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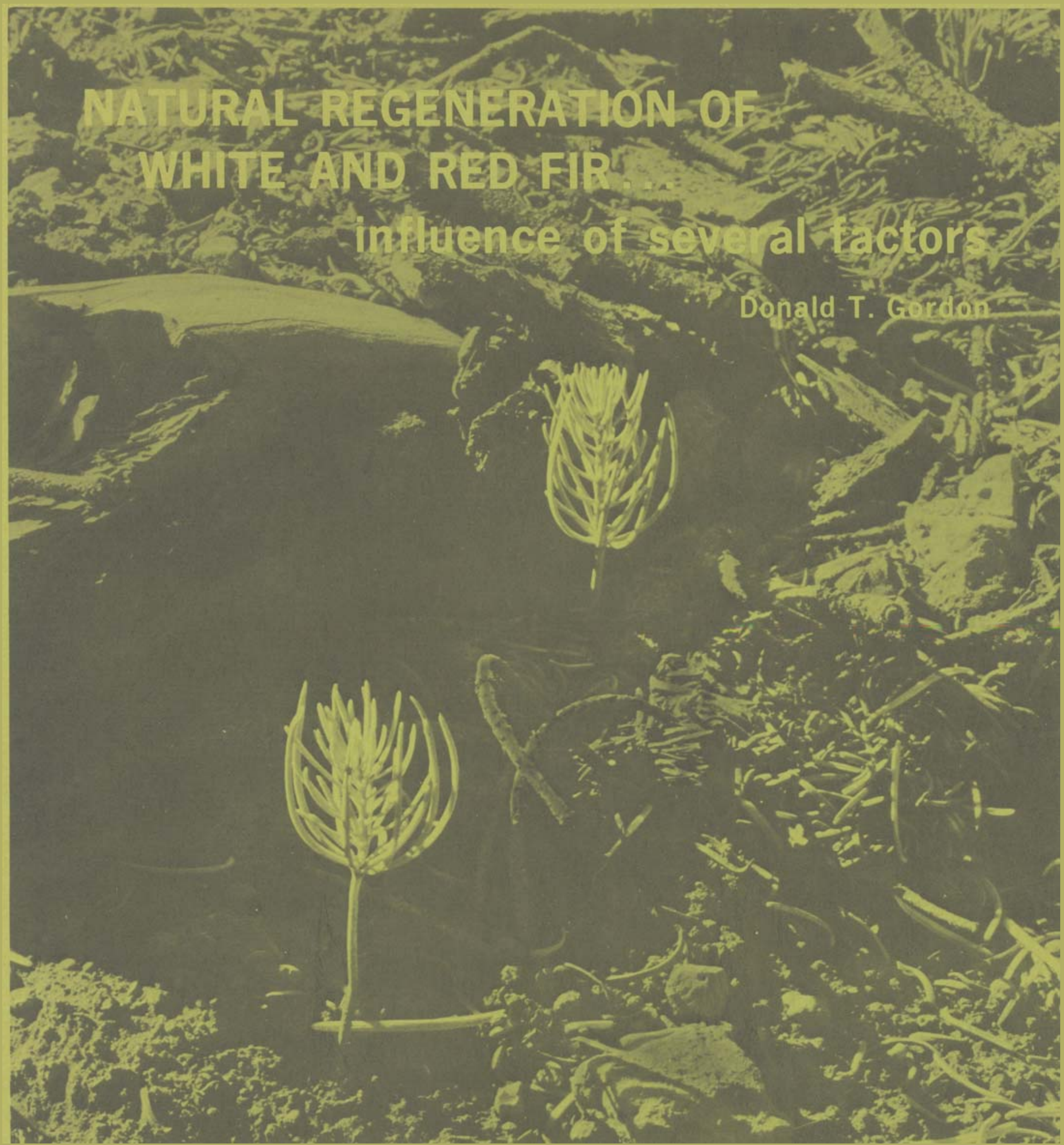

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Gordon, Donald T.

1970. **Natural regeneration of white and red fir. . . influence of several factors.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 32 p., illus. (U.S.D.A. Forest Serv. Res. Pap. PSW-58)

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Retrieval Terms: Abies concolor; Abies magnifica; Abies magnifica var. *shastensis;* natural regeneration; seedling establishment; seedbed; protective shading; seed production; seedling mortality; Swain Mountain Experimental Forest.

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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.

True firs make up about one-fourth of the commercial sawtimber in California, and contribute about the same proportion of growth (Oswald and Hornibrook 1966). Yet research on them has been fragmentary to date–often incidental to studies of other species. In California, the most important species of true firs are white fir *(Abies concolor* [Gord. and Glend.] Lindl.*)*, California red fir *(A. magnifica* A. Murr.*)*, and a variety of the latter–Shasta red fir *(A. magnifica* var. *shastensis* Lemm.*)*. For many years, forest managers considered these species "weeds," or at best, "less desirable." And until recently, these species were rated low in stumpage value–mainly because of trade customs, inherent characteristics of their wood, general lumber demand, and in the case of red fir, their relative inaccessibility.

But now that their stumpage value is on a general upswing, foresters are beginning to re-evaluate the worth of white and red fir. No longer are these species to be considered merely as a source of timber–they now have other values. Their location makes their culture increasingly important. Either white or red fir or both grow on some of California's prime mountain recreation areas. And red fir is one of the most prominent trees growing in the State's high-elevation snow belt. The need for an adequate water supply requires that intensive multiple-use management be practiced there.

The condition of stands of residual merchantable fir trees and natural regeneration varies widely because of different cutting practices in the past. I have seen numerous fir stands in selection cuttings, usually heavy, that were damaged by wind soon after initial harvesting. Conversely, similar stands elsewhere have scarcely been affected by wind. Early-day selection cutting and fire exclusion in the "mixed conifer type" (Type 243, Ponderosa pine-sugar pine-fir, Society of American Foresters 1962) favored white fir understory and the establishment of new fir seedlings. But this cutting practice hindered pine reproduction (Dunning 1923).

The results of large clearcuttings in dense mature fir stands have been mixed. In some instances, these stands have regenerated naturally (Gratkowski 1958; Stein 1954), but many large clearcuttings have not regenerated.[1] And the current trend is toward drastically reducing the size of clearcut openings.

To gather more specific information useful in management of true firs, the Pacific Southwest Forest and Range Experiment Station began a series of studies in 1958 at the Swain Mountain Experimental Forest in northeastern California. The research included studies of several factors that affect establishment of natural seedlings after logging. This paper reports results of these and other studies, outlines tentative recommendations for cutting, and considers other factors related to natural regeneration of white fir and red fir.

Any measure of regeneration success at Swain Mountain does not necessarily mean that the same results can be expected elsewhere. And we are not arguing clearcutting as an always preferable method for harvesting dense old-growth stands to prepare sites for natural regeneration. Forest managers should be able to decide on the best silvicultural treatment for their specific purposes by considering (a) results reported here, (b) variations in stand structure within the natural forest, and (c) past happenings on local cutovers and burns. Their specific purposes may be to produce wood, protect scenic values, or integrate cuttings with snow management. As additional research and field experience yield new findings, they will be able to make even sounder choices.

STUDIES AT SWAIN MOUNTAIN

Study Site

Swain Mountain Experimental Forest lies at the southern limit of the Cascade Range, at 5,700 to 7,054 feet elevation, about 10 miles north of Lake Almanor, California. The forest cover is essentially pure fir, with white fir (Type 211, Soc. Amer. Foresters 1962) predominating at the lower elevations. Near the top of Swain Mountain, red fir (Type 207, Soc. Amer, Foresters 1962) becomes the exclusive species.

Swain Mountain is a volcanic cone, with slopes averaging about 10 to 15 percent. Soil is derived from vesicular andesite, and is generally 3 to 8 feet deep. Rocks vary in size and constitute varying proportions of the soil mass.

[1]Gordon, Donald T. *Report of an examination of true fir regeneration on cutting areas in northern California and southwestern Oregon.* 1964. (Unpublished rep. on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Service, Redding, Calif.)

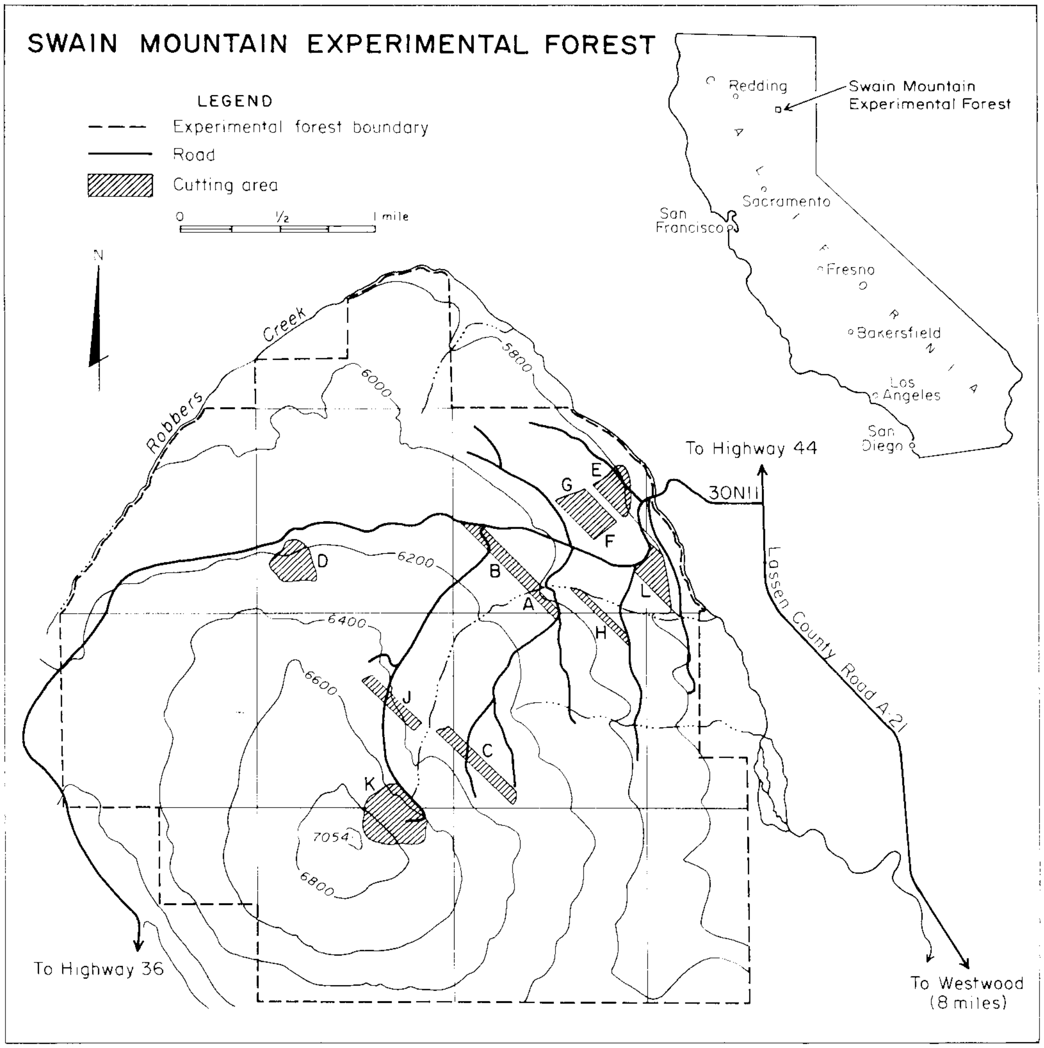

Figure 1.–*Swain Mountain Experimental Forest, northeastern California, where cutting areas were developed in 1958-60. Seedlings and seed were sampled in areas* A *through* D. *Most supplemental studies were in areas* B *and* E.

Precipitation falls mainly as snow. Monthly surveys during four winters revealed that maximum snow depths were between 8 and 10 feet. Forty to 50 inches of water equivalent a year have usually been recorded since the winter of 1957-58. Summers are dry except for occasional scattered thunder showers.

Stand structure varies widely. Volumes over 147,000 board feet per acre (Scribner) have been recorded for commonly-occurring dense stands of mature and overmature trees. Such dense stands have no understory. Less dense stands with volumes of 60,000 to 80,000 board feet per acre are more prevalent, and have abundant fir understories. Most of the Experimental Forest is classed as Site II (Dunning 1942).

General Approach

When these studies were first started, little information was available to guide us. Both white and red fir appeared to be manageable either in uneven-aged or even-aged stands. Management of even-aged stands was studied first.[2] A single set of observations on the Klamath National Forest indicated that red fir clear-cut strips with width not exceeding twice the height of border trees (5 chains wide or less) should become

[2]Hallin, William E. *Plan for operation of Swain Mountain Experimental Forest – true fir type.* 1956. (Unpublished rep. on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Service, Redding, Calif.)

regenerated naturally. Potential damage by wind was thought to be minimized by limiting strip width to this proportion.

Accordingly, a clearcutting program was begun in 1958. During a 3-year sale, several 3- and 5-chain wide strips and some irregularly-shaped blocks (up to 40 acres in size) were cut. Strips were cut in dense stands with little or no understory. Most blocks were cut in stands where decadent overstory had resulted in a bountiful understory. The blocks were cut primarily to provide opportunities to observe release phenomena rather than to secure new regeneration.

Before any strip was cut, the pre-determined area for its location was surveyed for windfalls. In every case, we found that wind from the southwest quadrant had caused most past damage. All strips were therefore oriented northwest-southeast, so that winds would be least damaging.

The main studies were made on or adjacent to four clearcuttings *(fig. 1):* a 3-chain wide strip (A) cut in 1958, two 5-chain wide strips (B cut in 1958, C cut in 1959), and on an irregularly-shaped 17-acre block (D) cut in 1958. Research had to be cut back when the first sale was finished. Therefore all studies were confined to the north and northeast slopes of the mountain.

Plans for early studies were influenced strongly by the urgent need for elementary information about true fir regeneration, and particularly those aspects of it which could be influenced most directly by future management practices. In 1959, three studies of regeneration were started. They concerned (a) cone and seed production; (b) seed dispersal; (c) other factors affecting seedling establishment and mortality, including condition of seedbed, competition from all sources, species, distance from cutting edges, causes of mortality, and unusual events.

Field observations for the cone and seed production study were within uncut stands immediately adjacent to clearcut strips A and B. Seed traps for the dispersal study were placed in and adjacent to cutting areas A through D. For the study of factors affecting seedling establishment and mortality, we used a sampling system of adjoining milacre plots in transects oriented northeast-southwest.[3] These transects were installed in each of three slash treatments on clearcut strips A through C. A single long transect was installed in the clearcut block (D), where slash was not treated.

Observations on transects began early in the summer of the year following logging. All milacres were examined annually through 1965, usually in September, except in 1962, when the "Columbus Day Storm" (October 12) prevented further field work that year.

Analyses were made as if data were from a completely random set of plots. We recognized this procedure as a potential source of statistical difficulty.

As work progressed, newly-found leads were studied. Some of these studies were concerned with: amount of insolation at ground level in openings and under crown canopy; soil surface temperature; shade effects on first-year seedlings; and determination of causes of seedling mortality on some selected milacres.

MAJOR FACTORS IN REGENERATION

Seed Production

Methods

An understanding of the factors affecting potential supply of sound seed provides the forester a powerful tool in fostering natural regeneration. Even so, much needs to be learned before we can exert more positive control of sound seed production. Probably the greatest potential lies in learning to control insect depredations.

