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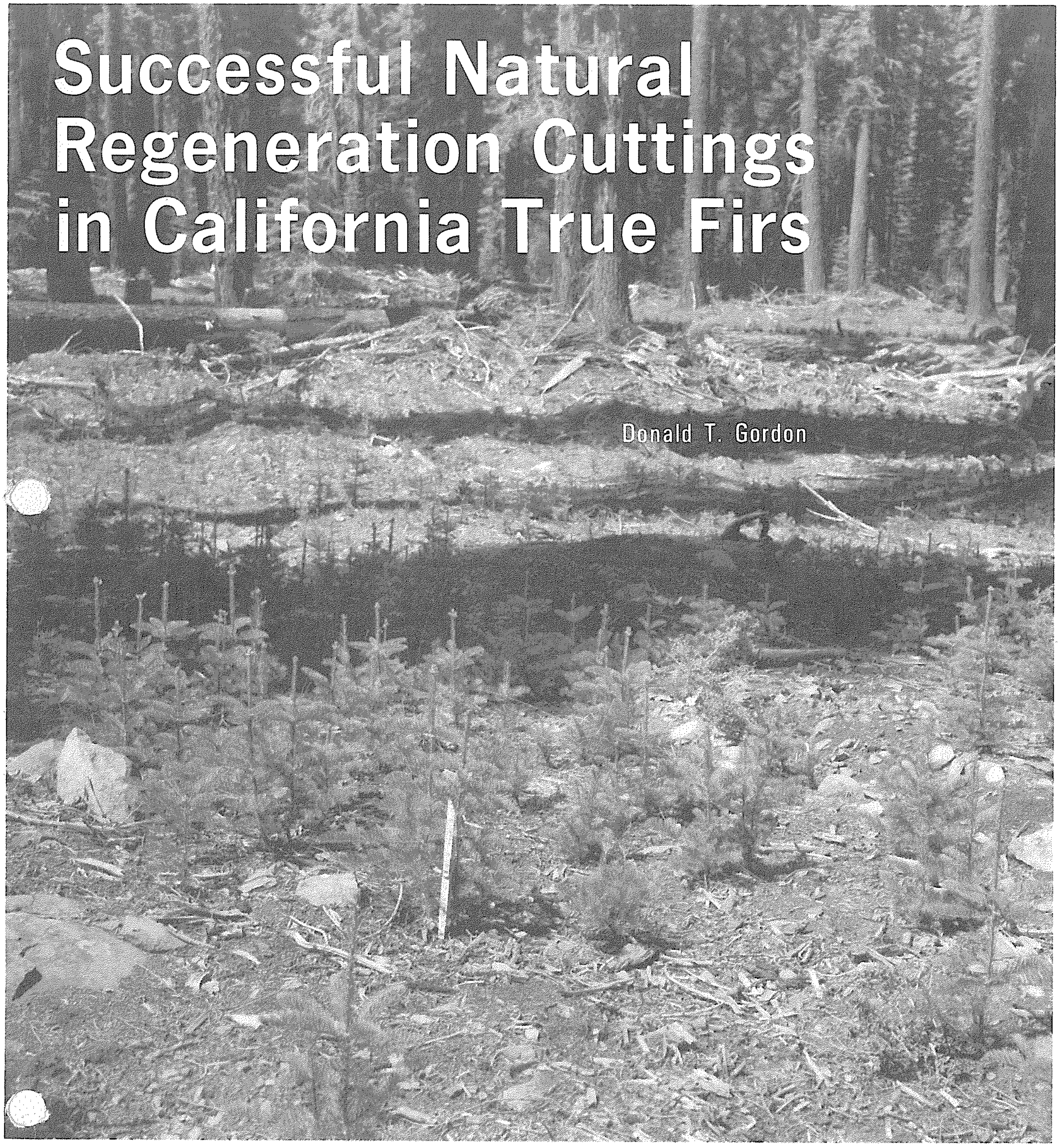
Successful Natural Regeneration Cuttings in California True Firs

Donald T. Gordon



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IN BRIEF...

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Retrieval Terms: cutting methods; slash disposal; seedbed preparation; damage; seedling stocking; seed; white fir; red fir; Swain Mountain Experimental Forest; natural regeneration.

Studies and observations reported here are partly extensions of previous work begun in 1958-60, and partly new trials. In the earlier work, regeneration was studied in clearcuttings 3 and 5 chains wide, and 13 to 40 chains long, in overmature mixed white and red fir stands. Damage in residual stands surrounding the cut areas was also studied. Results indicated that natural regeneration levels were high, but could have been fortuitously so. Reflection on results led to speculation that they might have been due to a beneficial combination of factors such as timing of logging and seed crops, and a relatively slow rate of development of low forms of vegetation (potentially competitive with fir seedlings). Therefore, new cuttings reported here were designed to surmount any combination of "average worst" conditions and whatever sequence of events occurred, so as to get a minimum of 30 percent of milacres stocked with fir seedlings within 3 years after cutting. Damage and mortality among residual old-growth trees again were monitored.

Ninety-nine cutting areas, prepared in 1970-72, formed the data-collection base for the regeneration studies. The cuttings at Swain Mountain Experimental Forest in northeastern California (also the location of earlier experiments), were mainly replications of these three groups:

Clearcut strips 1, 2 and 3 chains wide (20, 40, 60 m)
Clearcut squares 2 by 2, 3 by 3, and 4 by 4 chains
Seed tree cuttings, leaving 10, 20 and 30 largest and "best" trees per acre (25, 50, 75 per ha)

In addition, a group of 2-chain-diameter clearcuts and a series of parallel strips 2 chains wide were installed. Also, some of the strips 3 and 5 chains wide, cut in 1958-60, were widened 2 chains to windward (southwest) and 1 chain toward the northeast, simulating a possible follow-up practice where an even-aged stand covers a large acreage. A few areas approximating uneven-aged stand structure were cut so that no trees more than 150 years old, approximately, were left; included were some small regeneration areas, probably none exceeding 0.2 acre (.05 ha).

Mineral soil seedbed was prepared wherever regeneration was sought. Tractors equipped with normal blades or rock rakes windrowed all organic material. Tractor operators were instructed particularly to keep piles of debris out of the central area of each unit where seed and seedling sampling was to be done.

A heavy seed crop fell in 1971, and light crops in 1973 and 1974. Nearly all regeneration areas became stocked with seedlings at much better rates than the minimum of 30 percent of milacres stocked. Of the 99 areas included in the formal experiment, 87 percent exceeded the set minimum stocking. Eighty-three percent exceeded 50 percent.

Post-logging damage to residual old-growth was everywhere negligible. Least damage occurred in seed tree cuttings, showing that it is now possible to select trees which will produce abundant seed and yet not yield to normal wind storms.

Low vegetation developed slowly on regeneration areas; it appeared not to affect seedling survival.

