logging techniques were judged to be alike irrespective of regeneration method.

The nonfatal damage to the residual growing stock has impact of a different kind on future growth. This impact, such as rot encroachment on debarked portions of trees and in broken tops, will require separate study and evaluation. The listing of damage (*table 1*), however, suggests its extent and possible potential for growth loss. Debarking was proportionately the greatest of all nonfatal damage on sawtimber on both the selection and shelterwood cuttings. Many of these trees will be held through several cutting cycles, hence there will be opportunity for varying amounts of trunk rot.

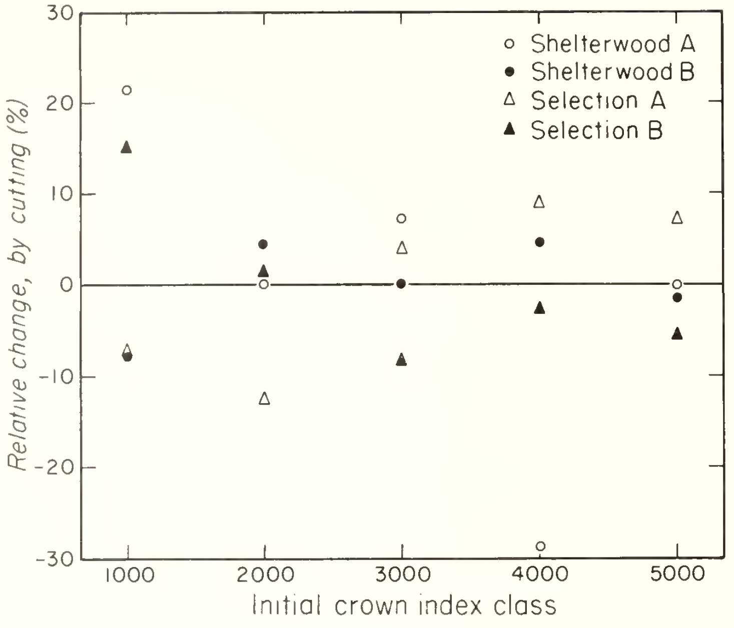

Figure 2—Crown index change in redwood 5 or more years after cutting shows no consistent pattern of crown improvement.

Table 1—*Principal logging damage*[1] *to the reserve stand, by cutting and three size groups, Redwood Experimental Forest, California*

Cutting and size group	Dead	Sprung roots	Broken top	Debarked	Stripped crown	None
	Percent of trees					
Selection A:						
Saplings	70.5	0	1.7	9.8	0	18.0
Poletimber	74.3	0	0	3.2	3.2	19.3
Sawtimber	20.7	7.5	3.3	33.3	0	35.2
Selection B:						
Saplings	93.0	1.6	0	0	3.1	2.3
Poletimber	62.4	2.1	2.1	6.3	0	27.1
Sawtimber	21.7	3.6	2.2	36.2	0	36.2
Shelterwood A:						
Saplings	81.3	2.0	3.0	3.0	0	10.7
Poletimber	80.4	3.1	0	10.3	1.0	5.2
Sawtimber	49.2	9.5	6.4	19.0	0.8	15.1
Shelterwood B:						
Saplings	95.9	0	0	0	0	4.1
Poletimber	96.8	0	0	3.2	0	0
Sawtimber	56.9	0	4.9	32.5	0	5.5

[1]Priority for determining damage class (for other than dead trees) if more than one kind of damage was present: (a) sprung roots, (b) broken top, (c) debarked, (d) stripped crown.

Growth

The sawtimber, poletimber, and saplings were grouped according to size at the beginning of each measurement period. Essentially the data represent Site I for old-growth redwood although part of shelterwood A and clearcutting A are Site II. Site I corresponds approximately to site index 200 and above for base age 100 years.