During summer of 1960, we chose 20 white fir and 20 red fir trees adjacent to clearcut strips for a cone counting study. Only mature trees with non-defective crowns within the upper canopy were selected. Such trees presumably would furnish the most seed for any natural regeneration method. Sample trees were 165 to 200 feet tall, and cones are borne only near the tops. Cones were counted annually by one of two methods, both based on observations from permanently staked points. In years of light cone production, counts were made in the field by using tripod-mounted binoculars. When cones were numerous, a telephoto counting technique (Gordon 1962) was especially advantageous. This method was based on projection-screen counts of cones in tree tops photographed with a 400-mm. telephoto lense. An

[3]I acknowledge the work of David C. Maul, now with the U.S. Forest Service, California Regional Office, San Francisco, in the early design and installation of the milacre sampling system from which parts of the reported data were derived.

appropriate conversion factor transformed these counts into binocular count equivalence. Only "seen cone" data are reported in this paper; no factor is used to estimate unseen cones.

During each year that they were available, several cones of each species were shot down from other than permanent sample trees, or obtained from fresh squirrel-cuttings. Each cone was completely dissected. Seeds were cut, examined, and tallied as sound, unsound, or insect-infested. To be judged sound, a seed had to have both female gametophyte and visible embryo. Insect damage in the form of larvae, larval holes, and feces was easy to identify.

One purpose in this study was to learn how many seeds are produced in each cone. All "seeds" were counted–even those having very small wings–some not over one-eighth inch long. Small "seeds" of this kind would be separated and culled in commercial seed-cleaning operations.

Damage caused by wind and insects reduced to 15 the number of white fir trees on which cones were counted. Three red firs also were lost. Data on two additional red firs were randomly eliminated so that the two species could be compared.

Results and Discussion

Individual white fir trees tended to produce cones at a consistently high, medium, or low level whenever there was a crop. Individual red firs followed an irregular production pattern.

White firs produced more cones than red firs during the study *(fig. 2),* but red fir cones contained twice as many seeds as white fir cones–on the average, 591 vs. 295 (*table 1).* However, percent of seed sound was greater for white fir (31 percent) than for red fir (7 percent). During the study period, white fir produced 3.7 times as many sound seed per tree as did red fir *(table 2).*

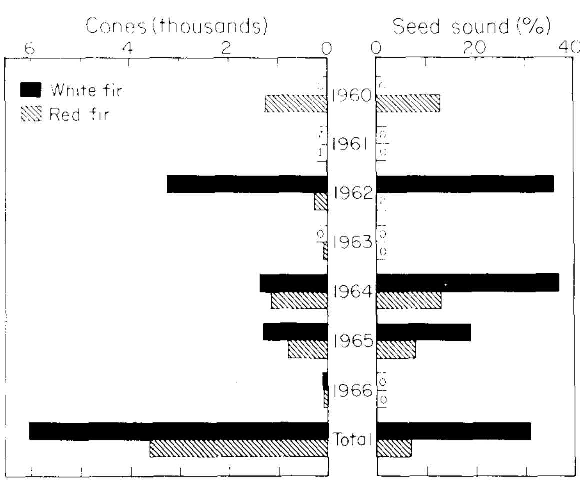

Figure 2.– *White firs produced more cones than red firs, and had a higher percentage of seed sound. Cone production in 15 trees of each species was counted from 1960-1966.*

A greater proportion of seed of both species is sound during years of abundant seed production *(table 3).* Conversely, insects tend to damage proportionately more seed when crops are scanty.

Table 1.– *Number of seeds per cone, white and red fir, 1960-1965*

Species and seed production	1960	1961	1962	1963	1964	1965	All years
White fir:							
Low	–	–	268	–	312	183	–
Mean	–	–	283	–	339	282	295
High	–	–	308	–	386	403	–
Basis: number of cones	–	–	5	–	3	6	–
Red Fir:							–
Low	367	–	428	645	553	372	–
Mean	556	–	532	729	641	553	591
High	688	–	631	795	689	623	–
Basis: number of cones	18	–	5	8	3	9	–

Table 2.– *Average total number of visible cones and sound seed produced per tree during a 6-year period (1960-1965)*

Species	Cones	Total seed[1]	Sound seed[2]
	Number		
White fir	396	116,820	36,214
Red Fir	235	138,885	9,722

Basis: 15 trees, each species.
[1]Based on average number of seeds per cone.
[2]Based on average percent of seed sound.

We have not tallied cone production long enough to determine with certainty if there is any cyclic arrangement of "bumper" seed crops (*table 3; fig. 2).* Rather erratic cone and seed production is evident; other data reinforce this conclusion. Heavy seed fall of both species occurred in 1956. In 1957, the cone crop was definitely smaller than in the preceding year, but seed was reported as being "abundant" (McKeever 1961). Only nine fir seedlings were found on 493 regeneration milacres on three clearcuttings in the early summer of 1959, indicating a minimum seed crop in 1958. No cones were produced in 1959.

Table 3.– *Annual cone production index*[1] *and proportions of sound, insect-damaged, and unsound seed,* [2] 1960-1966

	1960		1961		1962		1963		1964		1965		1966	
	WF [3]	RF	WF	RF	WF	RF	WF	RF	WF	RF	WF	RF	WF	RF
Cone production index	0	1.00	0	0	1.00	0.21	0	0.06	0.43	0.90	0.40	0.64	0.03	0.05
	Percent													
Sound seed	–	13	–		36	2	–	0	37	13	19	8	–	–
Insect-damaged seed	–	28	–		6	45	–	25	31	18	38	42	–	–
Unsound seed	–	59	–		58	53	–	75	32	69	43	50	–	–
Total	–	100	–		100	100	–	100	100	100	100	100	–	–

[1]Index computed for each species by dividing each year's total cones on 15 trees by number of cones in the most productive year.
[2]All "seed" included; e.g., 1960 red fir data in this table based on 10,009 seeds, not 8,538.
[3]WF = white fir; RF = red fir.

Each year of medium or better cone production during an 11-year period is indicated by an "X" in this tabulation:

Year	White fir	Red fir
1956	X	X
1957	X	X
1958	--	--
1959	--	--
1960	--	X
1961	--	--
1962	X	--
1963	--	--
1964	X	X
1965	X	X
1966	--	--

The cone crop information emphasizes that seed crops cannot always be counted on to recarpet regeneration areas with a flush of seedlings immediately after harvesting. In some locations, including Swain Mountain, some delay is not serious. But where aggressive competitive low vegetation can be anticipated immediately after logging, artificial seeding or planting and other cultural measures may be necessary if the sites are to be held by true firs.

Insects which damage true fir cones and seed were found to be numerous and active. Station entomologists identified the following species from Swain Mountain:

Cone moths:
Laspeyresia (sp.) (Prob. *bracteatana* [Fern.])
Barbara siskiyouana (Kearf.)

Cone maggots:
Hylemya (sp.)
Earomyia (sp.)

Cone midges (Itonididae):
(two spp.)

Seed chalcids:
Megastigmus pinus (Parfitt)
M. rafni (Hoffmeyer).

That control of seed-damaging insects could materially increase the amount of available sound seed is demonstrated by data from the 1960 red fir cone crop. Percent of seed sound was at its highest level for the species that year. Eighteen cones, containing a total of 10,009 seeds, were examined. By deducting 1,471 unsound small seeds found in cone ends, the net total became 8,538. Of these, 15 percent were sound and 33 percent were insect damaged. Complete insect control in this instance could have tripled the amount of sound seed available.

Seed Dispersal

Methods

The influence of seed-bearing trees on ultimate establishment of natural regeneration on a given area will be related to aerodynamic characteristics of the seed, wind direction and velocity, and the number, height, and direction of the seed trees from the area.

Seed dispersal in clearcut areas and in the uncut borders was measured by seed traps. To get a small sample of the heavy seed crop of 1956, large (8.2 sq. ft.) seed traps were placed in two openings created by road construction. The traps were the same type used by Fowells and Schubert (1956). Twenty-five traps were placed in one stand opening, 13 in another. These irregularly-shaped openings were from 100 to 135 feet across.

Seed fall was sampled in more detail in 1960, 1962, and 1964 with smaller traps. The traps were built of steel baking pans 2.5 inches deep and 10 by 14 inches in area (0.9722 square foot). Holes in the bottom provided drainage. A stiff screen with wires spaced 1/3 by 1 inch covered the top. The traps withstood heavy snow loads very well. No evidence of rodent entry was ever seen. Presumably, these traps did a sampling job as effective as one-foot square traps, and, in addition, sampled seed fall as well as 8.2-square-foot traps (Roy 1959).

These small traps were placed at half-chain intervals across clearcut openings, one foot from the edge of milacre regeneration transects. Long axes of traps were always oriented NW-SE for uniformity. Both ends of the seed trap lines extended for at least one chain into uncut timber.

Seed fall usually began about October 15, so traps were placed before that time. Traps were left in place over winter to catch seed which fell onto the snow and settled into the traps as the snow pack melted. Seeds were sorted from the litter material and cut to determine the amount of sound, unsound, and insect-damaged seed–using the same criteria as in the seed production study.

Results and Discussion

In 1956, on the opening holding 25 traps, an estimated 497,876 sound seed per acre fell. This amount was 39 percent of the total seed catch. On the area holding 13 traps, the sound seed estimate was 440,716 per acre, constituting 40 percent of the total seed. The percent of seed sound shown here should not be compared directly with that reported in the remainder of this section or in the preceding section on seed production. During examination of 1956 seed trap catches, very small "seeds" were not counted as they were in later observations. Therefore, the sound seed percents just cited are higher than they would be if later criteria had been used.

The amount of seed falling on clearcut areas varied with (a) distance from cutting edge, (b) general level of seed production, and (c) specific cutting area *(fig. 3)*.

The variability of seed fall with source distance could be anticipated because of the known aerodynamic characteristics of fir seed (Siggins 1933), and with year because of the irregularity of most coniferous seed crops. When studies began, little was known of the influence of stand density, tree age, or other conditions near uncut edges, on the levels of seed fall within clearcuttings.

One might suppose that relative level of seed fall on clearcuttings would vary directly with density of mature seed-producing trees in the timbered borders. But we gained little information by mapping stand structure and species composition for the timbered strip along uncut edges. The only obvious observation is that low density of seed-bearing trees on the southwest side of Cutting Area C probably accounts for the relatively lower seed fall there *(fig. 3)*. All other relationships of seed fall rate and stand structure are obscure.

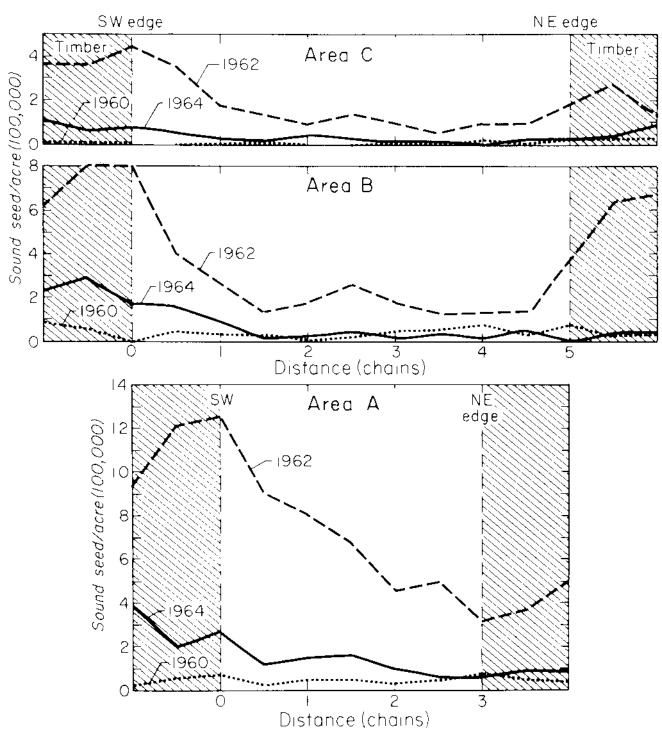

Figure 3.–*Amount of sound seed per acre which fell at various distances from edges of 5-chain- and 3-chain-wide clearcut strips during 3 different years. Each line was plotted from data derived by averaging records of three seed-sample transects.*

Orientation of cutting strips at right angles to the prevailing wind resulted in much heavier seed fall at the southwest than on the northeast sides of areas in 1962 and 1964. Irregular air currents apparently were responsible for the light seed distribution from the northeast edges into the strips. Sound seed fall in 1960 was so light that the observed results merit little credence.

A significant portion of seed produced by the northeast cutting edges in 1962 and 1964 was blown back under the uncut canopy, where it was not needed. This observation is further emphasized by ungraphed data from extensions of some seed sampling lines further northeast into uncut timber.

Seed dispersal over openings seems to be determined largely by amounts released at the windward cutting edge *(figs. 3,4).* Seed fall within narrow openings generally is higher than within wide ones *(fig. 3,* Cutting Area A vs. B; *fig. 4).* Wind eddies may influence seed dispersal much as they do snow deposition.

Both prevailing and strong storm winds blow from the southwest at Swain Mountain. Only occasionally has any significant amount of seed fallen there before October 15, and before the fall storms. And fir cones do not shatter as readily when wet as when dry. This means that much seed falls during winter months (a) in dry periods between storms, (b) when cones are damp and wind velocities are high, (c) as a result of the cone-shattering effect of heavy snow loads, or (d) freezing-thawing. Therefore, varying amounts of seed fall lo the ground or upon snow, depending upon whether early precipitation has been rain or snow. Additionally, distance of seed flight is inhibited whenever moisture content of seed is increased by precipitation, since the ratio of seed weight to wing area is increased. A late, dry fall with periodic strong winds is ideal for good seed dispersal.

Show[4] has offered a possible clue to explaining abundant regeneration at seemingly great distances from seed source. In an unpublished report, he wrote: "This winter, much to my surprise, I found that the Yellow and Jeffrey pines retained many unopened cones until well along in February, and it can readily be seen that the seed, falling on the snow, (which is packed and smooth at that time of year) may readily travel considerable distances, especially if on a steep slope or exposed to wind." Fir seeds might be dispersed in this manner, but a special sequence of weather conditions would be necessary.

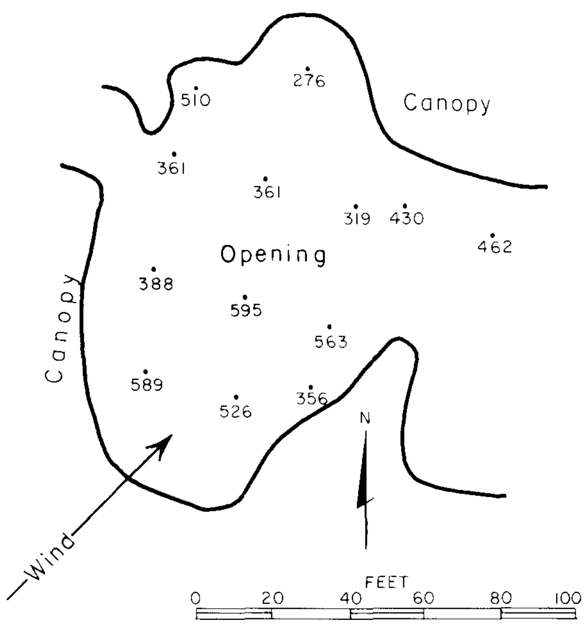

Figure 4.–*Sound seedfall in 1956 in a small opening. Numbers are thousand seeds per acre.*

Germination

The earliest time of year when white fir seeds were seen germinating was February, in 1963, at an elevation of 5,700 feet, about 8 miles northeast of the Swain Mountain study areas. Wherever there were patches of bare ground, either in bright sunlight or deep shade, radicles had extended as much as 1/4-inch from the seed coat. Snowdrifts were not examined for germinating seedlings.