The success of natural regeneration of white fir (*Abies concolor* [Gord. & Glend.] Lindl.) and red fir (*A. magnifica* A. Murr.) on logged areas has been found to be strongly related to the quantity of sound seed available and the presence of a mineral soil seedbed (Gordon 1970). Quantity of effective seed, in turn, was found to depend on periodic production of sound seed by a sufficient number of seed-producing trees; distance and direction of seedbed from seed source (considering wind currents only); and timing of snowfall—that is, whether seeds reached the seedbed before formation of a deep snowpack (seeds falling on permanent snowpack germinate in the spring but few become established in the soil).

Early research at Swain Mountain Experimental Forest, in northeastern California, provided some quantitative information on these matters. There was good stocking of fir seedlings on 3- and 5-chain-wide (60- and 100-m) clearcut strips wherever sufficient mineral soil seedbed was exposed through site treatment. The fact that seedlings were seen to be most numerous near cutting edges, which were the seed source, suggested that narrow or small clearcuttings should regenerate better than wide ones. Reflection on reported and unreported observations, however, indicated that good results, especially on the wider strips, might have been due partially to coincidence. Possibly, timing of logging and site preparation in relation to seed crops, and general lack of early aggressiveness of low vegetation on study areas were most influential.

Most forest managers would encounter practical difficulties if they accumulated regeneration areas to be cut only during good seed years. A preferable method is to cut and treat regeneration areas when other harvest methods are being used nearby. In true fir stands, a medium-to-good seed crop could be expected within 3 or 4 years after cutting. But, occasionally, a relatively poor seed crop might present the best probability for regenerating an area before it was "lost" to unwanted competing vegetation. The regeneration strategy to be followed should insure maximum advantage from any seed crop within the first few years after site preparation. Such advantage can be gained by providing enough good seed trees, located so as to disperse a relative abundance of seed on prepared seedbeds.

The design of the cutting is important. On the average, most fir seeds fall within 1 or 1½ chains (20 to 30 m) of the source. Clearcuttings therefore should not be wider than twice those distances. Seed tree or shelterwood cuttings should also be designed to provide sufficient seeds. Previous studies (Gordon 1970) confirm that clearcuttings not exceeding 3 chains (60 m) in width should produce abundant regeneration. Clues to required numbers of large trees to be left for the seed tree cutting method were provided by my study of an Eldorado National Forest red fir stand cut more than 15 years previously. There, 10 large seed trees per acre (25/ha) had provided good amounts of reproduction wherever soil surface was disturbed. Seed trapping also showed uniform seed distribution over such areas.[1]

The studies of natural regeneration in red and white fir reported here were designed to explore (1) the relation of type and size of cutting to seedling stocking; (2) the relation of seed quantity and dispersal to stocking; and (3) the relation of type and size of cutting to tree damage. As criteria for stocking level, the seedling requirements under consideration as part of the California Forest Practices Act were used. Adequate stocking was judged as a minimum of 30 percent, based on the number of milacres stocked with one or more live seedlings. Stocking was evaluated annually for 3 years after cutting.

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[1] Unpublished data on file, Pacific Southwest Forest and Range Experiment Station. Seed was sampled with 8.2-square-foot seed traps, 32 traps on each of two adjoining 1-acre areas. Mean seeds per trap for each of the two areas were 19.8 and 20.1, with standard errors of 0.90 and 1.13 seeds per trap. Mean seeds per trap for all sample lines ranged from 16.5 to 24.0.

Figure 1—Regeneration cuttings were placed in stand condition like that shown in the background: dense old-growth mixed white and red fir, lacking understory. (Swain Mountain Experimental Forest, California)

STUDY AREA

At the study location, Swain Mountain Experimental Forest, elevations range from 5700 to 7000 feet (1737 to 2134 m). Precipitation, which averages 40 to 50 inches (1020 to 1270 mm) a year, is mainly snow. Snow surveys during four winters found usual maximum snowpack depth to be about 8 feet (2.4 m); it was 14 feet (4.2 m) at some places during one winter. Summers are warm, and dry except for infrequent thundershowers. Soil is 3 to 8 feet (1 to 2.4 m) deep; it is derived from vesicular andesite and contains varying amounts of rock. Site quality is mostly rated at II (Dunning 1942), and old dominant trees average 150 feet (45 m) tall. Board foot volume as great as 147,000 per acre has been measured in a dense old-growth stand. White fir and red fir are mixed in various proportions through much of the Experimental Forest, but red fir becomes the exclusive species near the top of Swain Mountain.

METHODS

The methods used are described here under three major headings corresponding to the study objectives. The main study sampled regeneration which became established on a variety of cuttings. In the complementary studies, seed quantity and dispersal were checked by means of seed traps, and tree damage in or near regeneration areas was monitored.

Seedling Establishment Study

All regeneration cuttings studied were placed in dense, old-growth, mixed white and red fir stands lacking advance reproduction (*fig. 1*).

Cutting Treatments

Replicated cutting treatments were as follows: clearcut strips 1, 2, and 3 chains (20, 40, 60 m) wide, all 6 chains (120 m) long; clearcuttings 2, 3, and 4 chains (40, 60, 80 m) square; and seed tree cuttings 6 chains (120 m) square which left levels of 10, 20, and 30 of the largest and best trees per acre (25, 50, 75/ha) as seed source.[2]

For convenience and reference, a series of three widths of cutting strips was termed a "strip set," the three sizes of clearcut squares, a "square set," and a series of different seed tree densities, a "seed tree set."

In all, 99 cutting areas were sampled for different parts of the studies. Restricted access prohibited cutting of equal numbers of like cutting sets in suitable stands in each of the 3 years of the timber sale—1970, 1971, and 1972. The 3-year sale duration was planned in order to sample seedling establishment in relation to seed crop occurrence and time since seedbed preparation. The sale contract specified that site preparation had to be completed on all of a season's logged area before October 15, the approximate time when seedfall begins.

All cutting areas were designed to attain the minimum stocking level—at least 30 percent of milacres with one or more fir seedlings. The sizes and shapes of cutting areas selected for trial in the seedling study were based on previous research findings and on estimates made from observations. A desire to use only the minimum amount of forested area to achieve study objectives was a strong consideration.

A previous report showed that most sound seed fell at less than 1½ chains (30 m) from its source (Gordon 1970). Therefore, length of all clearcut strips was established at 6 chains (120 m) so that the central 2 chains (40 m) of length would not be measurably affected by windborne seed from the ends. Seed tree cuttings were 6 chains square so that a central 2-chain-square sampling area would be free of influence of seed from trees beyond the edges of the cutting. The square clearcuttings were judged to be subject to influence of windborne seed from any direction. Sides were cut straight to provide well-defined edges from which to measure any effects within study areas; ordinarily, edges would be slightly irregular to favor good seed trees, to minimize wind damage, and for pleasing appearance.

Because previous study showed that seed was dispersed mainly by southwest winds, most cuttings were oriented so that the long sides of strips, and any two sides of square clearcuts and square seed tree cuttings, were oriented northwest-southeast. Most strong storm winds in the area blow from the southwest, so the northwest-southeast orientation was judged helpful also to reduce susceptibility of trees just outside the cuttings to wind damage (Gordon 1973). A few cuttings were oriented in other directions for comparison.

