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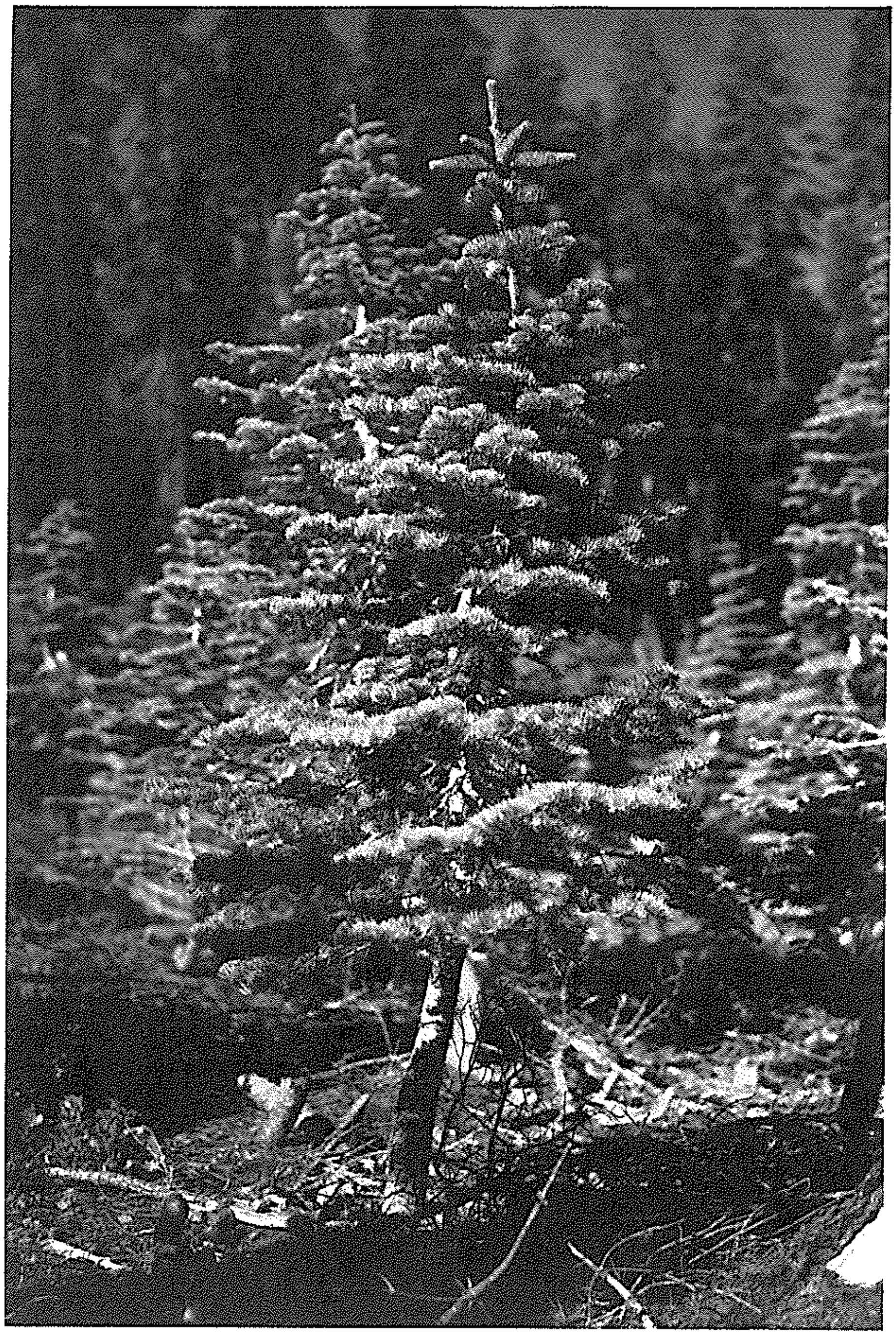
Growth of California Red Fir Advance Regeneration After Overstory Removal and Thinning

William W. Oliver



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IN BRIEF...

Oliver, William W. **Growth of California red fir advance regeneration after overstory removal and thinning.** Res. Paper PSW-180. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1985. 6 p.