Seedlings were studied in detail at Swain Mountain in 1963 at weekly intervals from June 19 until October 28. Date of final snow melt in the spring was irregular over the areas examined, but was complete about June 12. Seed germination was complete by July 8. Only five percent of germinant seedlings were found between June 19 and July 8.

At Swain Mountain, both white and red fir seed have been found germinated on, in, and beneath snow. Noble fir *(A. procera* Rehd.*)* and Pacific silver fir *(A. amabilis* (Dougl.) Forbes*)* have been reported to germinate on snow (Stein 1951). Franklin and Krueger (1968) recently reported that Shasta red fir, subalpine fir (*A. lasiocarpa* (Hook.) Nutt.*)*, and grand fir *(A. grandis* (Dougl.) Lindl.*)* germinate on and in the snowpack.

Many potential seedlings die because of the characteristic of germinating within the snowpack. Pri-

[4]Show, S. B. *Natural reforestation of brushfields.* 1913. (Unpublished rep. on file at Pacific SW. Forest & Range Exp. Sta, U.S. Forest Service, Redding, Calif.)

mary rootlets sometimes reach a length of 2 to 3 inches within the snow. When the snow melts, many of these rootlets dry, or are killed by heat, before their tips turn into the ground. On June 19, 1963, for example, 136 seedlings were found on a milacre plot. Of these, 30 were erect and normal-appearing, 14 had been killed by cutworms, and 92 (68 percent) were lying flat on the ground, dead, with dry rootlets.

An incident reinforcing observations of the waste of fir seed falling onto snow follows: abundant seedlings for a special study were wanted in the center of an eight-acre clearcut (E, *fig. 1*). In 1964, white fir seed was gathered locally and rough cleaned. About 10 pounds (a minimum of 82,000 seeds) were available, and a cutting test indicated that the seed was 54 percent sound. Unfortunately, the first snowfall on the area measured 22 inches. Seedlings were needed badly next spring, so all the seed were sowed on the snow over an area about 20 feet wide and 5 chains long. Next spring, only slightly more than 200 seedlings were found during a diligent search–indicating a maximum seed effectiveness of about 0.4 percent. The ground was littered with dead, germinated seeds. Seedlings on other parts of the area were practically non-existent, so natural seedlings did not affect the observed results. We can deduce that artificial seed sowing on snow will never be efficient.

Apparently, red and white fir seeds begin to germinate in the woods after three conditions have been met: (1) absorption of sufficient water, (2) exposure to an undetermined degree and period of low temperature, followed by (3) exposure to a period of higher temperature favoring germination. A period of cold seems necessary because no germinated seeds were ever seen before permanent snow pack was in place–even though in some years seeds had been well-wetted during fall. The period of favorable "higher" temperature mentioned may very well be close to 32°F. Observation of germination in both February and June seems to rule out length of day as a significant factor.

Field identification of seedlings often is desired soon after germination. Only meager notes on the subject can be given here. When red fir and white fir seedlings are growing together, I have not always been able to identify positively the species during the first few weeks of establishment. The largest seedlings definitely are red fir, and the smallest usually are white fir, but sizes overlap. Color shades of stems and cotyledons, and numbers of cotyledons, apparently intergrade. Some rather minute differences, visible for the most part only with a 10X hand lens, seem to exist between species, but these need further checking. In practice, species were recorded on the basis of the best evidence available; wherever errors later became apparent, records were changed.

Seedbed Condition

Work of numerous foresters with many species in the past has indicated the positive advantage of particular kinds of seedbeds for seedling establishment. We found that a mineral soil seedbed, easily created by machinery, has an edge over other kinds.

Methods

To compare effects of different seedbed conditions on seedling establishment, we treated slash on each clearcut strip three ways: no treatment, lopping and scattering, and bulldozing into piles to bare as much mineral soil as possible. Each treatment was intended to create a substantially different seedbed. And each was sampled by at least one continuous transect of milacres on each cutting area.

Seedbed condition of each milacre was recorded during each annual examination. A classification was not changed except when a well-defined shift occurred. Two major surface categories were recognized: (1) potential seedbed, and (2) physical obstructions to seedling establishment, such as stumps and rocks.

Potential seedbed surfaces were described by these terms:

Mineral Soil:

Bare soil or soil with very minor amounts of organic material on the surface or in mixture.

Litter:

Light: Uniform distribution of needles or small twigs over entire surface, but mineral soil visible, or, small patches of medium litter with mineral soil visible between patches.

Medium: Uniform distribution of needles or small twigs to about 1/4-inch depth, or, small patches of heavy litter with mineral soil visible between patches.

Heavy: Needles and small twigs usually 1/4- to 3/4-inch deep, but also deeper, generally in a compact mat, little or no mineral soil visible.

Slash:

Light: Small pieces of slash covering less than 30 percent of surface.

Medium: Any size slash covering 30 to 60 percent of surface.

Heavy: Any size slash covering over 60 percent of surface.

Mineral soil was an exclusive surface class; litter and slash were not exclusive. A given milacre could receive a classification such as "medium litter," or "light litter and heavy slash." Sixteen classifications of seedbed surfaces were possible.

Obstructions to seedling establishment were recorded as to type, and proportionate area of the milacre they occupied, by 10 percent classes. Objects judged physical obstructions included stumps, large rocks, large cull logs, and deep piles of debris (litter and slash).

The number of possible seedbed classifications was too large to permit reasonable statistical comparisons. After preliminary analyses, five seedbed classes were used for evaluation of chosen variables:

	Description of Class[1]	
	Litter	Slash
Seedbed class:		
Mineral soil	O	O
Light litter and slash	L	O or L
Slash	O	L, M, or H
Heavy litter	M or H	O
Heavy litter and slash	L, M, or H	L, M, or H[2]

[1]Symbols: L=light, M=medium; H=heavy; and O=none.
[2]Except for the combination of light litter and light slash.

Slope and aspect of each milacre were recorded. Neither aspect nor slope was used in any analysis because all aspects were in the northeast quadrant, and all slopes were gentle—seldom exceeding 10 percent.

In addition, an irregularly-shaped 8-acre block *(*E, *fig. 1),* where slash was heavy, was examined for regeneration from time to time. Essentially no seedlings were seen on it through 1964. In fall of 1964, slash was broadcast burned to prepare the area to receive a seed crop.

For preliminary statistical comparisons, strip cutting areas were grouped by year of treatment, which was the same as year of cut. This division avoided confounding by year of treatment, personnel, equipment usage, and rate of decay of organic matter. Slash treatments were compared, as were the distributions of seedbed conditions within slash treatments. Analyses showed that distributions of seedbed classes were different among slash treatments for both year-of-treatment groups, and at both initial and final examinations.

Results and Discussion

Bulldozer slash clearing produced more milacres with mineral soil, or light litter and slash than other treatments *(table 4).*

During the study, the number of milacres having bare mineral soil increased. The trend became apparent 3 and 4 years after the study began. This increase was accompanied by changes in other seedbed classifications from relatively heavy to lighter amounts of organic material *(fig. 5).*

On cutting areas treated in 1958, changes from

Table 4–*Seedbed condition, by slash treatment, at first and last examinations, in clearcut strips*

Slash treatment and year examined		Seedbed condition classes					
		Mineral soil	Light litter and slash	Slash	Heavy litter	Heavy litter and slash	Milacres
		Percent of milacres					*No.*
		TREATED IN 1958					
None:	1959	12	11	5	22	50	110
	1965	18	6	4	20	52	110
Lop and scatter:	1959	6	5	26	12	51	110
	1965	11	3	22	11	53	110
Bulldozer slash clearing:	1959	27	22	16	27	8	103
	1965	46	10	11	22	11	103
		TREATED IN 1959					
None:	1960	18	12	4	22	44	50
	1965	20	12	4	22	42	50
Lop and scatter:	1960	0	8	6	18	68	50
	1965	0	8	6	20	66	50
Bulldozer slash clearing:	1960	18	14	0	54	14	50
	1965	40	16	0	30	14	50

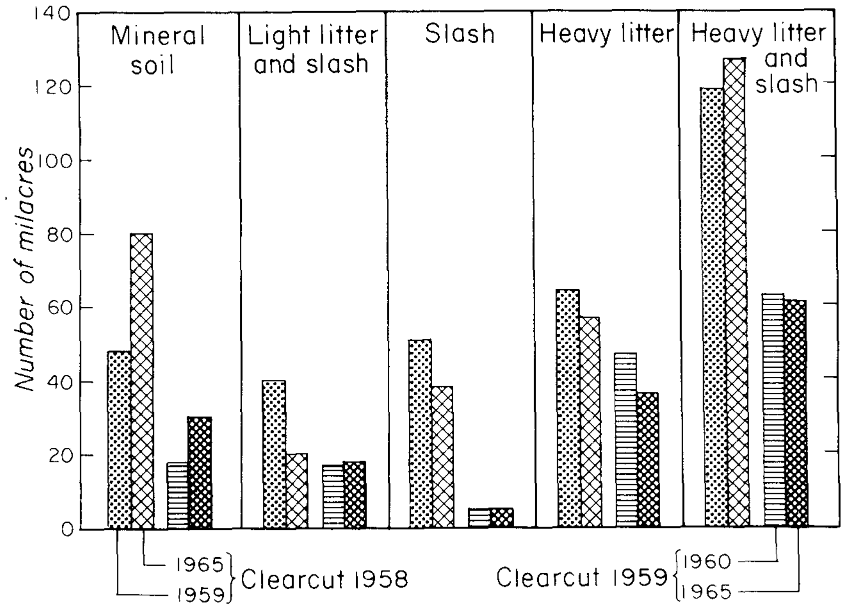

Figure 5.–*Comparison of number of milacres in each of five seedbed classes at first and last examinations.*

one seedbed class to another were highly significant during a 6-year period. Changes on the area treated in 1959, which was observed for 5 years, were not significant. These reasons may account for observed changes:

- Lack of overstory to contribute new litter fall,
- Disappearance of organic fines through decay,
- Animal trampling (simple scattering, or mixing with mineral soil),
- Bark slabs sloughing from large cull logs,
- Parts of wind-damaged tree crowns falling to the ground (near cutting edges).

Soil compaction from logging, clearing, or weight of snow pack was not a problem on clearcut areas studied. No comparative physical measurements of compaction were made, but soils were loose and drained well. Erosion was not a problem on the gentle slopes.

Experience with the milacre as a unit of area on which to rate certain surface characteristics was not completely satisfactory. Microsite observations of seedling environments might have led to more meaningful conclusions about seedling establishment.

On the 8-acre block (cut in 1959), litter and slash were so uniformly heavy that essentially no seedlings became established through 1964. A fairly good seed crop was apparent in 1964, so slash was broadcast burned in late autumn to prepare a better seedbed. Burning was accomplished before rain or snowfall, and an exceptionally good cleanup resulted *(fig. 6)*. Unfortunately, this treatment also stimulated germination of abundant seeds of mountain whitethorn ceanothus *(Ceanothus cordulatus* Kell.*)*. By fall, 1965, new fir seedlings were rare beyond a chain from cutting edges, indicating poor seed dispersal the preceding year. The part of the area without seedlings was planted in spring of 1966.

In treating true fir slash, certain problems–some peculiar to fir–become apparent. At the end of summer in which fir slash has been created, large pieces of the slash are still wet, and much of the fine material–needles and branch tips–is resistant to fire. At a certain stage in drying, needles and small twigs, particularly of red fir, often will not continue to burn when held in the air and lit with a match. A few burning trials in the year of felling were unsuccessful. Not enough slash in piles and windrows was consumed. Where slash is to be burned, a delay of 1 or 2 years after logging would insure destruction of more material. Although there may be certain dangers in letting slash accumulate for several years (burning load, insect buildup, etc.), certain advantages might be gained. If properly timed, delayed slash burning might create vegetation-free mineral soil seedbeds shortly before a good seed fall. At the same time, fire might stimulate germination of brush or other seeds which otherwise would have remained dormant.

Bulldozers were used for most slash-clearing operations at Swain Mountain. No comparative costs are available, but we know that slash clearing on fir clearcuttings was more expensive than in regeneration clearings in the ponderosa-Jeffrey pine type in northeastern California. In the fir forest, numerous large stumps and cull logs increased the cost of seedbed preparation. Seedbed preparation with tractors in selection or shelterwood cuttings would require extra care to avoid damage to residual trees.

Figure 6.–*Before,* top, *and after,* bottom, *burning slash on portion of logged area which was typical of medium density overstay with generally sparse mixed-size understory.*

Soil Surface Temperature

At many places in a true fir forest, temperature of the soil surface reaches heights lethal to new seedlings. Intensity and duration of solar radiation, ambient air temperature, character of soil surface, and soil moisture all influence soil surface temperature.

Methods

Observation of a 170°F. temperature in deep litter at Swain Mountain led to study of surface temperatures in various seedbeds and the related seedling mortality. Baker (1929) suggested that a 130°F. temperature could kill western conifer seedlings.

In a preliminary study during summer of 1963, temperature pellets were used to gain data on soil surface temperatures. Many different soil surface conditions were sampled on the milacre transects previously described. Melting points of the pellets were 113, 125, 138, and 150 degrees F. All 138°F. (and those of lower melting thresholds) melted. And most of the 150°F. pellets melted.

In a second study, soil surface temperatures were sampled in standardized media between June 26 and July 30, 1964. Batteries of Tempils having melting points of 125, 138, 150, and 163 degrees F. were placed in mineral soil and in litter 1/4-inch, 1/2-inch, and 1-inch deep at each sampling point. The pellets were placed edgewise into the dry material, so that half the diameter was buried. All sample points were leveled to eliminate effects of slope. For uniformity, fir litter, consisting mainly of dead needles, was carried to sample points from thick deposits beneath a closed stand. This material was "very dark gray," approximating "10 YR 3/1" on the Munsell (1954) soil color charts. The soil was "grayish brown," approximating "10 YR 5/2."

Within a 5-chain wide clearcut strip, sampling points were located as follows *(fig. 7)*: on lines parallel to the northwest-southeast oriented cutting edges, three points per line, points 1/2-chain apart; lines of samples were located 1/2, 1-1/2, 2-1/2, 3-1/2, and 41/2 chains from the southwest cutting edge. Three sample points were also placed deep within a dense overmature stand nearby, 1/2-chain apart on a northwest-southeast, oriented line. Three more points, spaced 1/2-chain apart and oriented southwest-northeast, were located near the center of a small opening surrounded by over-mature timber.

Results and Discussion

Altogether, 336 Tempils were installed. Of these, 68, or 20.2 percent, were rendered useless, mainly by

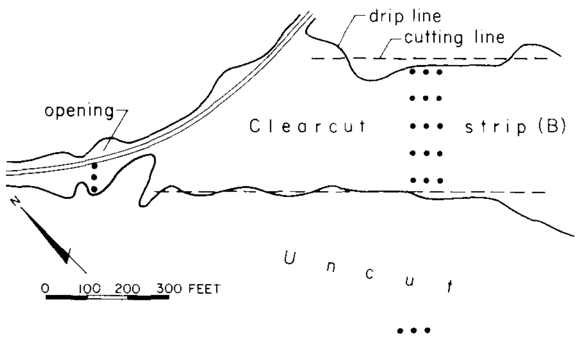

Figure 7.–*Soil temperatures and illumination were measured at sample points within a 5-chain wide clearcut strip, a small opening, and a dense uncut stand.*

rodents, cattle, deer, and possibly jays. Tempils are color-coded by melting points, but pellets of a particular melting point were not disturbed more than any other. Disturbed pellets were excluded from the calculations.