The cutting units that made up the strip sets, square sets, and seed tree sets were placed near each other. An uncut strip of timber of 2 chains (40 m) minimum width was always left between units to minimize possible differences attributable to seed source. The sets were installed on aspects ranging clockwise from west through southeast. (South and southwest aspects on Swain Mountain were covered with brush.)

In a supplemental test, some seed tree cutting units, including some on south aspects, were installed on several other National Forests in the California Region.

Seed Tree Criteria

Schumacher's (1928) stand tables for red fir show about 60 trees per acre (150/ha) larger than 24 inches (60 cm) d.b.h. at age 160 on most sites, so the residual seed trees constituted from one-sixth to one-half of the largest trees. Criteria for ideal trees to be left in the seed tree cuttings were (a) sound, pointed tops (fir seed is borne only near tops), (b) absence of evidence of mechanical defect such as rot, "dwarfmistletoe cankers," and fire scars, (c) probable strong root development (as indicated by relatively large amount of area occupied by tree), (d) position as dominant or codominant tree in overstory, and (e) spacing needs.

Sampling Areas

Stocking was evaluated on milacre plots in selected sampling areas. Stocking rate was based on the number of plots with one or more live seedlings, and on seedling counts on a limited number of plots.

The known seed dispersal patterns suggested that stocking rates and seedling counts would be at lowest levels near centers of cutting units. Sampling areas were therefore placed at centers of cutting units as follows: strips—½ by 2 chains (10 by 40 m);

[2] "Seed tree" is used as a phrase of convenience. Thirty trees per acre might be called "shelterwood."

squares—1 by 1 chain (20 by 20 m); seed tree—2 by 2 chains (40 by 40 m). Seedling stocking on portions of cutting units between cutting edges and central sampling areas was determined at the end of the study. A system of temporary milacres was used to gather stocking data for comparison with that obtained in the central sampling area.

Because mineral soil was already known to be the best seedbed, specifications called for this on at least 75 percent of the surface of any milacre plot to be installed. Therefore equipment operators were directed by Forest Service personnel to remove as much organic material as they could from central sampling areas. Piled or windrowed slash was placed mostly between the central sampling area and uncut edges. Straight bulldozer blades and brush rakes were both tried on this work, and we found little difference in results.

In the year after logging and site preparation, 30 permanent square milacre plots were installed randomly in each central sampling zone. Milacres were marked with two 6-inch spikes driven into the soil; locations were mapped and numbered. Wherever a random milacre could not be placed because of rock, stump, or other obstruction, a predetermined choice sequence eliminated bias in an alternate placement.

All milacres were examined in the fall of each year to determine stocking—the presence or absence of post-logging seedlings. In addition, two full sets of 1970 cuttings were selected at random for counts of seedlings. Every third milacre plot on those areas (180 plots in all) was specified for the seedling counts. Seedlings were counted separately by age classes in spring or fall, from spring 1972 to fall 1975.

At the first examination, descriptive data for each cutting unit were recorded as follows: aspect, slope percent, orientation of sides, year cut, and seed source rating. The seed source rating was intended to estimate potential red and white fir seedfall. For seed tree cuttings, the rating consisted of percentages of white fir and red fir seed trees counted. For the clearcuttings, it was an index number derived from examination of timber within 1 chain (20 m) of cutting edges, and considering age class, density of stocking, and size of any gaps in cutting edges. Also recorded for clearcuttings was the tree species (white or red fir) dominating all sides, and the southwest side only.

Seed Traps

Seed crops developing in 1971, 1973, and 1974 were sampled, using traps 10 by 14 inches (25 by 35 cm), designed to resist effects of snowpack loads.

Seedfall data were derived primarily from 10 seed traps placed centrally in each of certain cutting areas used in the seedling study. Traps were placed immediately adjacent to seedling-sampling milacres, beginning with milacre 2 and continuing with every third milacre to number 29. Traps were placed adjacent to all milacres on which seedlings were counted (two complete sets each of strip, square, and seed tree cuttings). Seed traps were also placed next to milacres on additional complete cutting sets as follows: strips—2 sets, square—1 set, seed tree—1 set. Where more than one choice of set was possible, selection was made randomly. In all, 10 complete sets of 3 cutting areas each were sampled with 300 traps.

Material in seed traps was bagged soon after snowmelt in the spring following a seed crop. Number of sound seeds per trap, as determined by cutting test, was the only statistic recorded.

A limited supplemental sample of seedfall was obtained between uncut edges and the central sampling zone of a few cutting areas. A complete set of cuttings, except for a 2- by 2-chain square, were sampled this way by from 6 to 16 traps, depending on size of areas (total 96 traps). This small sample served as a simple check on the assumption that seedfall within a central sampling zone would be less than at locations nearer to cutting edges.

Tree Damage Sampling

A previous study (Gordon 1973) determined amount and kind of damage to trees 4 inches (10 cm) d.b.h. and larger around some true fir clearcuttings. The study also allowed inferential determination of seed tree characteristics that might indicate low susceptibility to damage before natural regeneration is established.

Accordingly, the present study sought possible significant differences in tree mortality or damage to merchantable stems (11.6 in [29.5 cm] d.b.h. minimum) at these locations:

Adjacent to several sizes of small clearcuttings

Within seed tree cuttings having different numbers of seed trees

In undisturbed stands at some distance from any cutting

Around clearcuttings, the sample area extended one chain (20 m) from cut edges into uncut timber, at all sides of the areas. Within seed tree cuttings, and within uncut "control" areas in dense old stands, all trees became part of the potential sample.

Sample area locations and dimensions were as follows:

- *Adjacent to clearcut strips*

  Two complete sets (six in all), giving 9.6 acres (3.88 ha)

  Five additional 2-chain-wide (40-m) strips oriented other than northwest-southeast, giving 8.0 acres (3.24 ha)

  17.6 acres (7.12 ha) total area

- *Adjacent to clearcut squares*

  Two complete sets (six)

  A 3- by 3-chain (60- by 60-m) and a 4- by 4-chain (80- by 80-m) cutting area

  10.0 acres (4.05 ha) total area

- *Within seed tree cuttings*

  Two complete sets (six)

  21.6 acres (8.74 ha) total area, with theoretical total of 432 trees

- *Within uncut ''control'' areas*

  Six areas with 1.6 acres each

  Total 9.6 acres (3.88 ha).

All but two sample areas were located on 1970 cuttings in order to allow five winters of record.

After snowmelt in the spring, a cursory examination of the Experimental Forest was to be made to determine relative level of over-winter tree damage. If damage appeared to be normal, data would be collected in the fall (and this is what always occurred). Otherwise, data were to be collected in early summer so that salvage operations could begin. Damaged trees tallied in the study were sprayed with paint to prevent their being counted more than once.

In the field, for each dead or damaged tree, these data were recorded: species; direction of fall of whole or partial trees; d.b.h.; crown class; whether tree was live or dead; probable time of death or damage; whether tree was part of a damaged group or a single; whether tree was damaged directly or indirectly by wind; whether wind-damaged tree was down, leaning, hung up, broken, or struck by another tree; insect damage (by species, where possible); snow damage; other damage. Contributory causes of death or damage recorded were: root rot; bole rot; fire scar; shallow or wet soil; live or rotten bayonet tops; dwarfmistletoe; logging damage; snow; ''twinning'' (trees occurring in close proximity, often with resultant opposing fire scars and rot, lean, or incompletely developed root systems). The compass direction perpendicular to the side of a clearcutting at which damage occurred was also recorded.