Original sawtimber stand volumes varied considerably, some because of site, and others because of irregular stocking from past mortality or original density:

	Trees/acre (ha)	*Volume/acre (ha)*
		Cu ft (m^3)
Cutting:		
Selection A	44.8 (110.7)	55,199 (3862)
Selection B	51.7 (127.8)	78,897 (5520)
Shelterwood A	54.5 (134.7)	36,384 (2546)
Shelterwood B	80.5 (198.9)	66,499 (4653)
Clearcutting A	36.2 (89.4)	48,840 (3417)
Clearcutting B	33.2 (82.0)	57,248 (4006)
Uncut area	48.8 (120.6)	52,946 (3705)
Average	50.0 (123.6)	56,573 (3958)

The numbers and volume of trees cut per acre varied according to the regeneration method being tried and the density of original stands:

	Trees/acre (ha)		*Volume/acre (ha)*	
	Number	*Percent*	*Cu ft (m^3)*	*Percent*
Cutting:				
Selection A	14.8 (36.6)	33.0	27,515 (1925)	49.8
Selection B	17.2 (42.5)	33.3	41,680 (2916)	52.8
Shelterwood A	23.0 (56.8)	42.2	29,847 (2089)	82.0
Shelterwood B	39.8 (98.3)	49.4	50,309 (3520)	75.7
Clearcutting A[1]	31.0 (77.5)	85.6	48,193 (3372)	98.7
Clearcutting B[1]	32.2 (79.6)	97.0	57,226 (4004)	99.9

[1] A few small trees were missed during the logging.

In both the selection and shelterwood cuttings a full range of tree sizes was cut, but the relative reduction in average diameter calculated by cutting areas was highest on the shelterwood cuttings. The average tree diameters before and after cutting, and for the cut trees, are shown to be:

	Average diameter		
	Before	*Cut*	*Reserve*
	Inches (cm)		
Cutting:			
Selection A	60.8 (154.4)	74.5 (189.2)	52.6 (133.6)
Selection B	65.3 (165.9)	80.8 (205.2)	56.0 (142.2)
Shelterwood A	43.3 (110.0)	56.7 (144.0)	30.0 (76.2)
Shelterwood B	49.6 (126.0)	60.3 (153.2)	36.1 (91.7)

Basal Area

For the sawtimber-size group and the four partial cuttings (*table 2*), all the average net growth in annual basal area for 10+ years was negative. And that for the two selection cuttings represented the greatest loss—exceeding by a factor of 10 or more the net growth on the shelterwood and uncut stands. The high mortality rates on the selection cuttings were responsible for this large negative result. Furthermore, increment on surviving trees is relatively poor, considering the great amount of growing stock. Mortality was considerably lower on the shelterwood cuttings and accordingly the negative net growth was smaller. For the lower growing stock the increment on shelterwood B, which had not been recut, was fair. I had expected and found the uncut stand to be near zero or negative net growth because of the constant mortality. For this old stand the increment on surviving trees was poor, considering the large growing stock.

Mortality on selection A and shelterwood A were mainly from windfalls. But about 10 percent of the trees had been previously weakened by the logging (*table 1*); hence both wind and logging were involved in killing these trees. In 1962, an unusual phenomenon for north coastal California—a hurricane—increased mortality by wind an estimated three to six times above previous post-logging losses (Boe 1965). However, high windfall losses also occurred on selection A and shelterwood B several years after the hurricane, illustrating that damaging winter storms are not rare. On the selection B cutting, about 17 percent of mortality resulted from fire damage incurred while the heavy volume of slash among the reserved trees was burned. The remaining mortality was caused by wind and other conditions.