Highlights of this small study are *(table 5):*

- Most points on the soil surface reached a temperature of 150°F.
- There was no apparent relationship between the location of a sampling point and the observed pellet melt. Temperatures reached high levels under dense old stands as well as in large openings. This was probably the most striking result of the study.
- Surface temperatures on mineral soil seldom exceeded 163°F.
- Within the limits tested, surface temperatures tended to increase with litter depth.
- Temperatures which have been presumed lethal to seedlings occurred at nearly every sampling location.

Duration of high ground-surface temperatures was not measured. Melting, sometimes only in hairline traces, is nearly instantaneous whenever the melting point of a Tempil is exceeded. Little can be surmised about the duration of high temperature under intermittent shading, but in unshaded clearcut strips several hours of direct sunlight probably cause sustained high temperatures (see section on Insolation). The relatively poor seedling survival in large clearcuttings compared to that in a small stand opening may be explained, at least in part, by heat duration. Other investigators, particularly Baker (1929) and Silen[5] have suggested that absolute temperature is not necessarily the critical factor responsible for heat damage to seedlings; instead, within relatively broad limits, abundant time-temperature relationships can cause damage.

An additional factor may affect higher initial survival in small openings than in wide clearcuttings (and even under dense old stands). It is the soil or litter surface dampness which remains longer under cover, thereby delaying high temperatures until small seedlings are physiologically more resistant to that hazard.

Table 5.– *Effect of soil surface condition on temperature*

Soil surface condition	Tempil melting points (degrees F.)			
	125	138	150	163
	Percent of pellets unmelted			
Mineral soil	0	0	6.7	88.9
1/4-inch litter	0	0	6.7	46.7
1/2-inch litter	0	0	6.7	50.0
1-inch litter	0	0	.0	15.8

Insolation

Seedling establishment resulting from the seed crops of 1960 and 1962 was best near cutting edges and in small openings, such as road rights-of-way. Dispersal data showed a concentration of seed near its source, and, on 5-chain wide strips, decreasing amounts at greater distances from cutting edges. However, since the firs are tolerant, I hypothesized that shade also might influence initial seedling establishment. On a large proportion of the study areas, unfortunately, shade could be created only by the seed source trees, and duration of shade would be related to distance from them. Therefore, the relative influences of seed dispersal and shade could not be separated within the framework of the sampling system and cost limitation. Consequently, the objectives of a supplemental study were to determine (a) the relative amounts of solar illumination reaching the ground surface under varying conditions of sunlight and shade, (b) maximum solar energy received at the center of a 5-chain wide clearcut strip (B), and (c) effects of shade and sunlight on seedling survival.

Measurements of Insolation

To get near-maximum values of diurnal insolation, two kinds of measurements were made simultaneously on July 8, 1965, about 2 weeks after the

[5]Silen, Roy Ragnar. *Lethal surface temperatures and their interpretation for Douglas-fir.* 1960. (Unpublished Ph.D. thesis on file at Oregon State University, Corvallis.)

summer solstice: (1) a pyrheliograph recorded solar energy all day at the center of the same 5-chain wide clearcut used for the soil surface temperature study, and (2) illumination was concurrently measured at all the sampling points used in the soil temperature study *(fig. 7)*. The benzene-anthracene technique determined amounts of solar illumination at intervals during a day. Analyses of the sample solutions and of the data followed the methods of Waring and Major (1964).

Anthracene in benzene solution is sensitive to the ultra-violet portion of the spectrum, around 300-400 millimicrons wave-length. In this study, then, as in others using the technique, comparative light quality in shade or full sunlight was ignored. Light quality has little effect in ecology of coniferous forests. Logan and Peterson (1964, p. 7) cite several investigators who have reached this conclusion.

The primary purpose of this study was to compare amounts of illumination reaching the forest floor at the different sample points or zones, although indications of quantitative levels of illumination also were of interest.

Glass vials of solution, placed on uniform gray botany blotters during the night preceding exposure, sampled solar illumination. On the day of exposure, one vial from each point was picked up at 9 a.m., 12 N., 3 p.m., 6 p.m., and after dark. Labeled samples were picked up and placed in light-proof boxes in the same sequence each time.

Samples were calibrated by using unexposed vials, and others exposed completely or beneath varying degrees of shade from 10 a.m. to 2 p.m. Illumination on the calibrating vials was measured in foot-candles at 15 minute intervals from 10 a.m. to 2 p.m. with a Weston 603 illumination meter.

Four days after exposure, optical density of the solution in each vial was determined with a Beckman DU spectrophotometer at wave length 360 millimicrons, using a tungsten lamp and a 0.1 mm. slit.

The illumination meter and spectrophotometer used in this study are the same types used by Waring and Major (1964), so illumination data here should be comparable with theirs for California's northwest coast.

Results and Discussion

The day chosen for these studies was ideal–the sky was deep blue and cloudless. The flow of energy through the atmosphere was even, as shown by the shape of the pyrheliograph transcription *(fig. 8)*. Irregularities at both ends of the record were caused by tree shadows. Stands at the cutting edges approached maximum density for white and red fir *(fig. 9)*, yet their small influence on light at the center of this strip was obvious from the measurements.

Maximum energy received on the horizontal sensitive plates of the instrument was 1.60 gram calories per square centimeter per minute. Calculated energy perpendicular to the sun's rays was 1.7 calories–an amount to be compared with the so-called solar constant having average value of 1.95 above the level of the atmosphere (Forsythe 1954). A comparable horizontal plate pyrheliograph record showed a maximum of 1.51 gram calories on a clear day–June 24, 1966–at Redding, California. This city is at almost the same latitude, but at 500 feet elevation.

Measurement of illumination with the benzene-anthracene vials produced generally satisfactory results. In the regression analysis of optical density on percent light, all calibration data fell within 95 percent confidence limits. The coefficient of correlation was -0.9983.

The most striking result of this study is the relationship of total illumination at the edges and center of the wide strip *(fig. 10)*. Total illumination to 6 p.m. at the southwest side was 42,233 foot-candle-hours, which is 82 percent of the 51,367 recorded at the center. The narrow opening received 33,867 foot-candle-hours of illumination, or 66 per-

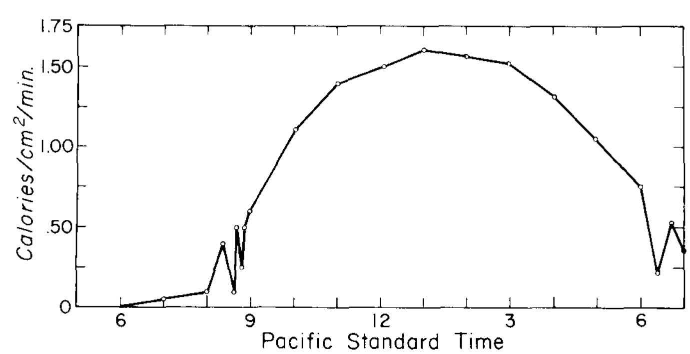

Figure 8.–*Solar energy incident to horizontal plane is shown by a transcript of pyrheliometer recording for July 8, 1965, latitude 40°26'N., longitude 121°05'W., elevation 6,200 feet.*

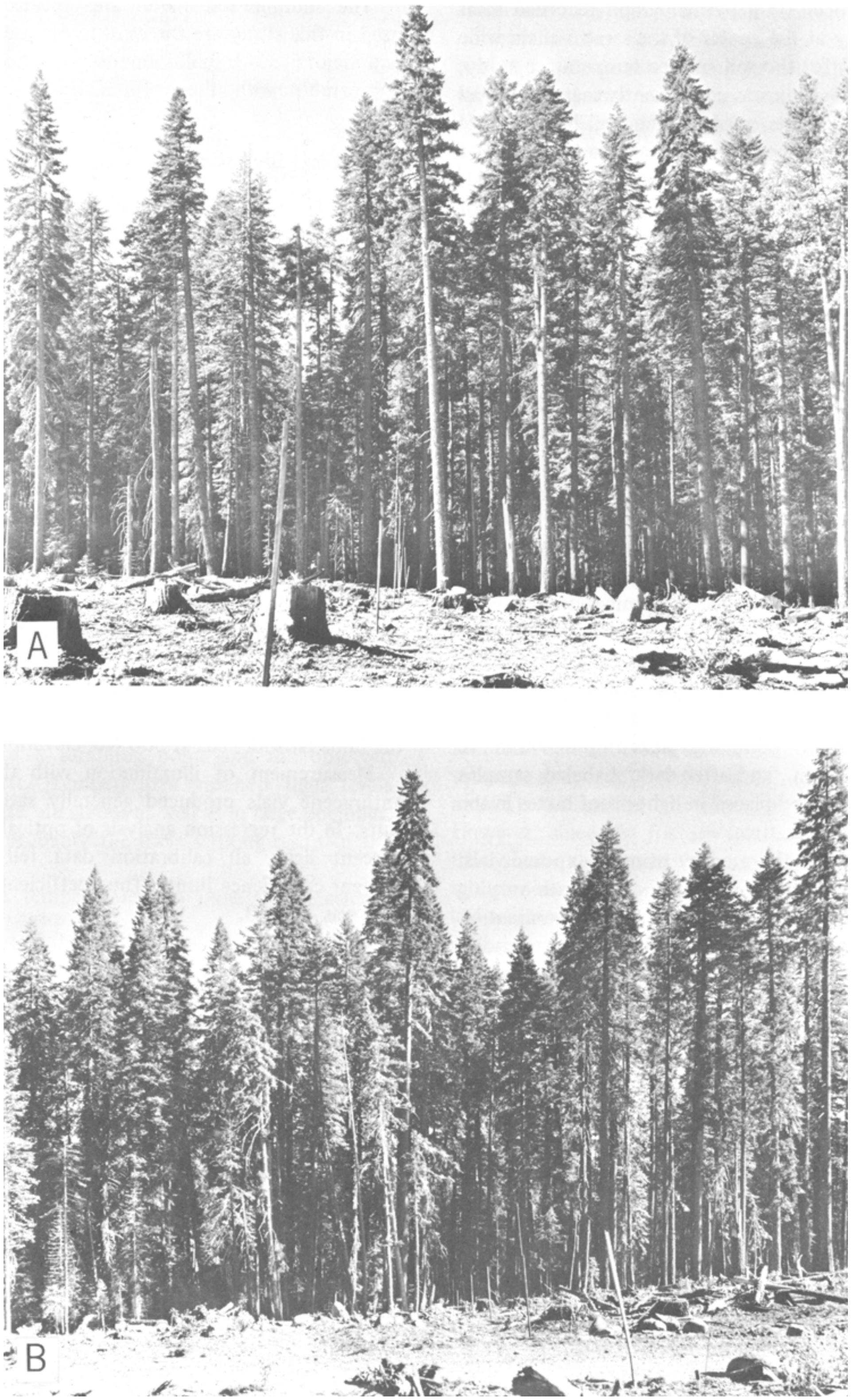

Figure 9.–*Fir stands immediately adjacent to cutting strip sample points shown in figure 7:* A, *southwest edge;* B, *northeast edge.*

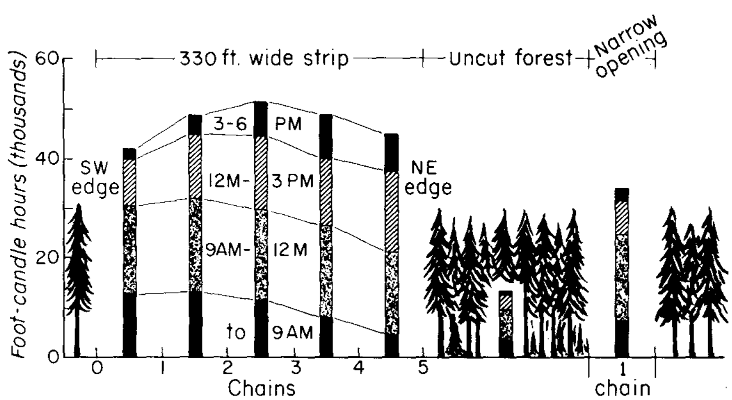

Figure 10.–*Illumination in forest and openings on July 8, 1965, Pacific Standard Time. Segments of bars are additive.*

cent of maximum illumination at the center of the strip. The uncut stand received 13,467 foot-candle-hours or 26 percent of maximum illumination at the center of the strip.

The NW-SE orientation of the 330-foot wide strip naturally contributes to the shape of the histogram of figure 10. The "narrow opening" bar represents a cutting area oriented approximately E-W and is most directly comparable to cumulative insolation at each side of the wide strip.

Results indicate that, for old pure fir stands, our common ocular estimates and shade diagrams for different solar angles at cutting edges lead us to overestimate "shade." Transmission of light through an overmature and heavily stocked fir stand is greater than we thought. We can infer that, where high fir crowns are involved, shade is of appreciable density and duration only near cutting edges of certain orientations. Cutting edges should not be thought of as solid curtains which produce dense shade. This point has been further illustrated through a series of aerial photographs taken at 2-hour intervals during a day (Gordon 1968).

The illumination data show that large clearcuttings of nearly any orientation will have large proportions of soil surface exposed to prolonged sunlight. This can mean long periods of above-lethal soil surface temperature. At the other extreme, single tree or small group harvesting would certainly reduce the time of exposure of seedlings to above-lethal temperatures.

An anomaly in the illumination data is mentioned as a caution to other workers who may contemplate using a similar time-interval technique. Of the total of 21 sample points, 15 had indicated full-day illumination which was equal to or less than cumulative illumination until 6 p.m. Polymerization of insoluble dianthracene is an irreversible reaction, so this process cannot explain the results. Experimental error in the form of leaking vials (which were not seen) or improper use of the spectrophotometer have been suggested as explanations. Yet, of the 84 field exposure samples collected to 6 p.m., only two appear to be out of line. Additionally, of the samples collected after 6 p.m., all those in the uncut stand, and two-thirds of those in the small opening, indicated less exposure than was recorded to 6 p.m. Thus, the riddle is not connected with exposures which might have resulted in solution changes exceeding the readable range of the spectrophotometer, nor with possible inaccuracies at the high foot-candle-hour end of the extrapolated calibration curve. I cannot readily explain the anomaly.

Data to 6 p.m. appear to be logical, and the histogram and general discussion are restricted to them. Data for the 5-chain wide strip were arranged in one analysis as three rows of samples running across the strip. The rows were not statistically different. Therefore, data for each of the bars *(fig. 10)* were obtained by averaging three measurements equidistant from a cutting edge.

Influence of Sunlight and Shade on Seedling Survival

Evidence of the influence of shade on seedling survival at Swain Mountain is limited but impressive. In 1965, shaded and unshaded first-year white fir seedling survival was compared at the center of an eight-acre clearcutting *(*E, *fig. 1).* Shades were placed a few days after snowpack had melted. Shade was provided by small pieces of sheet metal bent at a 90° angle *(fig. 11).* These sheets shaded the soil surface as well as the seedling stems, and often part or all of the cotyledons and needles. No browse protection was provided. Some browsing and trampling by deer and cattle were observed. By September 30, survival percents were 48.3 for shaded and 1.3 for unshaded seedlings.

If shade close to cutting edges of 3- to 5-chain strips is of some benefit for establishment of natural seedlings, its effect must occur principally within the first growing season. Such shade from large firs appears to have no beneficial effect on seedling

Figure 11.–*Sheet metal shaded the seedlings and the soil surface.*

survival during second and third years of the establishment period *(fig. 12).* The relative rate of seedling loss is greater near edges than at more distant locations. However, edge locations have more seedlings at the end of 3 years.

Since high surface temperatures had been found for deep litter, the influence of natural shade-creating objects on first-year seedling survival in litter accumulations was explored. One analysis concerned milacres covered with heavy litter accumulations, but no slash, and shaded or not shaded by advance reproduction. In this case, 58 percent of the shaded milacres and 36 percent of the unshaded milacres were stocked with new seedlings, and the effect of shade was statistically significant. Another analysis tested the influence of shade cast by various amounts of slash on seedling establishment in heavy litter. In this case, no significant effect was detected.