Retrieval Terms: California red fir, *Abies magnifica*, advance regeneration, tree growth, damage, mortality

Advance regeneration is common under decadent, old-growth stands of California red fir (*Abies magnifica* A. Murr.). Intense competition for the site's resources can create sapling stands of poor vigor and advanced age. When competition is reduced by overstory removal and thinning, suppressed advance regeneration has been shown to respond with increased growth. But, to select leave trees, land managers need to know which tree characteristics are associated with growth after release and thinning. This paper reports those easily measured tree characteristics found to be most closely associated with growth after 8 years, on the Swain Mountain Experimental Forest in northeastern California.

About 400 saplings were monitored after removal of the overstory and thinning on 10 acres, at 6700 ft (2044 m) on the northeast face of Swain Mountain. At this elevation, most of the annual precipitation falls as snow, which usually accumulates to a depth of 6 ft (1.8 m). Site index is 45 ft (14 m) at 50 years.

After trees were thinned to a 6-ft (1.8-m) spacing, about 200 were chosen randomly within 10 study plots to obtain at least nine trees each in nine live crown ratio classes from 10 to 90 percent. A variety of stem and crown characteristics expected to be related to growth was measured on the sample trees, which averaged 1 inch (2.5 cm) in diameter at breast height (d.b.h.), 6.8 ft (2.1 m) tall, and 60 years old. Also, measured annually for d.b.h. only were 200 other saplings of similar size that were randomly selected from among well-formed dominant and codominant trees.

Rates of d.b.h. and height growth increased for most saplings during the 8 years of observation. According to the criteria used, variation in diameter growth was explained best by the easily measured characteristics: 3-year height growth before thinning (3-YHG), the product (PLC • CD) of percent live crown (PLC) and crown diameter (CD), and initial d.b.h. (ID). For height growth, the most effective variables by the same criteria were 3-YHG and PLC • CD. These variable sets were chosen for each of four response periods—0 to 2, 0 to 4, 0 to 6, and 0 to 8 years after thinning. Although regressions were highly significant ($p < 0.01$) for all periods, unexplained variation was high and increased as the period after thinning lengthened. For the 8-year period, the 95 percent confidence limit about the mean was 0.5 to 2.4 inches (1.3 to 6.1 cm) for diameter growth and 0.1 to 4.5 ft (0.03 to 1.37 m) for height growth. These wide ranges of values make predictions based upon the equations unreliable.

Annual precipitation, an uncontrollable variable, affected growth of those trees measured annually for d.b.h. But the effect was negative: more precipitation was associated with less growth in d.b.h. This startling result probably is caused by lingering snowpacks, which critically shorten the growing season.

Although reliable equations to explain growth were not developed, PLC alone may serve as a rough guide for selecting leave trees. Sample trees with PLC of 40 or more suffered less postrelease damage and responded with increased rates of diameter and height growth. Mortality and damage were, in general, more prevalent in trees with smaller PLC. Trees with 20 PLC had an estimated mean mortality rate four times that of deeper-crowned trees. Wounds incurred in logging the overstory were slow to heal. And recent snow bend was four times more prevalent in trees with 30 PLC or less than it was in deeper-crowned trees. Sunscald, seemingly an ideal entry point for rot fungi, was also related to PLC. As a general guide, vigorous, well-formed dominants and codominants with 40 PLC or greater is suggested for choosing potential crop trees in similar stands.

Choosing this advance regeneration shortened the rotation length for the next crop by about 12 years compared with post-harvest regeneration. But before deciding on regeneration, the land manager should weigh the cost of precommercial thinning and the threat of future decay against the savings in rotation length, site preparation, and planting.

INTRODUCTION

Old-growth California red fir (*Abies magnifica* A. Murr.) stands often contain advance regeneration, which tends to form dense clumps of small trees under openings in the overstory. Competition within these clumps and with the overstory for sunlight, moisture, and nutrients can be severe. When competition is reduced, red fir advance regeneration responds well (Gordon 1973).

Advance regeneration, adequately spaced, can shorten the rotation needed for artificial regeneration and reduce the need for site preparation and planting. But if the trees are unable to respond to release, are injured by the release, or if response is long delayed, a shorter rotation and greater yield may be achieved by artificial regeneration. To select leave trees, forest managers need to know what tree characteristics are associated with growth after overstory release and thinning of clumps.