The small basal area of poletimber growing stock in the original stands was further reduced to negligible amounts by logging mortality on the partial cuttings (*table 2*). On clearcuttings, however, the remaining poletimber was removed in slash disposal as unneeded trees. Net annual basal area growth was positive or nearly so for all cuttings mainly because of ingrowth. In addition, some poletimber became ingrowth in the sawtimber group during the two growth

Table 2—*Annual basal area growth during two 5- to 6-year periods after cutting, by method, Redwood Experimental Forest, California*

Mortality and Growth	Selection		Shelterwood		Clearcutting		Uncut
	A	B	A	B	A	B	
	Sq ft/acre (m^2/ha)						
	Sawtimber 11+ inches d.b.h.						
Growing stock	405.03	573.52	123.08[1]	242.58	0	0	849.68
Mortality 1st period	−15.84	−24.16	−2.43	−.31	0	0	−4.28
Increment 1st period	1.56	1.01	.78	.87	0	0	1.64
Ingrowth 1st period	.07	0	.04	0	0	0	.04
Mortality 2nd period	−10.19	−1.28	−.33	−3.40	0	0	−1.85
Increment 2nd period	1.82	2.19	.19	1.64	0	0	2.35
Ingrowth 2nd period	.16	.50	.04	.05	0	0	.04
Average net growth[2]	−11.82	−10.87	−.86	−.57	0	0	−1.03
	(−2.7)	(−2.5)	(−.2)	(−.1)	0	0	(−.2)
Average gross growth[2]	14.82	14.57	1.90	3.14	0	0	5.10
	(3.4)	(3.3)	(.4)	(.7)	0	0	(1.2)
	Poletimber 5 to 10.9 inches d.b.h.						
Growing stock	0.58	1.83	1.60	0.43	0	0	1.48
Mortality 1st period	−.02	−.11	−.21	−.02	0	0	0
Increment 1st period	.03	.03	.01	.01	0	0	0
Ingrowth 1st period	0	0	.01	0	0	0	.03
Mortality 2nd period	0	−.15	−.05	−.04	0	0	−.03
Increment 2nd period	0	.03	.02	0	0	0	.03
Ingrowth 2nd period	.19	.15	.62	.04	1.02	.60	0
Average net growth	.10	−.03	.20	−.01	.51	.30	.02
	(.02)	(−.01)	(.04)	(.00)	(.12)	(.07)	(.01)
Average gross growth	.12	.24	.46	.06	.51	.30	.05
	(.03)	(.06)	(.11)	(.01)	(.12)	(.07)	(.01)
	Saplings 1 to 4.9 inches d.b.h.						
Growing stock	0.13	0.19	0.13	0.08	0	0	0.06
Mortality 1st period	−.02	−.03	−.01	−.02	0	0	−.01
Increment 1st period	.04	0	.03	0	0	0	.01
Ingrowth 1st period	.02	.02	.07	.03	.13	.23	0
Mortality 2nd period	−.04	−.01	−.01	−.01	0	−.04	−.01
Increment 2d period	.13	.21	.08	.27	.26	.61	.01
Ingrowth 2d period	.11	.53	.20	.60	1.46	.62	0
Average net growth	.12	.36	.18	.41	.95	.71	0
	(.03)	(.08)	(.04)	(.09)	(.22)	(.16)	0
Average gross growth	.18	.40	.20	.44	.95	.75	.04
	(.04)	(.09)	(.04)	(.10)	(.22)	(.17)	(.01)

[1]Growing stock the second period was reduced to 33.82 square feet by a second cutting.
[2]Net growth = increment + ingrowth − mortality. Gross growth equals the sum of the three components.

periods being measured. On the uncut stand, the average net growth was very small but positive because some trees became sawtimber ingrowth during the period and there was little initial growing stock upon which to accumulate wood.

In the sapling-size group, on all of the cuttings the ingrowth and the increment on that ingrowth were both substantial. Together they amounted to more average net growth than on the poletimber stand. Furthermore, the sapling stand furnished the ingrowth to the pole stand. The ingrowth and increment were relatively large, especially on the two clearcuttings, because of well-stocked reproduction. At the end of the second period, basal area increment and ingrowth on the clearcuttings were already one-half or more of that on the heavy sawtimber growing stock of corresponding shelterwood cuttings, and one-eighth or more on selection cuttings. On the uncut stand the increment and ingrowth of saplings, as expected, was negligible.