Stark (1965) reported, quite similarly, that white fir seedlings of different ages survive "best in dense shade with medium litter and on shaded bare soil," and that "white fir survival in heavy litter was greater in shade, an observation evident in many of the dense litter sites."

Seedlings sometimes become established under conditions contrary to those reported as general trends in this paper. I have seen, for example, two instances of abundant Shasta red fir regeneration in completely unshaded situations at great distances from "adequate" seed sources. One site was on the Union Creek District of the Rogue River National Forest in Oregon; the other was a few miles east of Mt. Shasta on the McCloud District of the Shasta-Trinity National Forest in California. In both locations, mineral soil was preponderant seedbed type–the only item of general agreement. Foresters often find themselves wishing for specific data on the total environment during a particular year of germination.

At Swain Mountain, white and red fir have responded similarly to light. And Shasta red fir at other locations appears to regenerate similarly to these two species. Similar response to light may extend even more broadly through the genus. Day (1964) found that subalpine fir *(A. lasiocarpa* [Hook.] Nutt.*)* reproduced more abundantly with increasing density and duration of shade. Vezina and Pech (1964) studied solar radiation in stands of balsam fir *(A. balsamea* [L.] Mill.*)*. They found that low solar radiation permitted balsam fir seeds to germinate, but under low radiation, seedlings generally died within a year. This result apparently is not "pure," for they imply that soil moisture conditions could also cause mortality of young seedlings under relatively dense stands. Vins (1964), in reporting on Czech experiments comparing effects of regeneration felling on silver fir *(A. alba* Mill.*)*, stated that group felling and strip felling (particularly on the south of the stand) produced the best conditions for regeneration. He also concluded that over-shading is a frequent cause of failure of regeneration. In context,

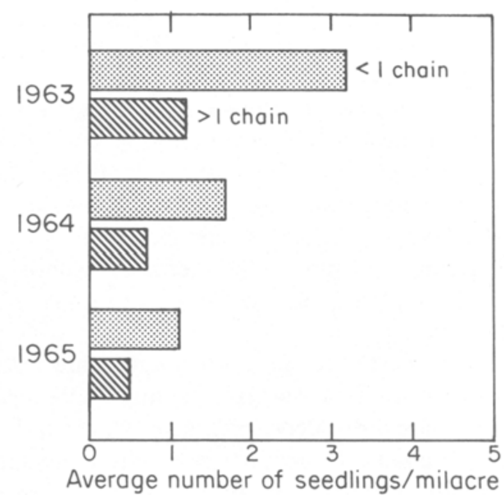

Figure 12.–*Relative abundance of seedlings at distances less or more than 1 chain from edges of clearcut strips, as recorded at end of growing seasons. Seedlings originated in spring 1963.*

this appeared to mean failure over an unstated period of time. Evidence generally indicates shade benefits fir seedling establishment– especially during the first year.

The U.S. Weather Bureau (1964) found that the area dominated by the Sierra Nevada and southern Cascade Range within California receives more daily solar radiation in July than any other part of the United States–700 to 750 langleys (cal/cm.^{2}). We can exert some control over insolation during the critical early period of seedling establishment. The highest ratio of seedlings to seed–efficiency–during the first year or two will result from shade, natural or artificial, combined with optimum levels of other factors.

Soil Moisture

Within a large opening in a fir stand, soil moisture seemed to be available all season at soil depths reached by roots of many new fir seedlings.

Methods

Watershed management personnel determined by neutron probe the soil moisture percent by volume at a number of points in and adjacent to a 5-chain wide strip clearcut (B) at Swain Mountain four times at monthly intervals in 1961. For purposes of this regeneration study, three points each on two of their soil moisture sampling transects were selected because there were no trees near them. The points within the strip were at the center and at half-chain distances from the southwest and northeast cutting edges. Of the data on watershed management soil moisture percent, I have used only that for the potentially most critical depths of 3, 6, and 9 inches. Soil bulk densities, and 15 atmosphere moisture percentages were determined in the laboratory for the same soil depths at a later date.

Results and Discussion

If we assume a 15 atmosphere moisture percentage as the wilting point for firs, seedlings would have had adequate moisture at the 6-inch depth and deeper throughout the summer of 1961 *(fig. 13).* Differences in moisture percents for wilting points, by stations and depths, probably were caused, at least partially, by the bulldozer operations in slash clearing and road building. The upper soil layers were disturbed to varying degrees, and so may have had artificially differing amounts of organic constituents, and compaction, superimposed on natural variation.

Since primary roots of seedlings germinating in snow reach lengths of 2 or 3 inches, the roots of those germinating at the soil-snow interface may penetrate soil to about the same depth before snow melts completely. We know that some white fir seedling roots will reach lengths of 6-12 inches or more in the first season,[6] and I assume this is true for red fir. Root growth of some first-year white and red fir seedlings begins early enough and progresses rapidly enough under average conditions in the open so that roots continue to have available soil moisture.

Although the soil at Swain Mountain is fine-textured, it is also porous. "Excess" water at time of snow melt percolates through it rapidly. Apparently, moisture is lost slowly from the soil after field capacity has been reached.

[6]Unpublished data on file at Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, Redding, Calif.

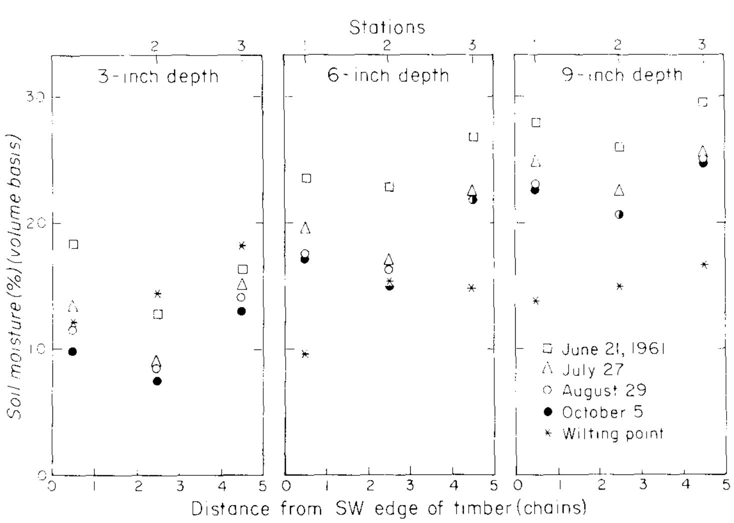

Figure 13.–*Soil moisture was measured at three depths at three points across a 5-chain wide clearcut strip. Each plotted point is an average of like points from two separate transects.*

Competitive Vegetation

In clearcut openings at Swain Mountain, the amount of low forms of potentially competitive vegetation stayed at a low level for several years. This low level undoubtedly aided initial seedling establishment, and contrasts with vegetation response at some other places.

Methods

Before timber cutting, low competing vegetation was scarce or spotty on the areas we studied. Small non-timbered openings in the Experimental Forest were occupied by several low species which could be seed sources. Viable brush seeds in the soil were expected to be at a low level in dense stands about 200 years old. We assumed that stand density would have eliminated brush at an early stage of stand development. Stand conditions at Swain Mountain appeared to differ considerably from those in which Quick (1956) found abundant viable brush seeds in duff and soil beneath old mixed conifer stands.

We had anticipated that small plants, such as forbs and grasses, might quickly become established in our clearcuttings. Each year, presence or absence of sedge, forbs, grass, brush, and ferns was recorded for all milacres of the regeneration transects. If present on a milacre, any of these classes of vegetation was rated as having an estimated light, medium, or heavy competitive effect with respect to establishment of fir seedlings. Rating was based on class, and on size, number, and distribution of plants. Fir trees of any size, on or within certain distances from a milacre, were also considered as being competitive. Trees less than 4.5 feet tall were judged like low vegetation; those taller than 4.5 feet were judged competitive if within a distance equal to 7 feet plus 1 foot for each inch of tree diameter.

Results and Discussion

Such a small amount of low vegetation developed that no effect of its competitiveness with fir seedlings could be detected in preliminary multiple regression analyses. In those analyses, all independent variables listed in the section on *Comparison of Several Major Factors* were used. Frequent observations indicated that no significant amount of vegetation was present during the summer that would not be recorded by the fall examination. Initial amounts and buildup of post-logging vegetation in any of the specific classes varied from one area to another *(fig. 14).*

Sedges *(Carex* spp.*)* appeared during the same season as cutting, and gradually became the predominant plants on several cutting areas. In a few places, small patches of grass reached such density that they appeared to inhibit seedling establishment. Ferns were rarely found. A variety of forbs, mostly small plants, was noted. A 3- to 4-foot tall thistle *(Cirsium* sp.*)* was the only large species which became established. And it was limited primarily to one cutting area. A few specimens of gooseberry and currant *(Ribes* spp.*)* were seen. Mountain whitethorn ceanothus *(Ceanothus cordulatus* Kell.*)* was the only brush species which became noticeable. Its distribution suggests that the expectation of essentially no viable brush seed beneath dense old fir stands is untenable. Germination was heaviest where slash fires best broke seed dormancy. Deer kept this brush species cropped to insignificant plant size for about 3 years. Spine-tipped branchlets then developed, and deer found the plants less palatable.

These observations show that, even within the small area of the Experimental Forest, establishment of low vegetation after timber cutting may be quite variable from place to place.

Analysis of 1965 data for clearcut strips showed that type of slash treatment had a highly significant effect on subsequent establishment of low vegetation. Some vegetation was rated on 48 percent of bulldozer-cleared milacres, on 35 percent where there was no slash treatment, and on 27 percent of lop-and-scatter milacres. Slash treatment had no significant effect on the relative number of milacres stocked with any one of the four classes of vegetation (sedge, forbs, grass, or brush).

Obviously, competition from low forms of vegetation was insignificant at Swain Mountain. Elsewhere, competing vegetation has been a serious deterrent to fir seedling establishment, or at least to early rapid growth. In one well-documented[7] instance, some strips clearcut in 1954 had adequate seedlings established on them soon after logging. A heavy growth of *Ribes* spp. and other plants also became established, apparently later. After 10 years, fir seedlings were scarce except in a band extending about a half-chain from one cutting edge. In this extreme case, seedlings at least appear to have been eliminated by competition from other vegetation. More usually, firs will become established and grow slowly under brush, eventually overtopping and killing it. But the time used in this process generally is greater than forest managers should tolerate.

Vegetation potentially competitive with fir reproduction will vary from place to place, and should be

[7]Unpublished data on file at Pacific Southwest Forest and Range Exp. Sta., U.S. Forest Service, Redding, Calif.

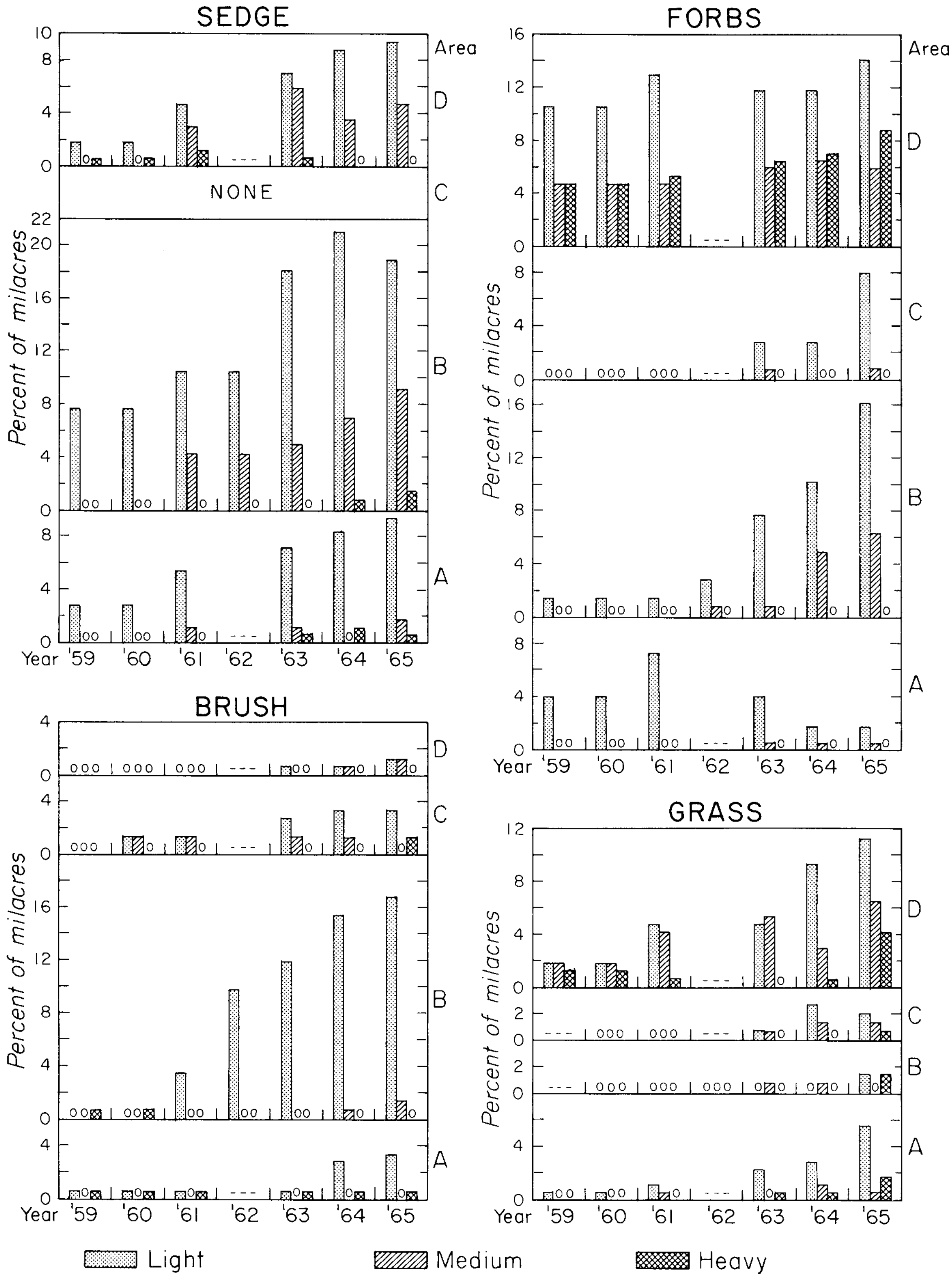

Figure 14.–*Portions of all milacres having sedge, forbs, brush, or grass rated as light, heavy, and medium competition to fir seedlings, by cutting area and year.*

evaluated wherever seedling establishment and good growth rate is desired. Appropriate treatments will have to be designed, probably locally, wherever control of undesirable vegetation is necessary.

Seedling Survival, Abundance, Distribution

Methods

New seedlings–how many are there, and where are they? Two basic sources are available for answering these inquiries: (1) data from annual fall examinations of all milacre transects, and (2) results of more detailed and frequent examinations of 22 of the milacres on those transects, plus 2 additional milacres in a narrow opening, during a 3-year period, 1963-1965. The numbers of fir seedlings initially recorded in the transect data were 1,041, and in the detailed study 341.

The lot of 24 milacres in the detailed study included a wide range of seedbed conditions and distances from cutting edges. The purpose of this study was to gain information on trends in seedling numbers during the early establishment period. In 1963, a flush of new seedlings, mostly white fir, was examined weekly. In 1964 and 1965, survivors among these same seedlings were observed at approximately monthly intervals.

In charts and tables, seedlings shown as ages 1, 2, and 3 are annual survivors of the seedling crop originating in spring 1963, only. Seedlings in the "all" age category are those originating since logging, and surviving to any age in 1965.