This paper describes the 8-year growth of suppressed red fir saplings after overstory removal and thinning of one stand in the southern Cascade Range of northern California. Crown and stem characteristics were tested for their correlation with growth after stand treatment. Stem defects that seem to be associated with thinning of suppressed advance regeneration are also discussed. Comparison with similar studies conducted elsewhere suggests that the results reported here have wide application.

STUDY AREA

The study area was on the Swain Mountain Experimental Forest, Plumas County, California. The area (lat. 40°25′ N. long. 121°6′ W.) lies near the summit, on the northeast face of Swain Mountain, at an elevation of 6700 ft (2044 m). Study trees were within a 10-acre (4-ha) area on slopes that range from nearly level to about 30 percent.

Average annual precipitation probably is more than 46 inches (1168 mm). Most of the precipitation between November and April falls as snow, which reaches a maximum depth of at least 6 ft (1.8 m) about April 1. Data were recorded by a 200-inch Sacramento-type storage gauge located 1½ miles (2.4 km) north of and 500 ft (152 m) lower in elevation than the study area. Both precipitation and snow depth were measured at elevations lower than the study area and, because precipitation and snow depth increase with increasing elevation in this area, the actual amounts may be greater at the study area.

The soil, derived from Pleistocene basalt, is similar to the Windy Soil Series (cindery, frigid, Typic Dystrandepts). Site index is 45 ft (14 m) at 50 years (Schumacher 1928).

A decadent overstory of old-growth red fir was removed in 1960, yielding 38,000 board feet (Scribner) per acre—about half the volume found in most stands in the experimental forest. A dense stand of suppressed saplings remained. When the study was begun 12 years later, an examination of past height growth indicated little growth since overstory removal, probably because sapling stand density was high— 9700 stems per acre (23,950 per ha), on the average.

Dwarf mistletoe (*Arceuthobium abietinum* f. sp. *magnificae*), the only threatening pathogen, infected the surrounding old growth and the larger poles scattered throughout the stand. Trees sampled in this study were free of infection. Stem deformities caused by heavy snow loads were ubiquitous; more than half of the trees had butt sweep, a deformity common in sapling stands on similar slopes at this elevation (Leaphart and others 1972).

EXPERIMENTAL DESIGN

In dense portions of the stand, 10 plots, 0.2-acre (0.08 ha) in size, were arbitrarily established as part of a spacing study. Pretreatment stand density and mean tree height were estimated from two 0.01-acre (0.004-ha) sample plots located at random within each 0.2-acre (0.08-ha) spacing plot.

In fall 1972, the plots were thinned from below to a uniform spacing of 6 by 6 ft (1.8 by 1.8 m). This "calibration" thinning was designed to improve vigor and remove differences in growth response caused by high stand density. Wherever possible, well-formed dominant and codominant saplings with live crown ratios of 50 percent or greater were selected as leave trees. But because such trees often were missing in areas with high stand densities, suppressed saplings with short crowns were chosen to obtain the required spacing.

For this study, trees were chosen at random from throughout the 10 thinned plots. Suppressed saplings were chosen in many areas where prethinning stand densities had been high. At least nine trees each in nine live crown ratio classes from 10 to 90 percent were selected. Sample trees varied in height from 5 to 12 ft (1.5 to 3.7 m). To determine live crown ratio, crown length was measured from the first whorl of live branches to the top of the tree, and was expressed as a percent of measured tree height. Percent of total height in live crown generally is believed to influence tree growth (Scharpf 1979) and to reflect the competitive position of the tree in the stand. Therefore, by selecting sample trees from a wide range of live crown ratio classes, a wide range of competitive states from suppressed to free-growing should also be selected. Selected trees were 1 inch (2.5 cm) in diameter at breast height (d.b.h.) and 6.8 ft (2.1 m) in height, on the average (*table 1*).

One sample of about 200 trees was tagged and the following were recorded:

• Stem d.b.h. to the nearest 0.1 inch (0.25 cm).

• Total height and 3-year growth before thinning, measured to the nearest 0.1 ft (0.03 m).