Volume

For growth expressed in annual cubic feet, the net growth values of sawtimber are negative and large (*table 3*) for the two selection cuttings in comparison to those for the shelterwood and uncut stand. Again the high mortality offset increment. Increment on surviving trees is fair on a per acre basis on all except shelterwood A. But increment as a percent of growing stock is poor; it is lowest on the uncut stand. Shelterwood A was recut after the first period; hence its growing stock was greatly reduced. Clearcuttings had no sawtimber growing stock.

In poletimber, the annual net volume growth in cubic feet was only minor and slightly negative on two cuttings (*table 3*). On the two clearcuttings, ingrowth during the second period accounted for all of the net growth. This condition is a sign of the accelerating rate of cubic volume to be expected on these cuttings. The ingrowth accumulates from the sapling stand, where it had no measurable cubic volume be-

Table 3—*Annual cubic-foot volume growth during two 5- to 6-year periods after cutting, by method, Redwood Experimental Forest, California*

Mortality and Growth	Selection		Shelterwood		Clearcutting		Uncut
	A	B	A	B	A	B	
	Cu ft/acre (m^3/ha)						
	Sawtimber 11+ inches d.b.h.						
Growing stock	24,962.3	36,591.6	5,520.9	14,589.8	0	0	52,945.8
Mortality 1st period	−972.1	−1,533.8	−89.9	−6.9	0	0	−217.7
Increment 1st period	100.3	70.2	41.7	57.4	0	0	109.8
Ingrowth 1st period	1.3	0	.5	0	0	0	.8
Mortality 2d period	−604.6	−56.2	−11.3	−181.1	0	0	−87.5
Increment 2d period	111.5	152.5	10.9	100.0	0	0	154.6
Ingrowth 2d period	2.9	1.0	.1	.9	0	0	.8
Average net growth[1]	−680.4	−683.2	−24.0	−14.8	0	0	−19.3
	(−47.6)	(−47.8)	(−1.7)	(−1.0)	0	0	(−1.4)
Average gross growth[1]	896.4	906.8	77.2	173.2	0	0	285.3
	(62.7)	(63.4)	(5.4)	(12.1)			(20.0)
	Poletimber 5 to 10.9 inches d.b.h.						
Growing stock	7.2	34.8	30.3	5.6	0	0	20.4
Mortality 1st period	−.2	−.6	−4.1	−.3	0	0	0
Increment 1st period	.5	.4	.2	.3	0	0	.7
Ingrowth 1st period	0	0	.1	0	0	0	0
Mortality 2d period	0	−3.9	−1.3	−.5	0	0	−.6
Increment 2d period	0	1.0	.4	0	0	0	.2
Ingrowth 2d period	1.9	1.0	7.1	.4	10.8	4.7	0
Average net growth	1.1	−1.5	1.2	−.1	5.4	2.3	.2
	(.08)	(−.10)	(.08)	(−.01)	(.38)	(.16)	(.01)
Average gross growth[1]	1.3	4.0	6.6	.8	5.4	2.3	.8
	(.09)	(.28)	(.46)	(.06)	(.38)	(.16)	(.06)

[1]Net growth = increment + ingrowth − mortality. Gross growth equals the sum of the three components.

cause the minimum tree for volume determination was 5 inches d.b.h.

Diameter

Diameter and Age—If d.b.h. and age are highly correlated, then d.b.h.—an easily measured variable—can be used alone to analyze diameter increment. For 78 observations, I found the correlation coefficient to be highly significant at the 0.01 level in a regression of age (Y) on d.b.h. in inches (X):

$$Y = 103.95 + 5.27\,X;\ r = 0.81$$

Because of this significant correlation, diameter was used as the principal independent variable in evaluating diameter growth.