Results and Discussion

The number of live seedlings on the 24 milacres dropped rapidly from late June to mid-August during the first year *(fig. 15).* By the end of September the number was comparatively stabilized. At the last examination for the year, October 28, survival was about 20 percent of the original base for seedlings on 22 milacres on 3- and 5-chain wide strips, and 46 percent on the two milacres in the narrow opening. Survival on clearcut strips at the end of the second year was 14 percent, and at the end of the third year, 11 percent. Superiority of the narrow 1-1/4-chain opening is shown by the 26 percent survival level at the end of the third year.

The other results reported in this section are based on fall examination of all milacre transects on clearcut strips.

Beginning with seedlings from the 1960 seed fall, the 3-chain wide strip continuously demonstrated superior seedling establishment to the 5-chain wide strips. The chief measurable reason was seed fall, but reasons for higher level of seed fall on the narrow strip were not obvious *(fig. 3).* Both stocking and average number of seedlings per milacre were greater for the narrow strip than for wide strips *(fig. 16).*

Further evidence favoring narrow strips, or small openings, is found in a comparison of seedlings established at greater or lesser distances from cutting edges. More than twice as many seedlings were present within a chain of seed source as at greater distances *(table 6).* Number of seedlings near the northeast edge of clearcut strips was usually slightly lower than near the southwest edge. But the difference was inconsequential, so seedling and stocking data for the two edges were combined for averaging.

Evidence indicates that narrow or small clearcuttings will regenerate with more certainty than wide ones. We may infer that even with relatively light seed fall, we might get satisfactory regeneration on narrow strips, but we might not on wider areas.

Type of seedbed affected seedling abundance and distribution *(table 7).* Except in the class of information "average seedlings per milacre for stocked milacres only," the highest seedling frequency at any age was on "mineral soil." "Light litter and slash"

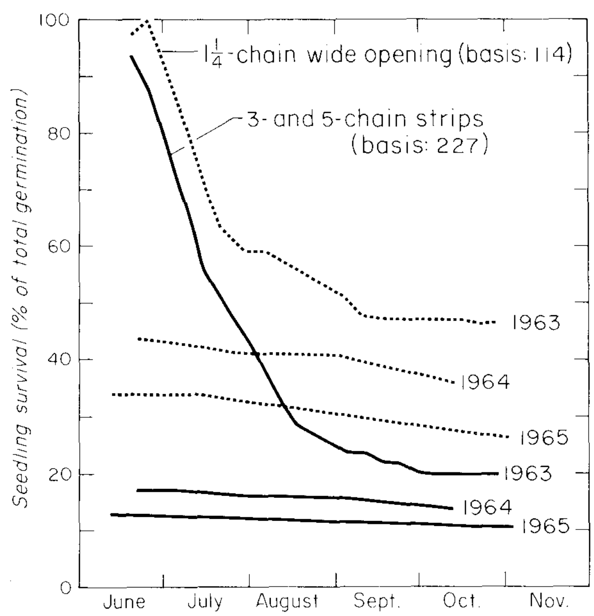

Figure 15.–*Seasonal survival trend of fir seedlings, first 3 years, in narrow and wide openings, shows a decline from the first year. Total germination is shown. Germination was not complete until July 8. That and mortality rates are responsible for curve origins and their early shape.*

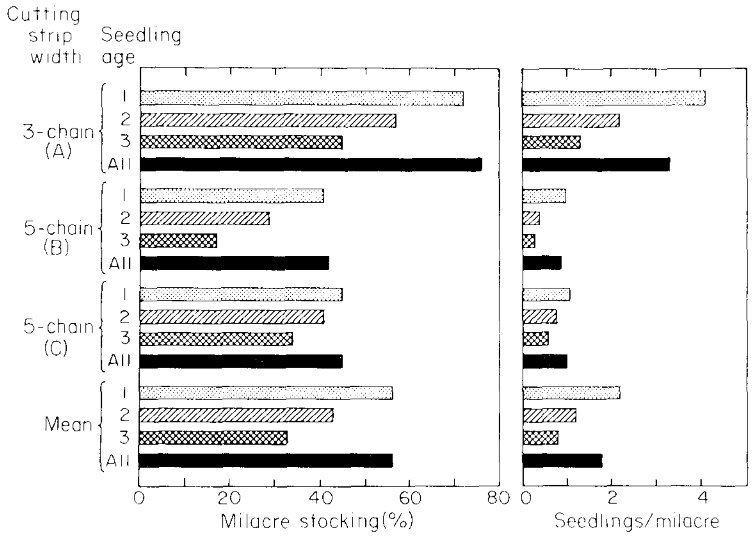

Figure 16.–*Size of clearcut strip affected stocking and mean seedlings per milacre (all milacres). "All"= all post-logging fir seedlings, any age, in 1965; ages 1, 2, 3, are seedlings of 1963 origin in 1963, 1964, and 1965.*

was quite favorable through the second year, but after that, it yielded its relative position to seedbeds with medium to heavy amounts of litter or slash or both. Stated another way, after the first year, survival of seedlings was relatively better on seedbed classes with heavy litter than on those without. This phenomenon is most evident if only stocked milacres are considered. Reasons for this switch are unknown. Seedling distribution on milacres with "mineral soil" or "light litter and slash" is generally superior to that on other seedbeds.

Red fir seedlings appear to be more tenacious than white fir *(fig. 17)*. Red fir survival for an even age class was examined in 1961 and from 1963 to 1965. Similar white fir records cover 1963 to 1965. Survival at the end of the third growing season was 54 percent for red fir, 36 percent for white fir–both percents based on number of seedlings at end of the first season. By the end of the fifth season, nearly 48 percent of the red fir still survived. These records may be confounded by differences in weather or other conditions by years, but are the only early local evidence that red fir appears to be superior not only in survival but in early vigor as well. Probably most informative of all, however, are results of a cursory survey of all cutting areas made in fall of 1969. The dominant seedlings remaining are all red fir of 1961 origin. Stocking is still high. The only white fir seedlings of early origin which remain are stunted to a few inches of height by browsing. Red firs in free-growing positions now average 3.8 feet in height, and grew 0.8 foot in 1969, 0.9 foot in 1968. They appear to be thriving.

The number of seedlings surviving at the end of

Table 6.–*White and red fir seedling abundance and milacre stocking on clearcut strips at less or more than 1 chain from cutting edge*

Seedling age	Year	Distance from edge	Average seedlings per milacre, all milacres	Index of seedling abundance	Stocking[1]	Stocking index
		Chains	*Number*	*> 1 ch=1*	*Percent*	*> 1 ch=1*
1	1963	<1	3.2	2.7	63	1.3
		>1	1.2	1.0	49	1.0
2	1964	<1	1.7	2.4	49	1.3
		>1	.7	1.0	38	1.0
3	1965	<1	1.1	2.2	39	1.5
		>1	.5	1.0	25	1.0
All[2]	1965	<1	2.5	2.1	61	1.2
		>1	1.2	1.0	51	1.0

[1]Stocking percent = (number of milacres with one or more seedlings / total milacres in distance class) X 100.
[2]All post-logging red and white fir seedlings, any age.

Table 7.– *Seedbed-seedling relationships on clearcut strips, white and red fir seedlings combined*

Seedling age and year and seedbed class [1]	Average seedlings per milacre		Index of seedling abundance[2,3]	Stocking [4]	Stocking index[3]
	Stocked milacres only	All milacres			
	Number		Percent		
1 -- 1963:					
1-Mineral soil	5.8	4.1	2.4	71	1.2
2-Light litter, slash	4.2	2.8	1.6	65	1.1
3-Slash	4.1	2.0	1.2	47	.8
4-Heavy litter	3.6	1.6	.9	45	.8
5-Heavy litter, slash	3.0	1.7	1.0	58	1.0
Mean	3.9	2.2	- -	56	- -
2 – 1965:					
1-Mineral soil	3.3	1.9	1.9	57	1.3
2-Light litter, slash	2.5	1.2	1.2	48	1.1
3-Slash	2.7	.8	.8	29	.7
4-Heavy litter	3.4	1.1	1.1	34	.8
5-Heavy litter, slash	2.4	1.0	1.0	42	1.0
Mean	2.8	1.2	- -	43	- -
3 – 1965:					
1-Mineral soil	2.6	1.2	1.7	45	1.3
2-Light litter, slash	2.1	.6	.9	27	.8
3-Slash	2.4	.4	.6	16	.5
4-Heavy litter	3.0	.9	1.3	30	.9
5-Heavy litter, slash	2.0	.7	1.0	34	1.0
Mean	2.4	.8	- -	34	- -
A11[5] 1965:					
1-Mineral soil	4.0	2.9	1.9	72	1.3
2-Light litter, slash	2.2	1.4	.9	62	1.2
3-Slash	2.3	.9	.6	40	.7
4-Heavy litter	3.7	1.8	1.2	49	.9
5-Heavy litter, slash	2.8	1.5	1.0	54	1.0
Mean	3.2	1.8	- -	56	- -

[1]Seedbed classes as rated in specified years.
[2]Basis: all milacres.
[3]Seedbed class 5 = 1.0.
[4]Stocking percent = (Number of milacres with one or more seedlings/total milacres in class) X 100.
[5]All post-logging red and white fir seedlings, any age.

each growing season during the period of study is shown in figure 18. Data include both fir species on all milacre transects on the three clearcut strips. Omitted from the histogram are one seedling each established in years 1959 and 1960. The usual pattern of reproduction waves, reported in other investigations within the genus, is apparent in this record. Seedbed conditions on the cutting strips improved with time (see section on *Seedbed Condition*). Competitive vegetation presented no problem through 1965. It has increased each year, but new seedlings from at least two seed crops since 1965 are present on all areas. Their continued survival is, of course, uncertain.

Seedling survival on the clearcut strips, as arranged by year of origin, permits an important inference *(fig. 18)*. It is that at this particular time and place we were fortunate that competitive vegetation did not become established in heavy amounts before fir seedings became established. More specifically: (a) the areas represented by data in figure 18 were logged in 1958 and 1959; (b) the first small wave of seedlings did not appear until 1961; (c) a "bumper crop" of seedlings did not get started until 1963; and (d) on these areas competitive vegetation was sparse during this time. This sequence of events contrasts strongly with events that I observed in some other fir regeneration areas, where dense vegetation became

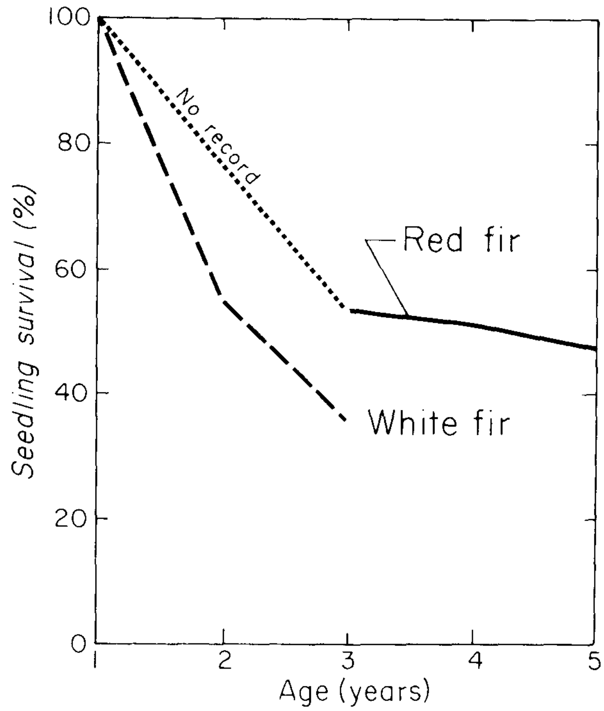

Figure 17.–*At the end of the third season, red fir had a higher rate of survival than white fir on clearcut strips. Number of seedlings for bases were: white fir, 1,030 (origin: 1963); red fir: 129 (origin: 1961).*

established within 2 or 3 years after logging. There, seedling establishment and early growth were inhibited or retarded.

Lodgepole pine *(Pinus contorta* Dougl.*)* was the only other species found on the milacre transects. Cones of this species are non-serotinous in the general Swain Mountain area. Isolated seedlings appeared on some cutting strips, with seed source a matter of conjecture. Only one lodgepole pine seedling was observed on transects of the three clearcut strips. The clearcut block D was next to a patch of lodgepole pine, however, and a number of pine seedlings became established upon it. Milacres with lodgepole pine seedlings were distributed evenly along 10 of the 17 chains of the transect through this cutting area. Accumulative seedling numbers on the block sample transect during the period 1958-1965 were:

Year	Lodgepole pine seedlings (number)
1961	12
1962	11
1963	120
1964	100
1965	148

This pine has faster early height growth than either red fir or white fir, and can overtop them. However, its final height is not as great. Observation of later stages of this mixture definitely indicates that the tolerant fir eventually overtops and eliminates the intolerant pine.

Seedling Mortality

Methods

In 1963, the supplemental seedling study on 24 milacres included field observations on causes of mortality for first-year seedlings. Weekly intervals for these kinds of observations were somewhat infrequent for the most precise work; nevertheless, information on factors causing most seedling losses was obtained.

Results and Discussion

At the end of the first season, seedling mortality was 71 percent. Cutworms were the most destructive agent. They killed 24 percent of the seedlings, and accounted for 33 percent of all mortality *(fig. 19)*. Fowells (1940) found that cutworms killed 34.4 percent of white fir seedlings during a study on the Stanislaus National Forest. Evidence of clipping and

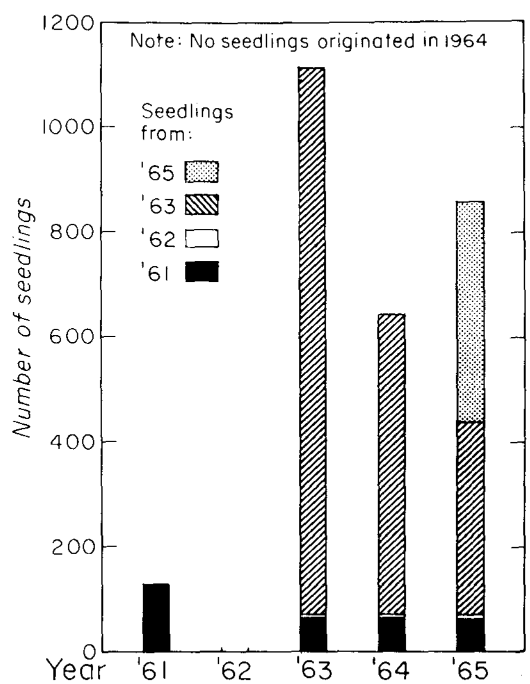

Figure 18.–*Pattern of white and red fir seedling survival followed the usual pattern of reproduction waves within the genus. Data are from milacre transects on clearcut strips. Survival was not recorded in 1962.*

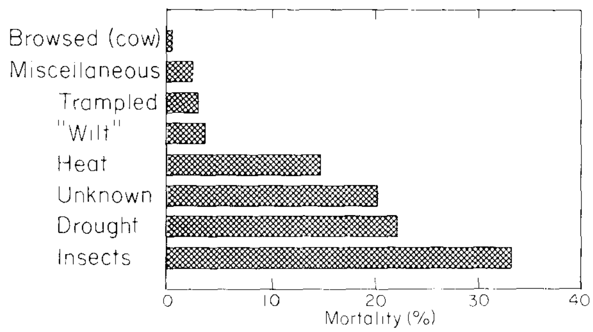

Figure 19.–*Insects and drought were responsible for more mortality in fir seedlings in the first year of growth than any other factors.*

consumption of cotyledons or stems or both at Swain Mountain was essentially the same as that observed by Fowells. Few seedlings died when less than half of the cotyledons were destroyed. Most mortality from cutworm damage occurred before July 15, but some mortality, with insect damage as the probable original cause, was recorded up to September 16.