Special Cutting Trials

Trials of a few additional cutting systems were installed during the 1970-72 timber sale period. In one group of cuttings, some older clearcut strips, 3 and 5 chains wide, were widened by clearcutting 2 chains toward the southwest (windward) and 1 chain to northeast. The objective was to learn whether such cuttings would acquire adequate natural regeneration.

On another group of four cuttings, Duncan Dunning's ''unit area control'' silvicultural concept (Hallin 1951) was applied. The areas ranged from 14 to 42 acres (5.5 to 17 ha). All consisted of stands appearing to be relatively uneven-aged, or even-aged by small groups. Cutting objectives were to:

- Remove all trees more than about 150 years old
- Secure natural regeneration wherever small openings were created (rarely as large as 0.2 acre [0.08 ha])
- Release understory groups from the growth-suppressing effect of older overstory (usually scattered)
- Change some age class structures by means of improvement cuttings
- Salvage some trees having bole defects such as breaks and ''dwarfmistletoe cankers''
- On two of the areas, selectively thin some of the smaller immature age class trees to reduce competition

The purpose of these four cuttings was to establish for future study some areas representing uneven-aged stand conditions.

In planning the cuttings, we hoped to find a cooperator interested in studying their immediate effects on snow deposition and melt, and the later effects of newly regenerated areas on the snow as trees grew progressively larger and were subjected to planned manipulation. For this reason, another small but significant category of ''snow cuttings'' was made, consisting of four parallel clearcut strips 2 chains wide, separated by 1.3 chains of uncut timber. The result was an area with 60 percent of the timber removed—a condition found elsewhere to be about optimum for water yield where trees were spaced randomly. Additionally, a series of eleven circular clearcuts, 2 chains in diameter, was established on 3-chain centers. This simulated a ''honeycomb'' cutting—a concept attracting interest since the earliest snow surveys (Church 1933).

RESULTS

The main objective of these natural regeneration cuttings—achieving better than 30 percent of milacres stocked within 3 years after cutting—was realized on 87 percent of the 99 cutting areas in the seedling study, and 83 percent were stocked at a rate of 50 percent or greater.

Principal events affecting studies are shown here:

Event:	1970	1971	1972	1973	1974	1975
Summer cutting and site preparation	×	×	×			
Fall seed crop		×		×	×	
Spring seedling establishment			×		×	×
Fall rating of seedling stocking			×	×	×	×
End of study						×

The 1971 red fir seed crop was much heavier than the white fir crop of 1973 and the red fir crop of 1974, and provided abundant seedlings. But an encouraging result of the regeneration cuttings was that the lighter seed crops of 1973 and 1974 produced good stocking on unstocked areas, or increased stocking on areas already stocked well.

Logging the seed tree cuttings and small clearcuttings turned out to be easier than expected. Methods of slash disposal and site preparation were chosen to facilitate installation of studies reported here. The main objective—to ensure a high proportion of mineral soil seedbed—was achieved.

Results indicated, however, that ordinarily problems of slash disposal make regeneration site preparation difficult in true fir cuttings, especially seed tree cuttings. The number and large size of pieces of currently valueless cull material; dead material existing before logging; the presence of obstructions to bulldozer operation, such as stumps and living trees; and the resistance of green (wet) fir wood to burning for a year or more after logging—all these factors may affect the time required to do the job, its cost, and the appearance of the site. Additionally, large cull logs may obstruct seed tree removal at a later date.

Seeds and Seedlings

Seedfall

The seedfall sampling system was designed to give conservative results, for I assumed that fewer seeds fall near centers of cutting areas than along the edges. This assumption seems valid. In the 27 samples (9 cuttings, 3 seed years), seed counts at centers of areas were less than near edges in 17, equal in 2, and greater in 8; there was no apparent relationship to type of cutting. As will be shown, seedfall sampling was adequate to reveal such a relationship if it had existed.

No data are available for testing to indicate whether or not any of the regeneration cuttings might have stimulated or depressed cone production. Levels of cone production during the study are suggested by data drawn from a long-term study at Swain Mountain:

	White fir cones[1]	Red fir cones[1]
Year:		
1970	308	0
1971	2291	1510
1972	0	1
1973	1152	13
1974	6	688

[1] Visible cones counted; no adjustment for nonvisible cones.

Seed crop size is ordinarily useful information for interpreting potential seedling crops. Red fir cone production was high throughout the Experimental Forest in 1971, and large numbers of red fir seedlings appeared in 1972. The 1974 red fir cone crop was good enough to improve the average seedling stocking rate of many cutting areas, a few of them substantially. In addition, full milacre stocking was reached on a few cutting areas in 1975, reversing the previous condition, in which plots were nearly unstocked. The white fir cone crop of 1973 resulted in some seedling establishment. However, two examples of contrary white fir cone crop indications were noted at Swain Mountain. First, no white fir seedlings were found during seedling plot establishment in 1971, following the small cone crop of 1970. Then, in 1971, the northeastern section of the Experimental Forest (which included the source of data for the tabulation) was the only part showing scattered evidence of a heavy white fir cone crop, but few resulting white fir seedlings were found there in 1972. These examples strongly indicate that the cone counting study did not necessarily represent average cone production of white fir on the Forest as a whole.

Sampling with seed traps indicated that seedfall on specific kinds of areas may vary tenfold or twentyfold between years of heavy crops and recognizable lighter crops (*table 1*). In a heavy crop year, sound red fir seeds fell on regeneration areas at rates of 300,000 to

Table 1—*Estimate of sound seed falling near centers of cutting areas in three different years, Swain Mountain Experimental Forest*

Cutting treatment	Seeds, by seedfall year		
	1971	1973	1974
	—— *Thousand/acre* ——		
Clearcut strip:			
1 chain wide	704	47	55
2 chains wide	721	24	37
3 chains wide	566	21	19
Clearcut square:			
2× 2 chains	[1]620	31	54
3 × 3 chains	[1]311	30	27
4 × 4 chains	[1]412	29	27
Seed tree cutting:			
10 trees/acre left	460	19	60
20 trees/acre left	439	30	30
30 trees/acre left	637	63	52
Average	541	33	40

[1] Based on two replications rather than three.

700,000 per acre (740,000 to 1,730,000/ha). These data agree closely with those from the previous study (Gordon 1970) at Swain Mountain.

For each of the 3 years studied, there was no statistically significant difference in seedfall between three clearcut strip widths, three clearcut square sizes, or the three levels of leave trees in seed tree cuttings. Neither were there any significant differences between the major cutting treatments—strip, square, and seed tree.

Seedling Establishment

In 40 of the 99 cutting areas in this study, the seed source for regeneration was predominantly white fir. In an earlier study (Gordon 1970), white fir trees were found to produce more sound seeds than red fir. Yet, established seedlings on the wider cutting areas of that study, as well as on those of the current study, are mostly red fir. On the older cuttings there is some observed but unmeasured tendency for white fir to become established in the shade of other young trees and brush. Schubert (1956) and Stark (1965) also reported this trait of white fir for regeneration openings in Sierra Nevada mixed conifer stands.