Growth and Crown Index—The crown index and its change with time seemed to be a useful variable to explain and predict diameter growth. By separate regression analyses for each cutting, I first determined that crown index increased as diameter increased. This relationship would result in a confounding effect with diameter as an independent variable in multiple regression; therefore, I discarded the initial crown index.

Next I examined the relationship of crown index ratio (ratio of crown index at the end of a growth period to that of the crown index at the beginning) to diameter. The result was that crown index ratio was independent of diameter; therefore, it would be a useful independent variable for diameter growth analysis.

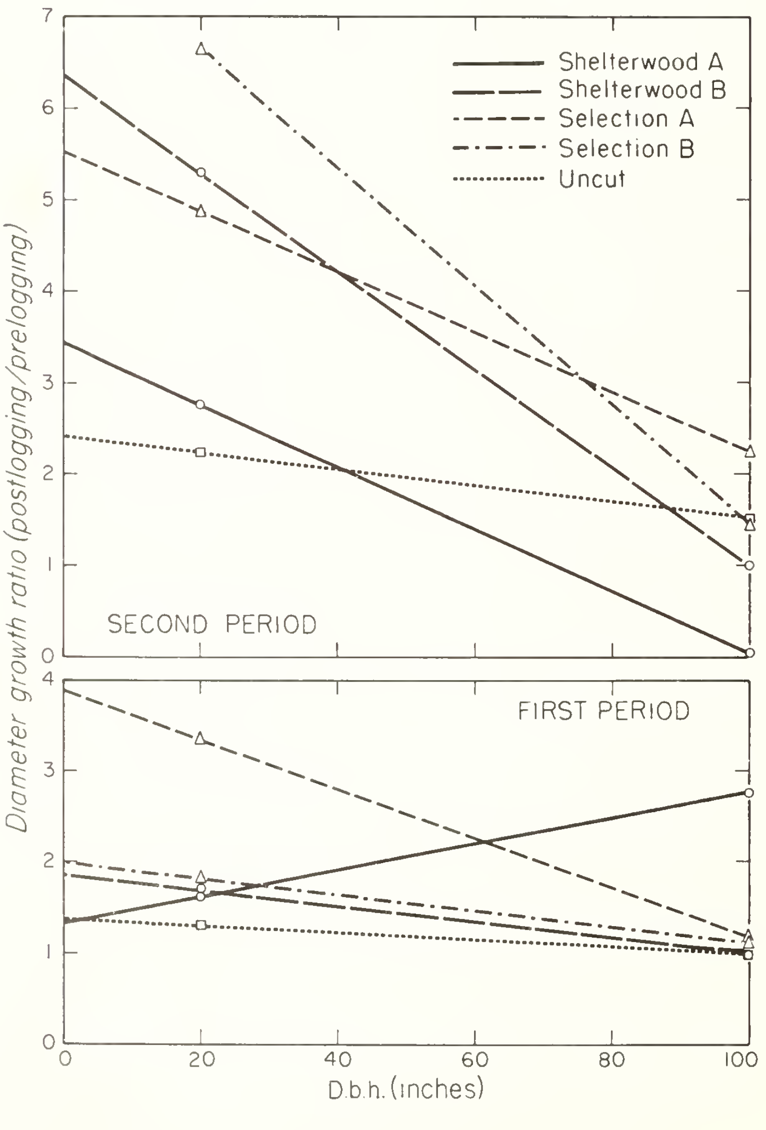

Figure 3—Relative diameter increase in redwood for postlogging periods was affected by initial diameter (correlation: r** = 1 percent level; r* = 5 percent level; r N. S. = not significant).

Diameter growth ratio, i.e., that annual growth for the first period after logging divided by annual growth for the immediate 10-year period before, is a relative measure of diameter increment. I analyzed its relationship to crown index ratio. On three of four cuttings, there was a positive regression for growth ratio to increase as crown index ratio increased. For diameter growth to increase in direct proportion to an increase in crown area was an expected relationship. The data on only one regression, however, were significantly correlated. When crown index ratio was used as an independent variable in a multiple regression analysis of diameter growth ratio, the correlation coefficient was surprisingly small. Since little of the variation in diameter increment could be explained by the combination of variables including crown index ratio, I concluded that crown index estimates in old-growth redwood stands are not useful as tree variables.