Drought accounted for 22 percent of mortality. Many seedlings judged as drought-killed were noticed, even in early summer, to be situated in loose mineral soil or mineral-litter mixture, often associated with earth dikes resulting from tractor operation. Some of these sites appeared never to have been wet. Undoubtedly most of them had been wet–if only to a superficial degree. Otherwise the seedlings would not have survived long enough for repeated observation.

Unusual summer precipitation has an unclear effect on seedling survival. In 1963, usual dry summer conditions prevailed. On the milacre transects, 30 percent of 324 first-year seedlings (mostly white fir) survived. In 1965, unusually heavy precipitation fell in July and August. In that year, on milacre transects 107 new red fir seedlings were found initially. Only 24 percent survived at the end of the season. It seems possible to infer, tentatively, that even during normally dry summers, natural fir seedlings in openings have adequate soil moisture for survival at most microsites, and that the total of other agents will be responsible for possible high mortality rates.

Mortality attributed to heat, about 15 percent, usually was caused by excessive high soil surface temperature. Constriction of the seedling stem at ground level was used as evidence of high temperature.

Twenty percent of mortality fell in the "unknown" category, which included uncertain instances of heat or drought killing, and other kinds of seedling loss. Several staked seedlings simply disappeared, without a trace of stem left above or below ground.

"Wilt" was probably caused by damping off, but no laboratory examinations were made. Only 4 percent of mortality was from this cause, and all occurred between June 19 and July 1.

Trampling deaths were attributed chiefly to cattle, a very few to deer, and I confess to one or two. Even though trampling damage might appear slight, it was recorded when observed. Any seedling which died soon after being trampled was recorded as killed by trampling.

No deer browsing was seen in the sampled milacres, but it occurred elsewhere on the area in 1963 and at other times. Less than 1 percent of seedlings that died were pulled up by cattle.

The "miscellaneous" category contained several seedlings which were destroyed in an interesting way. They were scrubbed out by the curling action of drying limbs lying on the ground. An animal, probably a rodent, caused one death when it clipped most cotyledons from a seedling while detaching an unshed seedcoat. A little more than 2 percent of mortality was assigned to the miscellaneous category.

On June 29, 1963, a 32°F. minimum temperature at Swain Mountain killed new lateral (but not terminal) growth of white fir advance reproduction, but did not have an observable effect on recently-germinated seedlings of either white or red fir. Schubert (1956) reported for another location apparent differential response of young white and red fir to temperature below 32°F., the white fir being damaged more heavily. He also suggested that initial establishment of white fir reproduction would be better beneath the radiation and browse protection of pines or brush, the latter to be removed early to release the firs. Greater resistance to frost damage might be one reason that red fir replaces white fir as elevation increases.

About half the seedling mortality could be controlled. Cost of control measures is another matter.

COMPARISON OF SEVERAL MAJOR FACTORS

The relative influence of each of certain variables on seedling establishment at Swain Mountain is best shown through results of statistical analyses. Some of these results have been mentioned earlier. The intent here is to bring material together so that comparisons may be made.

Variables

The milacre regeneration transects and seed traps furnished data for stepwise multiple regression analyses. Only data associated with seedlings of 1963 origin were used. Data for other years were judged to have too many zero observations to allow significant or economical analysis. Variables available were:

Dependent

Seedlings per milacre (number): Total number of white and red fir seedlings on a milacre at end of the first growing season. More explicitly–we are dealing with about 20 percent of the original seedlings which survived the first growing season on 3- and 5-chain wide strips.

Seedlings per sound seed (ratio): Ratio of seedlings per milacre to estimated sound seed falling on the milacre.

Independent

Seed (number of sound seed per milacre): Number of sound white and red fir seed falling on a milacre, as estimated from seed trap data.

Distance (from nearest cutting edge seed source): Distance of milacres from seed source was used linearly, squared, or classed as greater or less than 1 chain. In some of the analyses distance was defined as being (a) from the nearest cutting edge, or (b) from the southwest cutting edge only.

Slash disposal (three methods): The three slash disposal treatments–none, lop and scatter, exposure of mineral soil by bulldozing–were coded. The intended effect of treatments was the creation of gross differences in general seedbed conditions.

Seedbed condition (five classes): Five coded classes of seedbed condition were based on mineral soil or three relative levels of litter or slash or both. A statistical test showed that the distribution of seedbed classes within I chain of the cutting edges did not differ from that of seedbed classes on the rest of the cutting.

Shade (four classes): Four shade classes were based on the number of small residual trees on a milacre. Size, location, or arrangement of trees on the milacre were not considered. Some milacres had more than 20 residuals. This variable was used only in analyses applying to the irregularly shaped block, since this area was entirely different from the clearcut strips.

Competitive vegetation (five classes): Each of five kinds of low vegetation which became established was rated according to its estimated competitive effect on seedling establishment in each milacre. Competition was coded as none, light, medium, or heavy. A competition index for each milacre was obtained by adding these coded numbers. Because early analyses indicated competition had no effect, this variable was dropped.

Statistical Analyses

An existing stepwise multiple regression analysis program[8] for the IBM 1620 computer was used to determine relative importance and relationship of the variables. Table 8 lists the most informative results of initial analyses. Evaluation was based on the terms expressing (a) contribution of each variable or group of variables to regression sums of squares (R^2), and (b) T-ratio (regression coefficient/standard error) for each variable, which had to be 2.00 or greater to indicate an appreciable effect.

Appropriate models were then compared by F-tests to determine (a) whether regression slopes or intercepts differed significantly, and (b) which classes of independent variables were contributing significantly to information about the dependent variables.

The most significant information from regression analyses and F-tests of the models is reported here. Major findings summarized are in terms of relative influence of each variable on white and red fir seedlings at the end of the first growing season.

Dependent Variable: Seedlings Per Milacre

1. Number of sound seed per milacre was by far the most significant variable whenever it appeared in an equation.
2. Distance from nearest cutting edge was usually significant, and had an inverse relationship to number of seedlings. Distance, as a variable, may be influenced to an unknown degree by the effects of shade from the cutting edge.
3. Differences in the influence of various seedbeds on seedling establishment were highly significant *(fig. 20).* Mineral soil (seedbed class 1) was the best

[8] Powell, Marcus P. *The new regression system.* Version 1. 1966. (Unpublished manuscript on file at Dep. Agr. Econ., Univ. of Calif., Berkeley.)

seedbed, followed by class 2, which had only light litter and light or no slash.

4. Slash treatments were highly significantly different in their influence on seedling establishment. Bulldozing to mineral soil was the superior treatment. But why lop-and-scatter treatment was superior to no treatment is not clear. Appearance of the lop-and-scatter areas for a couple of years after treatment– rather uniform distribution of a relatively deep layer of organic fines– suggests that it would be a poor seedbed initially. Apparently lop-and-scatter treatment improved with age.

5. An additional series of F tests compared regression models incorporating different combinations of independent variables within these general classes: sound seed, distance, seedbed, and slash treatment. Within and among the variables, the most seedlings were, in order, (1) quantity of sound seed, (2) mineral soil seedbed, and (3) bulldozer treatment of slash (to expose mineral soil).

6. Since many milacres on the clearcut block were stocked with stems of advance reproduction, the possible influences of natural shade and seedbed on seedling establishment were examined. In this analysis, a series of linear regressions were run in addition to the multiple regressions. Results were too unreliable for inclusion here. A reliable example of the influence of small tree shade on seedling survival appears in the section on insolation under *Sunlight and Shade Influence on Seedling Survival.*

Dependent Variable: Seedlings Per Seed

During the early part of the analysis, an attempt was made to develop simple indexes of "seed efficiency" for various conditions, but no reliable information on the subject could be developed.

Table 8.–*Selected data from multiple linear regression analysis showing relative importance of variables in different combinations; applicable to clearcut strips only*

Model number	Dependent variable	Independent variables and combinations	R^2	T-ratio	Number of observations
1 a	Seedlings/milacre	Seed/milacre	0.15301	8.23	377
b	Seedlings/milacre	Distance	.05413	4.63	377
c	Seedlings/milacre	Distance	.05414	1.31	377
		+(distance)[1]		.05	
d	Seedlings/milacre	Seed/milacre	.16040	6.88	377
		+ distance		1.81	
e	Seedlings/milacre	Seed/milacre	.16054	6.87	377
		+ distance		.82	
		+(distance)[1]		.25	
2A a	Seedlings/milacre	Seed/milacre (in seedbed 1)[2]	.34536	4.76	45
b	Seedlings/milacre	Seed/milacre (in seedbed 2)	.46730	6.00	43
c	Seedlings/milacre	Seed/milacre (in seedbed 3)	.18227	3.24	49
d	Seedlings/milacre	Seed/milacre (in seedbed 4)	.05012	2.24	97
e	Seedlings/milacre	Seed/milacre (in seedbed 5)	.10801	4.13	143
2B a	Seedlings/milacre	Seed/milacre	.18021	8.55	377
		+ seedbed 1		2.74	
		+ seedbed 2		2.43	
		+ seedbed 3		.21	
		+ seedbed 4		1.89	
		+ seedbed 5		([3])	
b	Seedlings/seed	Distance	.06110	2.00	377
		+ (distance)[1]		2.29	
		+ seedbed 1		3.68	
		+ seedbed 2		2.14	
		+ seedbed 3		.73	
		+ seedbed 4		1.83	
		+ seedbed 5		([3])	
3A a	Seedlings/milacre	Seed/milacre (in slash 0)[2]	.31746	7.65	128
b	Seedlings/milacre	Seed/milacre (in slash 1)	.05882	2.83	130
c	Seedlings/milacre	Seed/milacre (in slash 2)	.14358	4.43	119

See end of table for footnotes.

Table 8.–*Selected data from multiple linear regression analysis showing relative importance of variables in different combinations; applicable to clearcut strips only,* continued

Model number	Dependent variable	Independent variables and combinations	R^2	T-ratio	Number of observations
3B	Seedlings/milacre	Seed/milacre	.16618	8.36	377
		+ slash 0		2.35	
		+ slash 1		1.75	
		+ slash 2		([3])	
4A	Seedlings/milacre	Seed/milacre	.18802	8.52	377
		+ slash 0		1.69	
		+ slash 1		.25	
		+ slash 2		([3])	
		+ seedbed 1		2.40	
		+ seedbed 2		2.31	
		+ seedbed 3		.18	
		+ seedbed 4		1.54	
		+ seedbed 5		([3])	
4B	Seedlings/seed	Distance	.07838	1.59	377
		+ (distance)[1]		1.76	
		+ slash 0		2.62	
		+ slash 1		1.38	
		+ slash 2		(3)	
		+ seedbed 1		2.80	
		+ seedbed 2		1.67	
		+ seedbed 3		1.31	
		+ seedbed 4		.95	
		+ seedbed 5		([3])	

[1](distance) squared.
[2]Legend for variables:

Seedbed

Code	Litter	Slash
1	O	O
2	L	O, L
3	O	L, M, H
4	M, H	O
5	L, M, H	L, M, H (except combination of L litter and L slash)

Slash

Code	Treatment
0	None
1	Lop and scatter
2	Cleared w/dozer

[3]In these instances, seedbed class 5 and slash class 2 were entered in equations with values set at 0, so no T-ratios were developed.

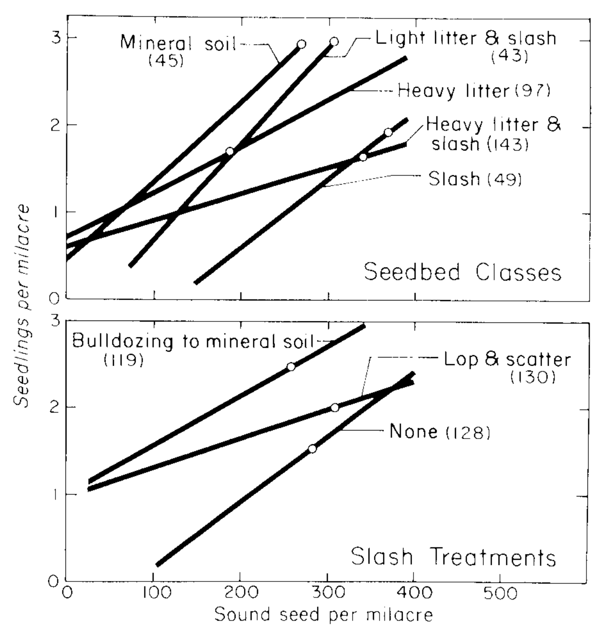

Figure 20.–*Regression lines from relating seedlings per milacre to sound seed per milacre on clearcut strips. Separate regression analyses were made for each seedbed and slash class. The number of observations is given in parentheses; means are indicated by (°).*

OTHER FACTORS IN REGENERATION

In addition to the major factors that affect regeneration of white and red firs, we studied other factors. These observations and findings were not subject to statistical analyses.

Injury and Rot

Mechanical damage to residual trees should be kept at a low level in fir stands. Fungi can become established quickly wherever fir bark is broken and may cause future losses from rot and windbreak. Such losses should not be ignored. Broken tops will reduce seed production potential for a number of years, since all fir cones are produced close to tree tops. To help keep injuries down, stands may be logged in two or more stages. Experience has shown stage-logging to be essential to minimize log breakage where timber stand volumes are heavy.

Wind Damage

Wherever fir stands are opened, increased wind damage may occur. The amount of wind damage seems to be related to amount of timber removed from an area. Size and shape of openings, orientation, topographic location, and direction of prevailing storm winds should be considered. Individual tree or small group cuttings may help to reduce wind damage. Intensity of cutting, and spacing of residual timber, is the key. Heavy wind damage after heavy cutting is common. But I do not know of any recorded information on wind damage to white or red fir residuals in "medium" or "light" selection cutting, although I have seen such damage. Harvesting plans should provide for salvaging wind damaged trees.

Dwarf Mistletoe

Dwarf mistletoe is present in varying amounts in many fir stands. Two simple methods can reduce its spread to new seedlings or advance reproduction. The first is to remove nearby infected trees soon after adequate regeneration has been established–certainly before seedlings are 3 feet high. Scharpf (1969) has shown that if an overstory is infected, understory trees have low, medium, or high amounts of mistletoe in the same direct relationship to their height. The second method, which may have less frequent application, relies on artificial seeding or planting. Since the two forms of dwarf mistletoe growing on white and red fir are host-specific (Parmeter and Scharpf 1963), regeneration of one species can be established beneath or next to mistletoe-infected trees of the other without danger of infection of the seedlings.

Animal Damage

In localized situations, birds, cattle, and other animals may be important enough to require special attention. At present, insects, deer, and rodents hold the highest potential for causing difficulties in fir regeneration. Specific instances of damage are numerous, and, even after years of study, there is no reliable method of controlling these animals in an acceptable way and at reasonable cost.

Insects

Although cone- and seed-eating insects often greatly reduce seed supplies, I know of no research having been done to guide alleviation of this problem in fir species. Insecticides can probably control cutworms in the soil, but a high level of control of seed-destroying insects through use of insecticides or by other means would be much more rewarding in a number of ways, including more seed and fewer seed trees necessary.