Seedling survival trends were 21 percent for red fir after 4 years, and 23 percent for white fir after 2 years. In a previous study, white fir survival after 2 years in 3- and 5-chain wide strips was 15 percent, and in a 1¼-chain wide opening it was 36 percent (Gordon 1970).

The abundance of established seedlings is illustrated by a frequency distribution of milacres by number of seedlings per milacre at final examination (1975) of 18 cutting areas *(fig. 2)*. It is interesting that 17 of the 19 milacres with no seedlings were on only two cutting areas—one 3 by 3 chains, one 4 by 4 chains—the two most poorly stocked areas in the study.

Trends of seedling establishment from three seed crops on some randomly paired cutting areas *(table 2)* are consistent with previous research results on the influence of seed dispersal, shade, and other factors (Gordon 1970).

Seedlings were most abundant on the narrowest clearcuttings, both initially and at the last examination. Seed tree cuttings had most seedlings where most seed trees were left *(fig. 3)*.. Further evidence of the effectiveness of small or narrow regeneration areas is the flush of new seedlings observed at Swain Mountain in road rights-of-way, in selection cuttings, and in eleven 2-chain-diameter clear-cuttings.

One-year-old seedlings made up about a fourth to a half of all seedlings observed at different areas in 1975. Although some of those will die soon, seedling numbers for all ages are high on the nine kinds of cutting areas: about 2000 seedlings per acre, from 1 to 4 years old, is the minimum (on the 4- by 4-chain areas in 1975, *table 2*). Even this minimum undoubtedly will exceed present requirements of the State of California Forest Practice Rules for completely regenerated areas—300 established seedlings per acre (741/ha) 5 years after cutting.

Survival of seedlings was comparable to that in four samples previously reported (Gordon 1970) to give results in the range of 10 to 50 percent after three growing seasons.

Stocking Factors

Stocking of milacres by one or more fir seedlings in 1975 was analyzed to determine what variables affected stocking rates significantly. Variables tested were (a) the 3 major and 9 minor cutting treatments, (b) year of cutting, (c) interactions of treatments and years, (d) "seed source index" (which attempted to quantify the "goodness" of seed source), and (e) species. A series of multiple regressions yielded means which were compared for difference by using F-tests at $\alpha = 0.05$. Through a process of elimination of least significant elements, only three variables survived in the most satisfactory model, which yielded a coefficient of determination (R^2) of 0.81. In that model, significant differences of means were found for (a)

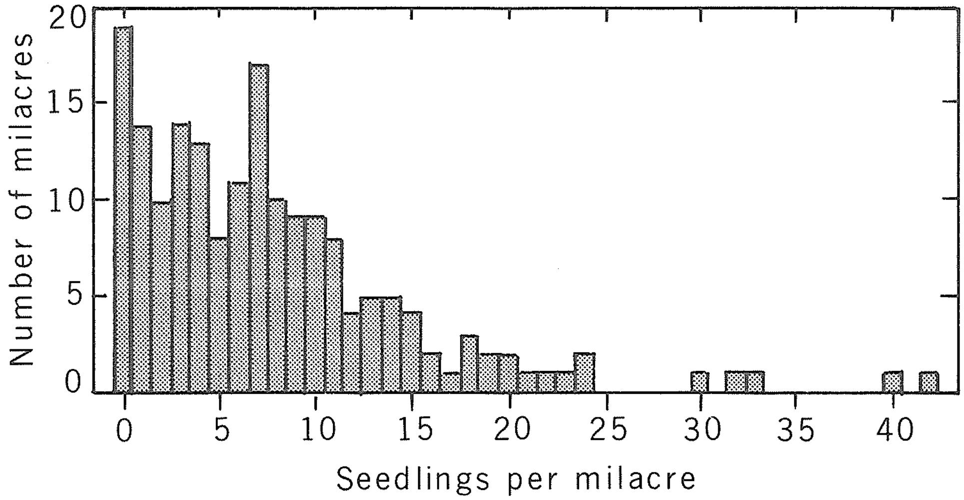

Figure 2—Seedling abundance at final examination of 18 cutting areas in 1975 is evident here from a frequency distribution of milacre plots by number of seedlings per plot. Total count was 1407 seedlings (any age) on 180 milacres. (Swain Mountain Experimental Forest, California)

Figure 3—Five-year-old red fir seedlings were abundant on an area where 30 large seed trees per acre were left. (Swain Mountain Experimental Forest, California)

Table 2—*True fir seedlings, from three seed crops, observed on cutting areas,*[1] *Swain Mountain Experimental Forest, California*

Time of observation	Seed crop year	Seed tree cuttings, leaving (trees/acre)			Clearcuttings					
					Strips			Squares		
		10	20	30	1 chain wide	2 chains wide	3 chains wide	2 by 2 chains	3 by 3 chains	4 by 4 chains
		Average seedlings per milacre								
1972, spring	1971	15.0	17.3	22.3	20.9	14.3	11.8	18.3	7.5	14.3
1974, fall	1971	3.1	6.1	8.3	6.4	2.8	2.2	4.0	0.8	0.8
1975, fall	1971	2.7	5.6	7.4	5.9	2.7	2.2	3.3	0.7	0.8
1974, spring	1973	3.5	2.9	16.4	3.4	0.2	4.9	3.7	3.7	2.3
1974, fall	1973	1.4	1.4	6.5	1.2	0	1.7	1.2	0.9	0.8
1975, fall	1973	0.5	1.0	5.6	0.8	0	0.5	0.7	0.4	0.3
1975, fall	1974	3.8	2.5	5.2	5.9	1.5	5.9	1.5	0.4	1.0
1975, fall	1971, 1973, 1974	7.0	9.1	18.1	12.6	4.2	8.6	5.5	3.1	2.1
		Survival, percent[2]								
After 4 years	1971	18	32	33	28	19	19	18	9	6
After 2 years	1973	14	34	34	24	0	10	19	11	13

[1] Data from two cuttings of each kind except, for strip 2 chains wide, one area only.

[2] For seed crop year 1971, based on 1975 fall count/1972 spring count; for seed crop year 1973, based on 1975 fall count/1974 spring count.

major treatments, (b) year of cutting, and (c) interactions of treatments and years.

The differences between the means for cutting treatment *(table 3)* are apparently real. Differences between years occurred principally because the 1970 and 1971 cuttings both received the abundant seedfall of 1971, as well as the lighter seed crops of 1973 and 1974. But the 1972 cuttings received only the two lighter seed crops. In reality, then, the effect of year of cutting chiefly reflects timing of seed crops.

An alternative interpretation is that for each major cutting treatment, each of the three minor treatments had about equal influence on the mean level of stocking. The relatively poor showing of clearcut squares is unexplainable when compared with relatively good stocking on other small openings of the same ages at Swain Mountain.