Growth Ratio and Growing Stock—Diameter growth in a stand after cutting should be affected by competition from the growing stock; in this study the basal area of this growing stock was used to express this competition. Two linear regressions were calculated for each cutting and for the uncut stand—one for each of the two periods after cutting.

Data from the two shelterwood cuttings show that slopes of regressions were positive the first period, i.e. an accelerated growth was evident with the larger reserved basal area. Slopes for the second period were negative. Data from the two selection cuttings and for two periods shows that only one slope was negative. For both periods on the uncut stand the regression slopes were positive—opposite to the expected. From these results I concluded that basal area of the reserved growing stock is a weak variable for estimating the trend of diameter growth after cutting. Further testing of basal area in the multiple regression analysis with crown index ratio led to the same conclusion: basal area of the reserve stand was not a useful variable for estimating diameter increment of the reserved trees.

Diameter Growth Ratio and Diameter—The initial diameter of reserved trees was a satisfactory variable for explaining diameter growth in the stand after cutting. For diameters less than 100 inches d.b.h., accelerated growth occurred on three cuttings and on the uncut stand. (*fig. 3*). The rate, as expected, decreased as diameter increased in all except shelterwood A; this relationship seemed to be atypical. In shelterwood A, the rate increased as diameter increased, but the correlation coefficient, unlike the coefficients for the other regressions, was not significant. On the uncut stand the height of the regression line above the 1.0 growth-ratio ordinate axis would indicate a climatic effect; therefore, the release effects of cutting are mainly the differences between the regressions for the cuttings and the uncut stand (*fig. 3*).

During the second growth period of about 5 years (10 years after cutting) the levels of growth rates based on the first 10 years before logging were considerably higher than those compared to the first period (*fig. 3*). Since the relative growth in the uncut stand also was about double that in the previous period, we can assume that favorable climate accounted for some of the increase of the cuttings. Nevertheless, on the selection cuttings A and B and shelterwood B cutting there were substantial gains, after adjustment for climate, over the previous period. Half of the shelterwood A had been cut after the first study period, and too few trees were left on the remainder to yield a significant regression.

The regressions and their correlation coefficients on the same three cuttings in both growth periods showed similarity. Therefore, I considered it proper to combine all of the data on the cutover stands into a linear regression equation for growth prediction:

$$Y = 4.009 - 0.026X; \; r = 0.329$$

in which Y = diameter growth ratio for a 10-year period, X = initial d.b.h. (inches), and the correlation coefficient is highly significant at the 0.01 level.

DISCUSSION AND CONCLUSIONS

In the conversion of old-growth redwood stands to younger managed stands, the regeneration cutting options are to strive for even-aged stands by clearcutting and shelterwood cutting (also seed-tree cutting), or for uneven-aged stands by selection cutting. Among the many factors to evaluate as advantages or disadvantages for a particular method are growth and mortality on reserved growing stock and development of new growing stock from regeneration. The measurements in uncut stands provide a baseline for comparison with cut stands, and resource information for estimating growth in old-growth stands that are being held for future harvesting.

The results document that tractor logging mortality is heavy, is related to the volume or level of cut, and is especially destructive of small trees. Therefore, if heavy partial harvests are made, such as shelterwood and selection cuttings, specific procedures should be followed to save the smaller trees.

A manager will ordinarily view the growth on the reserved shelterwood growing stock somewhat differently from that on selection cuttings. If he uses the shelterwood method, he first wants regeneration over the entire harvested area. The growing stock is retained for seed production, protection to the seedlings, and short-term growth gain. But the future stand yield will be based on the new even-aged stand. On selection cuttings, however, regeneration is mainly required in openings, and the reserved growing stock should optimally produce wood increment during the rather long conversion period to an uneven-aged stand, in which the oldest trees will eventually be the chosen rotation age. On clearcuttings the principal growth is accumulated on the new young stand.