Rodents

McKeever's studies (1961; 1964) indicated that (a) gross rodent populations in a true fir forest are lower than in nearby ponderosa and lodgepole pine forests; (b) the pine squirrel *(Tamiasciurus douglasi)* moves to areas where food is most abundant; (c) the golden-mantled ground squirrel *(Citellus lateralis)* sometimes moves from one forest type to another, and is more abundant in cutover than in uncut stands; and (d) deer mice *(Peromyscus maniculatus)* and chipmunks *(Eutamias* spp.*)* are generally most numerous of the rodents found in forested areas of northeastern California. Tevis (1956) found that the golden-mantled ground squirrel moved into Douglas-fir and white fir forests as they were progressively opened by logging. That more rodents will move into true fir forests as they are progressively logged seems probable. This could cause difficulty with true fir regeneration. During several years following first cutting at Swain Mountain, rodents did not seriously interfere with the regeneration process. However, potential rodent activity at any specific area should be evaluated for its impact on regeneration processes.

Porcupines seem to cause little damage in fir forests. Pocket gophers, however, are sometimes active in wet meadows and occasional open glades, so their numbers and activities may need evaluation.

Deer

Deer browse heavily upon small firs in some areas. The most succulent new growth of the current or immediately preceding year always is browsed in preference to older tissue. Browsing may eliminate plants or greatly restrict their height growth. In some locations, small firs may be the only green food available as deer follow the spring snow melt to increasingly higher elevations. Regeneration of firs or any other species may be difficult along the main annual migration routes of large deer herds.

Logging Plans

In planning roads, skid trails, and fire lanes, and in marking timber, the future as well as the present should be considered. Otherwise, current activities may obstruct or make less efficient future harvesting or cultural work. Future activities could also destroy recently acquired regeneration if improper logging activities are forced or permitted.

TENTATIVE RECOMMENDATIONS

General

Where natural regeneration of white or red fir is sought, creating conditions which have high probability of insuring at least minimum stocking from light seed fall can be recommended. This is most advantageous when factors (e.g., vegetation, erosion) related to time after logging might critically inhibit seedling establishment.

Can too many fir seedlings become established? I do not believe so. Studies to date on free-growing fir seedlings and saplings (free of overstory) indicate that several thousand young trees per acre will grow rapidly and become thinned gradually through competition and snow damage. And gains from Christmas tree harvesting can add income above "making thinning pay for itself." Nevertheless, research is needed to compare growth and other data in thinned and unthinned stands of "unmerchantable" size.

The following recommendations offer a framework for securing natural white or red fir seedlings where desired. Timber cutting techniques or patterns, and simple cultural work, are tools for accomplishing this objective. These recommendations are based mainly on two premises: (1) sound seed supply must be abundant, and (2) a treated seedbed, preferably mineral soil, will ensure advantages not otherwise gained. Emphasis is placed on cutting method.

Clearcutting

Clearcutting is the most practical method of harvesting true firs where stands of old-growth timber are dense (no understory) or light with abundant understory. The latter instance can be labeled "release" or "liberation," and little or no new regeneration is sought. Reasons for clearcutting are based mainly on logging simplicity, the confinement of potential damage to residual trees along cutting edges, ease of cultural treatments such as preparation of seedbed, ease of fire hazard reduction, and probable benefits in managing even-aged stands. Other cutting methods will be found preferable in many instances, but wherever possible, clearcutting probably will be used. Dimensions of clearcut units are of fundamental importance where new regeneration is sought.

- *Dense Old-Growth, No Understory: Clearcut Strips*

Limit width of strips to 2 or 3 chains where a solid wall of seed trees exists on both sides. Use narrower strips where seed trees are less abundant. Straight sides are not essential to regeneration. Orient generally with consideration for slope, topographic position, prevailing wind pattern, and insolation. Cut progressively toward wind or sun later. Strips can be cut sequentially to make use of Anderson's (1956) "wall-and-step" method of maximizing snow accumulation and delaying melt, particularly in cases where long cutting cycles can be used, and where mistletoe infection has low potential or can be tolerated.

- *Dense Old-Growth, No Understory: Clearcut Blocks*

Keep blocks small, not more than 3 or 4 chains in greater dimension. (The influence of seed fall from all surrounding timber probably will allow greater dimensional limits here than with strips.) As with strips, keep dimensions smaller where seed trees are less abundant. When planning the first cut, determine how succeeding cuts will be made.

- *Scattered Old-Growth, Abundant Understory*

Cutting stands like this often consists only of removing the overstory with enough care to minimize damage to the advance growth. Experience indicates that damage to the advance growth increases with density of overstory and as size of the understory increases. Leave a good seed source at any localized spot where logging damage may become unusually severe.

Other Cutting Methods

A wide variety of partial cutting methods and intensities probably will secure adequate regeneration. We know that new fir seedlings will become established in moderate-sized openings, and in rather dense shade. If shade is dense, seedling growth will be slow until competing vegetation, whether trees or brush, is removed. No partial cuttings were studied at Swain Mountain, but available evidence–including work reported in this paper, observable patterns in the woods, and survey of the literature as far back as Dunning's (1923) early work–indicate that true firs will regenerate in partial cuttings. Limitations of cutting intensity, however, still need investigating. In one case, we found that a cutting which left about 10 large seed trees per acre adequately restocked an area. But in another similar cutting, the area was not restocked. Reasons for the difference are unknown.

- *Uniform Shelterwood System*

Areas of dense old-growth having little or no understory can be harvested to leave a fairly uniform distribution of large seed trees which should be harvested in one or more increments as regeneration becomes established. Probably more than 10 seed trees per acre should be left–at least until we gain more experience with intensity of cut.

- *Group Shelterwood System*

Areas of dense old-growth having little or no understory can be harvested in small groups to begin a cycle like that described in the next section. Groups or areas of advance growth which have no overstory could be used as focal points around which new regeneration is sought by cutting old-growth on the perimeter. Although entire perimeters might be cut, preference should be given to cutting towards the south or the prevailing wind–provided that seed trees exist in such directions. Early trials should be conservative, extending about 1 or 11/2 chains into the old-growth. (In the initial stage or stages, this cutting might approach the "honey-comb" system recommended by Church [19331 for inducing greater deposition of snow and delaying its melt.)

- *Selection System*

Where stands with pronounced crown differentiation occur, remove individual trees or small groups from the upper canopy so residual seed trees will remain within 1 or 2 chains of the cutting–preferably "upwind" from the cutting.

Also, selection cuttings could be made in dense old-growth of relatively uniform height. Either slow or rapid conversion of stand appearance and other characteristics could be achieved this way.

Reproduction which becomes established in the very small openings created by selection cutting will grow slowly until released, or until it grows into the large pole class. This pattern occurs frequently in natural stands.

SUMMARY

Several factors that influenced the establishment of white and red fir seedlings from natural seed fall were studied at Swain Mountain Experimental Forest, in northeastern California, beginning in 1958.

The choice of even-aged management for early studies at Swain Mountain necessarily has influenced the nature of the work reported. Liberation cutting, and clearcutting for natural regeneration of white and red fir were the only cutting methods used to any extent in the first trials. The regeneration cuttings were confined to 3-chain and 5-chain wide strips and a single 8-acre block. Liberation cuttings were applied to irregularly-shaped areas to almost 40 acres in size. We anticipated that some small areas within the liberation cuttings might require regenerating. Accordingly, data were obtained from three clearcut strips and a block, and from one liberation cutting–or from uncut areas immediately next to them.

Cone crops of both white and red fir were found to be irregular in size and occurrence. Tree-for-tree, white firs produced much more sound seed than red firs. Individual white fir trees tended consistently to produce seed either at a relatively high or low quantitative level whenever there was a crop; individual red firs produced cones at irregular levels.

Sound seed fall on a particular location varied quantitatively with (a) relative size of seed crop, (b) abundance of seed trees, (c) distance and direction from seed trees, (d) and direction of wind currents. Wind speed was not measured, but is a significant factor in seed distribution. Weather conditions in the fall season can strongly affect the timing of cone-shattering, and consequently the eventual effectiveness of released seed. Seeds falling on the ground before permanent snowpack may germinate in spring and survive. But most seeds falling on snowpack germinate within the pack and die when snow-melt lays the seedlings on the ground.

Mineral soil and soil with less than one-fourth inch of litter proved to be better seedbeds than heavy accumulations of litter and slash. Soil surface temperature may account for much of this difference. In one experiment, the surface of mineral soil seldom exceeded 150°F., while inch-deep litter usually exceeded 163°F.

Early survival of seedlings was better where they were shaded by small trees, artificial objects, and uncut timber edges than where they were unshaded.

Soil moisture at the 6-inch depth and deeper across a 5-chain clearcut strip remained above the assumed wilting point throughout the growing season. At the end of the first growing season numerous seedlings are known to have roots from 6 to 12 inches long. Therefore, drought was not an overwhelming obstacle to seedling establishment, although 20 percent of the seedling mortality was attributed to drought caused by microsite conditions.

Low vegetation which could compete with fir seedlings remained scanty for several years after clearcutting. This phenomenon and the timing of seed crops probably account for the generally good stocking of fir seedlings at most locations within clearcut strips at Swain Mountain. At the end of 7 years, milacres in the central portions of clearcut strips were about 50 percent stocked with post-logging seedlings. Stocking within a chain of cutting edges was higher.

More seedlings survived in narrow than in wide openings. Red fir seedlings were definitely more tenacious and vigorous than white fir in the strips studied.

Cutworms, drought, and heat at soil surface were the principal early causes of seedling mortality. About half that mortality could be controlled by some means. A few years later, deer browsing preferentially on white fir caused much mortality and delayed height growth.

Analyses of data from Swain Mountain indicated that the most significant factors favoring establishment of white and red fir seedlings are in order of importance: (a) quantity of sound seed, (b) mineral soil seedbed, and (c) some amount of shade. On the negative side, we found that destruction of seeds and seedlings by insects caused by far the greatest reduction in regeneration potential, and that deer browsing creates havoc, especially with white fir seedlings. Excessive insolation and drought were the next most damaging agents to seedlings. Other factors were relatively insignificant.

LITERATURE CITED

Anderson, Henry W.

1956. **Forest-cover effects on snowpack accumulation and melt, Central Sierra Snow Laboratory.** Amer. Geophys. Union Trans. 37(3): 307-312.

Baker, Frederick S.

1929. **Effect of excessively high temperatures on coniferous reproduction.** J. Forestry 27(8): 949-965, illus.

Church, J. E.

1933. **Snow surveying: Its principles and possibilities.** Geog. Rev. 23(4): 529-63.

Day, R. J.

1964. **The microenvironments occupied by spruce and fir regeneration in the Rocky Mountains.** Can. Dep. Forestry Publ. 1037, 25 p., illus.

Dunning, Duncan.

1923. **Some results of cutting in the Sierra forests of California.** U.S. Dep. Agr. Dep. Bull. 1176, 27 p., illus.

Dunning, Duncan.

1942. **A site classification for the mixed-conifer selection forests of the Sierra Nevada.** U.S. Forest Serv. Calif. Forest & Range Exp. Sta. Res. Note 28, 21 p., illus.

Forsythe, W. E.

1954. **Smithsonian physical tables.** Ed. 9., 827 p. Washington, D. C.: Smithsonian Institution

Fowells, H.A.

1940. **Cutworm damage to seedlings in California pine stands.** J. Forestry 38(7): 590-591.

Fowells, H. A., and Schubert, G. H.

1956. **Seed crops of forest trees in the pine region of California**. U.S. Dep. Agr. Tech. Bull. 1150, 48 p., illus.

Franklin, Jerry F., and Krueger, Kenneth W.

1968. **Germination of true fir and mountain hemlock seed on snow.** J. Forestry 66(5): 416-417, illus.

Gordon, Donald T.
1962. **Trial of a photographic technique to count cones.** J. Forestry 60(8): 546-547.

Gordon, Donald T.
1968. **Tree shadow patterns and illumination measurements within clearcut strips and irregular openings in a true fir forest.** U.S. Forest Serv. Res. Note PSW-172, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 9 p., illus.

Gratkowski, H. J.
1958. **Natural reproduction of Shasta red fir on clearcuttings in southwestern Oregon.** Northwest Sci. 32(1): 9-18, illus.

Logan, K. T., and Peterson, E. B.
1964. **A method of measuring and describing light patterns beneath the forest canopy.** Can. Dep. Forestry, Forest Res. Br. Publ. 1073, 26 p., illus.

McKeever, Sturgis.
1961. **Relative populations of small mammals in three forest types of northeastern California.** Ecology 42(2): 399-402, illus.

McKeever, Sturgis.
1964. **Food habits of the pine squirrel in northeastern California.** J. Wildlife Manage. 28: 402-404.

Munsell Color Company, Inc.
1954. **Munsell soil color charts.** Baltimore, Md. illus.

Oswald, Daniel D., and Hornibrook, E. M.
1966. **Commercial forest area and timber volume in California, 1963.** U.S. Forest Serv. Resource Bull. PSW-4, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 16 p.

Parmeter, J. R., and Scharpf, Robert F.
1963. **Dwarf mistletoe on white and red fir in California.** J. Forestry 61(5): 371-374, illus.

Quick, Clarence R.
1956. **Viable seeds from the duff and soil of sugar pine forests.** Forest Sci. 2(1): 36-42.

Roy, D.F.
1959. **Small seed traps perform well in the Douglas-fir type of California.** U.S. Forest Serv. Res. Note 150, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 7 p., illus.

Scharpf, Robert F.
1969. **Dwarf mistletoe on red fir... infection and control in understory stands.** U.S.D.A. Forest Serv. Res. Paper PSW-50, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 8 p., illus.

Schubert, Gilbert H.
1956. **Early survival and growth of sugar pine and white fir in clear-cut openings.** U.S. Forest Serv., Calif. Forest & Range Exp. Sta. Res. Note 117, 6 p., illus.

Siggins, Howard W.
1933. **Distribution and rate of fall of conifer seeds.** J. Agr. Res. 47(2): 119-128, illus.

Society of American Foresters.
1962. **Forest cover types of North America (exclusive of Mexico).** 67 p. Washington, D.C.

Stark, N.
1965. **Natural regeneration of Sierra Nevada mixed conifers after logging.** J. Forestry 63(6): 456-457, 460-461.

Stein, William I.
1951. **Germination of noble and silver fir seed on snow.** J. Forestry 49(6): 448-449, illus.

Stein, William I.
1954. **Natural reproduction of Shasta red fir from one good cone crop.** U.S. Forest Serv. Res. Note 100, Pacific NW. Forest & Range Exp. Sta. 5 p., illus.

Tevis, L., Jr.
1956. **Invasion of a logged area by golden-mantled squirrels.** J. Mamm. 37:291-292.

U.S. Weather Bureau.
1964. **Mean daily solar radiation, monthly and annual (map).** Sheet of National Atlas of U.S. Washington, D. C.

Vézina, P. E., and Pech, Gy.
1964. **Solar radiation beneath conifer canopies in relation to crown closure.** Forest Sci. 10(4): 443-451, illus.

Vinš B.
1964. **(The effect of silvicultural treatment on regeneration of Abies alba.)** Pracé Výzkum. Ust Lesn. CŚSR No. 28, 221-279. (In Czechoslovakian. English abstract.)

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

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Gordon, Donald T.

1970. **Natural regeneration of white and red fir. . . influence of several factors.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 32 p., illus. (U.S.D.A. Forest Serv. Res. Pap. PSW-58)

In a group of studies at Swain Mountain Experimental Forest in northeastern California, seedling survival and mortality were analyzed within the general framework of seed production and dispersal, germination, seedbed condition, soil surface temperature, insolation, soil moisture, and vegetative competition. Factors found to favor seedling establishment were abundance of sound seed, mineral soil seedbed, and probably some shade in the first year. Chief obstacles to seedling survival and growth included strong insolation, deep litter, insects, competing low vegetation, and time between good seed years. The most practical approach to securing natural regeneration appears to be keeping abundant seed trees close to a prepared mineral soil seedbed.

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