The relation of number of seedlings to number of seed was examined but with little success. Data analyzed were seed caught in traps immediately adjacent to milacres on which seedlings were counted. Seedlings in early spring of 1972 and 1974 were compared with seedfall of 1971 (heavy) and 1973 (light), respectively. Regression lines plotted through the two sets of data *(fig. 4)* show only in a general way what we would normally suspect: that seedling numbers increase as seedfall increases. Large sampling error in seed numbers prevents "error band" confidence statements, so the trends shown must be regarded with reservation. An interesting comparison is that for a year of heavy seedfall, seedling numbers doubled with

Table 3—*Milacre stocking with fir seedlings of any age in 1975, by major cutting treatment and year of cutting, Swain Mountain Experimental Forest, California*

Cutting treatment	Stocking by year of cutting			
	1970	1971	1972	Mean
	Percent			
Clearcut squares	65	95	25	53
Clearcut strips	84	67	53	68
Seed tree	98	99	73	95
Mean	86	92	42	

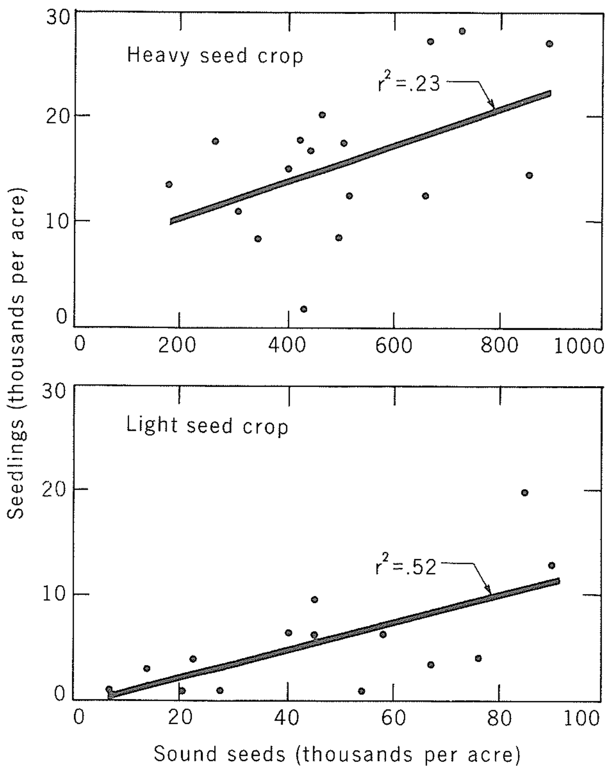

Figure 4—Seedlings counted shortly after germination are obviously related to seeds trapped after heavy and light seed crops. Notice that crops are graphed at different scales because of seed numbers; the slopes actually are not parallel. (Swain Mountain Experimental Forest, California)

a fourfold increase in seed, whereas, in a year of scarcity, seedling numbers doubled with only a twofold increase in seed. Such a difference could be due to the sum of influences of several factors.

Seed tree cuttings with the same numbers of residual trees as in this study were planned on several National Forests, for comparison with Swain Mountain results. Only two installations were prepared in time to be included in comments here. But in the fall of 1976 I observed that natural regeneration was abundant wherever mineral soil was exposed in red fir cuttings on south aspects on the Pacific Ranger District of the Eldorado National Forest, and on generally eastern aspects on the Downieville Ranger District of the Tahoe National Forest. Results on those areas indicate that regeneration success on seed tree cuttings is attainable at different locations in the red fir forest type.

Heights of 5-Year-Old Red Fir Seedlings

In 1976, a small supplemental study of 5-year-old red fir seedlings showed average total height to be 8.6 inches (21.8 cm). The sample consisted of 30 seedlings randomly selected in the usual sampling zone in each of 18 paired cutting areas, representing the 9 replicated cutting treatments. Analysis of variance indicated no significant height differences between treatments (each pair of cuttings was considered a treatment). Neither were there any significant differences between means of the major cutting groups: strip, square, and seed tree.

Though 5-year trends suggest that seedling growth was unaffected by cutting method, the fact should be noted that fir seedlings normally develop very slowly the first 3 or 4 years of their lives before height growth accelerates. Thus, seedling heights at 5 years do not indicate the competitive effect of residual trees. Even so, seedling heights did decrease slightly with nearness to seed trees—as noted previously for ponderosa pine (Teeguarden and Gordon 1959, McDonald 1976), a species with rapid early growth. Seed trees should be removed early where fast rates of seedling height growth are important.

Special Cuttings

In the four areas cut to create uneven-aged conditions, stands are now in an overall younger and more vigorous condition than before, and small openings are nicely regenerated. Although no studies are installed there, these areas have had considerable use as demonstration units for stand manipulation.

The widening of older strip clearcuts worked out well. In all four instances, the area that was cut 2 chains into the windward edge regenerated better than the 1-chain-wide strip to leeward. Seedling stocking in 1976, measured by randomly located milacres, ranged from 42 to 66 percent of milacres at the windward locations, 20 to 56 percent at the leeward. Because all of these areas were cut in 1972, they did not benefit from the heavy seed crop of 1971.

Two areas, the so-called "snow cuttings" installed in 1971, benefited from heavy seedfall. All 4 strips and 11 circular openings are observed to be covered with reproduction. The "honeycomb" area received little wind damage, but the parallel strips did receive some; it was relatively light, but, experience suggests that considerable damage could have occurred if strong winds had hit the area. Such cuttings in unmanaged old-growth expose to wind trees known to be most susceptible to damage—mainly trees of intermediate and suppressed crown classes, close-growing pairs (which have imperfectly developed root systems, and frequently, opposing fire scars with accompanying bole rot), and trees with mechanically defective boles (those with fungal brackets, severe fire scars, and dwarfmistletoe cankers). Opportunities for study of snow on the several kinds of cuttings on the Experimental Forest will remain for many years.

Damage to Residual Stands

The damage study monitored events within one chain (20 m) of edges of 19 clearcuts, within 6 seed tree cuttings, and within 6 uncut "control" plots.

The most informative results of the damage study were these:

1. Seed tree cuttings were damaged only lightly *(table 4)*, and least of any kinds of natural regeneration cuttings tried—showing that we can successfully choose true firs which are especially resistant to damage.

2. Uncut stands adjacent to clearcut narrow strips and small squares also were damaged only lightly. There was no evidence of unusually severe damage during the study; the annual range in damage adjacent to clearcuts was about the same as that around slightly larger clearcuts in an earlier study (Gordon 1973), during years without unusual storm damage.

3. A small trial of nonstandard clearcut strip orientation produced these results:

a. Two-chain-wide strips oriented north-south and east-west did not show damage noticeably different from strips with "standard" northwest-southeast orientation.

b. A single 2-chain-wide strip oriented with its long axis southwest-northeast (parallel with the usual storm winds) illustrates the care needed to minimize potential damage from wind. The northeast end and southeast side of this area were damaged moderately by a southwest or west wind in the first winter after cutting; here, the number of trees and volume lost per acre of uncut adjacent area was more than double that of any other kind of cutting. Though based on a single instance, this exemplifies the principle that cuttings should not create narrow or restricted corridors for normal storm winds to pour into.