Selection cuttings in old-growth redwood, however, as judged from these results, are not likely to produce initially a volume of wood commensurate with the site potential. Although a hurricane was the cause of greatly increased windfall in our cuttings, the expected heavy mortality usually results in negative net basal area and cubic volume growth for sawtimber. If this killed timber can be salvaged then gross growth may appear to be favorable. But increment on surviving trees will be low—considering the square feet of basal area and cubic volume of growing stock. Prospective growth rates of from 0.2 to 0.8 percent indicate the over-all poor response.

And because initial poletimber growing stock may be minimal in old-growth stands, expected immediate net growth likewise will be small. But if healthy young sawtimber, poletimber, and saplings are present they should be protected because they are a valuable addition to the new young growing stock.

After a few years, on selection cuttings, the sapling component, which will be mainly from new reproduction, is the future hope for growth. These trees are the source of ingrowth into poletimber plus increment on sapling ingrowth. The level of growth, however, appears to be potentially consistently less than for the other cuttings.

The short-term growth gain of sawtimber trees on shelterwood cuttings will ordinarily be low in proportion to growing stock and site quality because of mortality and tree response. In these old-growth stands, diameter and age are strongly correlated. The smaller younger trees, on the average, respond well to additional growing space and generally provide the most increment during the regeneration and conversion period. Fritz (1951) also found that percent increase of small trees left after cutting in old-growth redwood was large. These smaller trees, however, are usually inadequate seed producers for natural regeneration (Boe 1968); therefore, some larger trees will need to be reserved for this purpose. Hence the reserved sawtimber should be viewed essentially for seed production and minimal growth.

As on selection cuttings, not much growth can be expected from poletimber on shelterwood cuttings because there are usually relatively few of these trees, and mortality can be high. Individual trees respond very well to the ample growing space, but the greatest potential for net growth ordinarily is new reproduction.

Saplings that develop from the expected good regeneration on shelterwood cuttings provide the growing stock for potential best growth. I expect that the first few periods of net basal area and cubic volume growth probably always will be better than on selection cuttings, but growth will be generally less than on clearcuttings. When the shelterwood overstory is removed, an effort to limit damage to the reproduction and to assure restocking of any nonstocked areas is essential.

Where complete utilization of sawtimber is possible, small clearcuttings appear to be a good method, considering only effect on growth, for converting to younger managed stands. Unless there are young, healthy saplings and poletimber in the stand, which it may not be possible to save anyway, an entirely new stand must be started. This can be done successfully by natural regeneration, or if needed, by seeding and planting. By the end of 10 years, net basal area growth will easily surpass that on either the selection or shelterwood cutting—essentially because of mortality on the latter two. And increment on surviving trees and ingrowth will approach that on selection and shelterwood cuttings and likely surpass it in another 10 years.

APPLICATION

A linear regression for the combined two growth periods based on initial diameter can be useful for reliably predicting growth. This approach can be applied to similar stands on good sites elsewhere. To use the equation: (1) multiply the prelog 10-year diameter growth for a size class by the computed growth ratio to get the predicted postlog 10-year growth; (2) add this result to the previous diameter to provide the new diameter for each class; (3) arrange these results in table form with columns for present and projected basal areas and cubic volumes. For short time periods, bark growth is ignored.

By use of basal area tables and local cubic volume tables, both the prelog and postlog stands may then be computed. The difference between these two is the increment on the surviving trees. It is best to estimate mortality for each stand to adjust increment to get net growth.

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Oxford: 174.7 *Sequoia sempervirens:* 221.2:228

Retrieval Terms: Sequoia sempervirens; regeneration cuttings; stand development; logging damage; mortality.