Two-thirds of damaged trees were red fir, one-third white fir. This approximates the proportions of both species in the stands cut. At the times tree damage was recorded, 91 percent of trees were dead, 9 percent still alive. Buprestid and Scolytid beetles were listed as causal agents in the death of 54 percent of the trees. Wind damaged 43 percent of trees, of which one-third were windthrown and two-thirds broken. Three-

Table 4—*Five-year mean total of dead and damaged trees, by cutting area type and unit of sampled area, Swain Mountain Experimental Forest, California*

Cutting area type and size[1]	Mean trees/acre	Mean volume/acre	Mean basal area/acre	Mean volume/lineal chain[2]
		Bd. ft.	Sq. ft.	Bd. ft.
Clearcut strips, oriented NW-SE:				
1 by 6 chains (2)	1.43	571	3.35	57.14
2 by 6 chains (1)	.62	94	.87	9.37
3 by 6 chains (3)	2.22	4,331	14.72	433.15
Mean (6)	1.73	2,565	9.21	256.53
Clearcut strips, oriented as shown:				
2 by 6 chains, N-S (2)	2.19	2,666	10.37	266.56
2 by 6 chains, E-W (2)	.62	1,262	4.43	126.25
2 by 6 chains, SW-NE (1)	5.00	13,219	41.67	1,321.87
Mean (5)	2.12	4.215	14.26	421.50
Clearcut squares, oriented NW-SE:				
2 by 2 chains (2)	2.50	5,562	18.56	556.25
3 by 3 chains (3)	.83	1,764	6.07	176.39
4 by 4 chains (3)	2.71	3,362	12.98	336.25
Mean (8)	2.00	3,139	11.38	313.90
All clearcuts, means:	1.94	3,246	11.45	324.64
Seed tree cuttings, leaving:				
10 trees/acre (2)	.14	169	.68	------
20 trees/acre (2)	.14	281	.98	------
30 trees/acre (2)	.42	1,104	3.66	------
Mean (6)	.23	518	1.77	------
Uncut plots (6)	1.77	2,683	9.71	------

[1] Number of replications shown in parentheses.
[2] Mean volume per lineal chain of cutting edge, clearcuts only.

fourths of the broken trees had bole rot, mostly affecting 70 to 90 percent of diameter at the break. Mycelial fans of *Armillaria mellea* were found beneath basal bark of only three damaged trees.

Distribution of damaged trees by crown class was as follows: dominant, 37 percent; codominant, 18 percent; intermediate, 20 percent; suppressed, 25 percent.

The diameter class distribution of damaged trees is compared with calculations based on Schumacher's

(1928) red fir stand table for all trees, site 50 feet at 50 years, age 160:

	Damaged trees	Stand table values
D.b.h., inches:	*Percent*	
12-20	30	24
21-30	24	38
31-40	26	29
41+	20	9

The distributions by crown class and diameter indicate that damage to residual trees, especially at cutting edges, was proportionately greater among smallest and largest trees. Some unknown amount of mortality could be attributed to normal ''breakup'' or ''deterioration'' within the old stands in which cut and uncut areas were placed. At Swain Mountain, 147,000 board feet per acre has been measured in dense old growth stands, and I would estimate that mean volume of study areas would exceed 100,000 board feet per acre. The mean volume and basal area of damage per acre *(table 4)* indicate relatively little loss, and no noticeable trends attributable to area differences.

Only a fourth of all cutting areas were included in the damage study. It is appropriate to say, then, that areas sampled appear to represent well the events which occurred elsewhere.

Damage to Seedlings

Visible damage to seedlings by animals was not great, and most of that seen was attributable to deer. Some seedlings which had been hedged more than once still appeared vigorous. On the average, browsed seedlings were about as tall as others. A few seedlings pulled up by cattle were seen lying on the ground, as if they had been pulled up accidentally with herbage and then spat out. Earth mounds of pocket gophers appeared on some cutting areas, but population of the animals never seemed great. Scarcely any damage could be assigned to them.

Details of early seedling mortality have been covered previously (Gordon 1970).

Development of Low Vegetation

During the period of study, low vegetation did not develop aggressively on most cutting areas. On the few areas where rapid revegetation occurred, sedge, small herbs, grasses, and the shrub *Ceanothus cordulatus* were the commonest plants. Development of such vegetation was mostly at locations with high water tables, such as flat benches and flat drainages. Such areas supported recognizable amounts and kinds of vegetation even beneath fairly dense old-growth tree canopies. Proliferation of that vegetation and other species occurred after logging, and after removing slash, litter, and small amounts of top soil during regeneration site preparation.

DISCUSSION

The regeneration trials reported here were designed principally for applications in even-aged management. Irregularly shaped strip or patch cuttings could be used to regenerate small isolated even-aged stands, or to regenerate larger stands by stages. Seed tree and shelterwood cuttings could be used to regenerate even-aged stands of any size. Judicious use of cutting system and pattern, and appropriate site preparation, should result in seedling stocking comparable to that reported here. Size of the regeneration units in this trial would also fit conveniently into some concepts of group selection cuttings for uneven-aged management.

No rigorous comparison can be made of seedling establishment of the two fir species on the kinds of regeneration cuttings tried at Swain Mountain. This is principally because there was no white fir seed crop that could compare in quantity with the red fir seed crop of 1971 falling on freshly prepared sites. I believe that most of the cuttings would favor establishment of red fir, which is better adapted silvically to fill those niches, especially in the tension zone occupied by both species. White fir has been shown elsewhere to be damaged by late spring frosts, and to survive better under brush or trees than in unprotected locations (Schubert 1956). Low artificial side shade alone greatly increased survival of first year white fir seedlings at Swain Mountain (Gordon 1970). But there is no information affording a clear separation of the benefits to fir seedlings of overhead plant cover as it relates to reduction of damage either from excessive insolation or frost.

All of the strip, square, and seed tree cutting areas had straight sides. This condition was created to give clearly defined uncut edges for research purposes. Ordinarily, meandered edges would give a more pleasing appearance, and allow the forester to leave the most windfirm and ''best'' seed trees there. However, narrow islands and peninsulas of trees, and deeply cut pockets, should be avoided in order to reduce the potential for wind damage.

The success of reproduction on clearcut strip widening indicates the utility of that process. A similar process has been used in other places to enlarge irregular patches of established reproduction. Cutting "toward the sun" (south) can be helpful in establishing species which have early sensitivity to strong insolation.

The success of seed tree cuttings was particularly encouraging because of new seedling abundance and the near lack of wind damage. Two other advantages then become obvious: (a) implications of wind direction have no meaning with regard to seed dispersal or potential for damage, and (b) within a stand condition appropriate for a natural regeneration cutting, size or shape of area actually cut at one time is immaterial.

Where 10 or 20 seed trees per acre were left, appearance led most visitors to agree that those areas could properly be called "seed tree" cuttings. Thirty trees per acre seemed to fit a shelterwood classification best. At that level, about half the original trees were left, constituting a "residual" stand of perhaps 40 to 50 thousand board feet per acre. This obviously cast more shade than the heavier cuttings, but absolute or relative insolation at different kinds of cuttings was not measured. These shelterwood cuttings can apppear as attractive as some uncut stands elsewhere, if slash has been eliminated.

A condition immediately obvious to observers is that where only 10 seed trees are left, only those which are phenotypically "best" are present. As progressively more trees are left, some poorer specimens must remain. The heaviest cutting, then, will leave trees which probably have best form, growth potential, and adaptation to local site factors.

Because of the abundance of seedlings on areas with 10 seed trees, I believe that cuttings down to 5 or 6 large residuals per acre should be tried. Where establishment of reproduction is the ruling purpose, only the necessary number of seed trees should be left. Then, when seed trees are removed, logging damage to seedlings will tend to be minimal.

After the third growing season, mortality of seedlings is much reduced. In an earlier study at Swain Mountain, red fir seedling survival at the end of the third, fourth, and fifth seasons was 54, 50, and 48 percent, based on number of seedlings present at end of the first season. When one or more increments of seedlings exceeds desired stocking standards for an area, seed trees should be cut, or cutting edges adjoining small clearcuts should be moved back (where stand structure allows), to remove the growth-retarding effect of large trees on seedlings in the first cutting area. An additional advantage can be gained by insuring removal of large trees at an early date: dwarf mistletoe in the overstory seldom infects trees less than 3 feet (1 m) high (Scharpf 1969). Observation of reproduction on previous study areas indicates that this height is reached at about the tenth year, so seed trees should be removed between the third and tenth years after establishment of adequate reproduction.

Dwarf mistletoe infection is present in the few cutting areas described as having stand structure which is uneven-aged, or even-aged by small groups. There would seem to be no easy way to eliminate the infection from such areas. This may limit the applicability of selection systems, especially where infection rate is heavy, and tree growth remains slow due to competition in dense stands. But where silvicultural treatment allows trees to grow rapidly, dwarf mistletoe may have only an inconsequential effect (Scharpf and Parmeter 1976).

Because of past difficulty in securing adequate natural regeneration in true fir cuttings, research emphasis has been directed toward developing means for attaining it. One concern has been that too many seedlings may become established, and that stagnated thickets could develop. Observation of seedling, sapling, pole, and larger-sized tree groups still indicates that where there is no suppression by larger trees, rapid-growing dominant stems will develop to occupy available space. Suppression and mortality will occur among the poorer stems. At some stages of development, artificial thinning may increase or sustain growth rate of residual stems, but economic feasibility will also need study. Where deep snow packs are the rule, permanent stem bending or breaking by snow loading causes mortality, especially among weaker trees, but stocking by dominants usually remains satisfactory.

Heavy establishment of low forms of vegetation occurred on only a few cutting areas in these studies, and appeared not to have influenced fir seedling stocking. We cannot yet predict species or time of abundant development for most areas. There is certainty, however, that seeds of plants of lower successional stages lie stored in the forest floor for perhaps 300 years (Quick 1956). When a dense tree overstory is removed, conditions become favorable for germination of some or all of the stored seeds. A recent survey of 32 red fir cutting areas scattered widely in northern California (Gordon and Bowen 1978) indicated the diversity of vegetation to be expected, and that sampling vegetation on uncut areas results in poor predictions of plants of earlier successional stages which will appear on cut areas. Foresters must begin to build a body of empirical data for vegetation to be expected on specific areas.

Although low vegetation has not been aggressive on most cutting areas in these studies, plants are there, and will continue to develop—at least for a few years, until new young tree growth becomes so dense as to force them out again. That these low forms of vegetation may afford early and adverse competition with seedlings for soil moisture is one side of a coin. The other side is that these plants have a potential function as wildlife food and habitat, and as food for domestic livestock.

Slash disposal is closely related to regeneration results reported here. The most imperative need is for preparation of a loose mineral soil seedbed. Fire prevention needs are secondary. There is no necessity for a new young tree on every milacre of ground in a regeneration area. Therefore, some form of partial slash disposal is all that is required. Only enough mineral soil need be exposed to ensure a predetermined minimum count and distribution of new seedlings. (How much is enough will become evident in practice.) Large cull logs should be eliminated wherever residual trees are to be cut and removed within a few years, merely to reduce tree breakage when next felling occurs. Fine slash might be removed to expose mineral soil in strips alternated with fines left in place. A bulldozer with angled blade could work along contours, meandering between stumps or live trees, throwing slash to one side. Almost continuous forward motion of the machine should make such a system inexpensive. Effective slash disposal and site preparation methods and costs probably differ considerably from those which will be necessary when forests are managed completely and intensively.

CONCLUSIONS

The natural regeneration studies at Swain Mountain Experimental Forest have shown that high rates of red fir seedling stocking and adequate rates for white fir can be achieved through proper use of several cutting systems and patterns. Silviculturists can use those tried systems with confidence. The two most basic considerations in attaining regeneration goals are provision for (a) abundant seed supply and (b) a mineral soil seedbed. Effects of vegetation development and of damage from wind and other agents were negligible under the conditions created by the study.

LITERATURE CITED

Church, J.E.
1933. **Snow surveying: Its principles and possibilities.** Geog. Rev. 23(4):529-563.

Dunning, Duncan
1942. **A site classification for the mixed-conifer selection forests of the Sierra Nevada.** U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 28, 21 p. Berkeley, Calif.

Gordon, Donald T.
1970. **Natural regeneration of white and red fir . . . influence of several factors.** USDA Forest Serv. Res. Paper PSW-58, 32 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

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

Gordon, Donald T., and Eugene E. Bowen.
1978. **Herbs and brush on red fir regeneration areas.** Res. Note PSW-329, 10 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S.Dep. Agric., Berkeley, Calif.

Hallin, William E.
1951. **Unit area control in California forests.** U.S. Forest Serv., Calif. Forest and Range Exp. Stn. Res. Note 77, 7 p., Berkeley, Calif.

McDonald, Philip M.
1976. **Inhibiting effect of ponderosa pine seed trees on seedling growth.** J. For. 74(4):220-224

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

Scharpf, Robert F.
1969. **Dwarf mistletoe on red fir . . . infection and control in understory stands.** USDA Forest Serv. Res. Paper PSW-50, 8 p., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Scharpf, Robert F., and John R. Parmeter, Jr.
1976. **Population buildup and vertical spread of dwarf mistletoe on young red and white firs in California.** USDA Forest Serv. Res. Paper PSW-122, 9 p., illus., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

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

Schumacher, Francis X.
1928. **Yield, stand and volume tables for red fir in California.** Univ. Calif. Agric. Exp. Stn. Bull. 456, 29 p. Berkeley, Calif.

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

Teeguarden, Dennis E., and Donald T. Gordon.
1959. **A precommercial thinning in ponderosa and Jeffrey pine.** J. For. 59(12):900-904.

Gordon, Donald T.
1979. **Successful natural regeneration cuttings in California true firs.** Res. Paper PSW-140, 14 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

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Retrieval Terms: cutting methods; slash disposal; seedbed preparation; damage; seedling stocking; seed; white fir; red fir; Swain Mountain Experimental Forest; natural regeneration.

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