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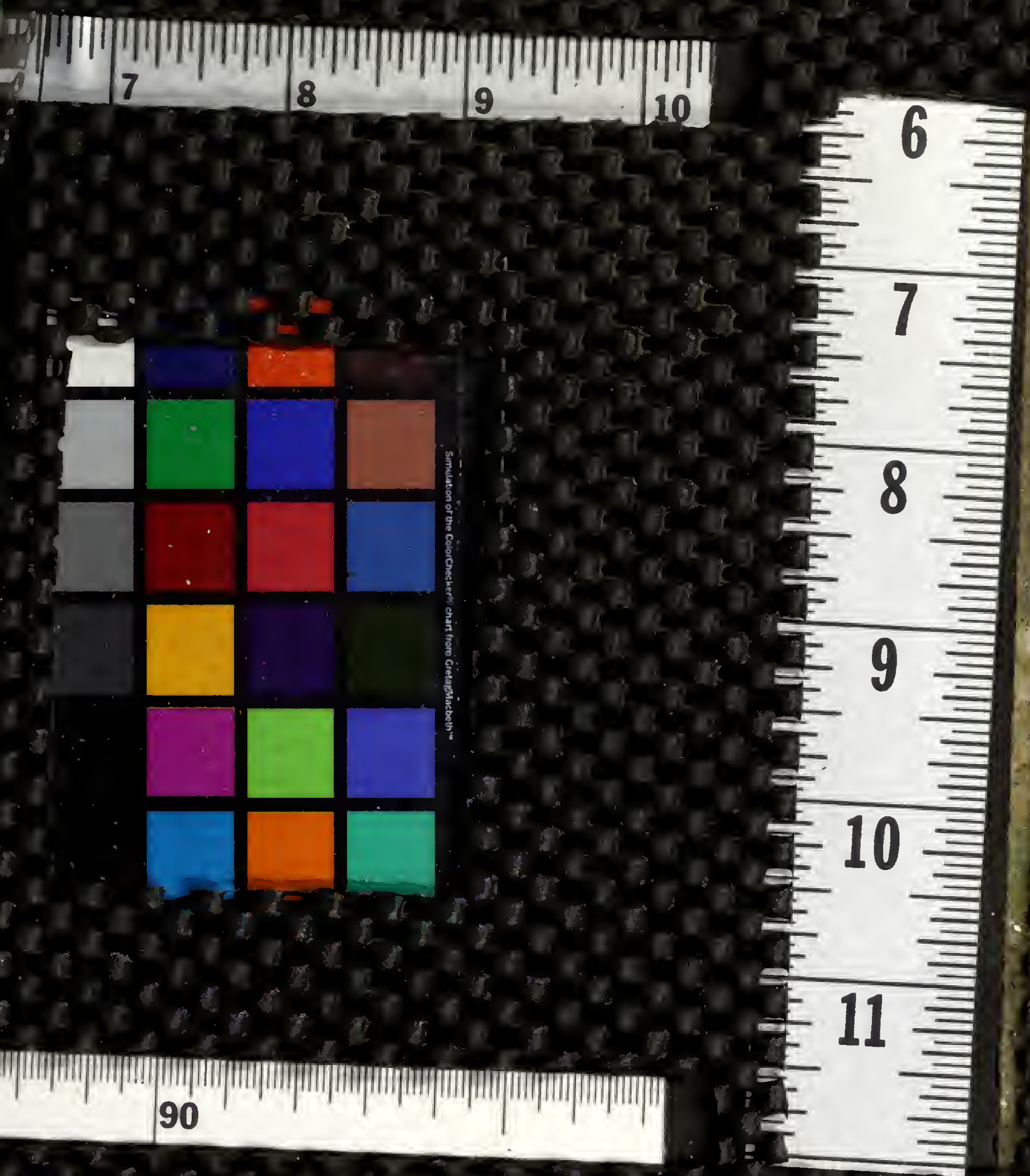
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