• Live crown—height to the first all-living whorl, and crown diameter recorded as the average of two readings taken at right angles—to the nearest 0.1 ft (0.03 m).

• Distance from stump of overstory tree if less than 20 ft (6 m). Distances greater than 20 ft were recorded as 20 ft.

• Epicormic branching and damage, by causal agent.

D.b.h., height growth since the previous measurement, and epicormic branching and damage were recorded biennially for 8 years. Crown volume was estimated as the volume of a cone with base equal to crown width and height equal to crown length. After the final measurement, sample tree stems were severed at ground line and a disk removed to the laboratory for determination of total age.

In another sample, for best crop trees, 200 saplings with diameters of 1 inch (2.5 cm) and live crowns of 60 percent—on the average—were selected at random from throughout the well-formed dominant and codominant component of each of the 10 thinned plots. D.b.h. was measured annually.

DATA ANALYSIS

Of the many variables that affect growth of trees after thinning, I considered only a few that I judged would be useful in identifying potential crop trees. All possible subsets and some squared transformations and combinations of the following independent variables were tested for those trees living through each of the four periods:

• Live crown percent
• Height growth for the 3 years before thinning
• Crown diameter
• Crown volume
• Total height
• D.b.h.
• Age
• Distance from stump of overstory tree

Criteria for selecting the subsets that best explained the variation in height and d.b.h. growth were these: the statistics R^2 and Cp; those with fewest terms; ease of measuring the variables in the field; and, consistency of the subsets' correlation for all periods. The synthesis of these criteria necessarily caused the choice of subsets to be partially subjective. Coefficients for multiple linear equations of the form

$$Y = b_o + b_1x_1 + b_2x_2 \ldots + b_nx_n$$

were calculated for each period and dependent variable. Because of the problem of repeated measures, separate equations were calculated for each period.

Sample correlation coefficients were calculated for other suspected relationships such as diameter growth versus precipitation and various damaging agents versus percent live crown.

Table 1—*Mean characteristics of California red fir advance regeneration immediately after thinning and live trees at the end of the study, by live crown classes, in northeastern California*

Live crown class (pct)	3-year height growth before thinning	D.b.h.	Height	Crown diameter	Age	Live trees at end of study
	Ft	*Inches*	*Ft*	*Ft*	*Yr*	
10	0.12	0.74	5.9	2.3	60	9
20	.28	.98	6.6	2.7	63	16
30	.47	1.22	7.3	2.9	62	24
40	.79	1.31	7.5	3.2	62	21
50	.79	1.03	6.7	3.0	59	21
60	1.06	.98	6.9	3.2	55	19
70	1.39	.83	6.7	2.8	47	28
80	1.50	.79	6.5	2.8	34	20
90	1.89	.79	6.6	2.9	28	28

RESULTS

Variables and Growth

Two subsets of variables, one for d.b.h. and another for height, were selected to explain variation in growth after thinning (*table 2*). For d.b.h. growth, the variables included 3-year height growth before thinning (3-YHG), the product (PLC • CD) of percent live crown (PLC) and crown diameter (CD), and initial d.b.h. (ID) (*fig. 1*). For height growth, the most effective variables were 3-YHG and PLC • CD.

Table 2—*Coefficients of equations explaining growth in diameter at breast height (d.b.h.) and height of California red fir advance regeneration for four periods after thinning, in northeastern California*

Period after thinning (years)	3-YHG[1] (b_1)	PLC • CD[2] (b_2)	ID[3] (b_3)	Intercept (b_0)	Mean (Y)	R^2 adjusted	Standard error of the estimate
	Y = d.b.h. growth for period						
0–2	0.0362	0.0006	−0.0211	0.0711	0.21	0.60	0.0943
0–4	.0494	.0012	.0064	.2734	.55	.58	.1841
0–6	.0410	.0016	.1222	.4100	.86	.40	.2585
0–8	.0414	.0021	.1991	.6225	1.22	.33	.3692
	Y = height growth for period						
0–2	0.0771	0.0010		0.0834	0.37	0.65	0.1634
0–4	.0852	.0029		.2926	.90	.43	.4315
0–6	.0680	.0048		.6379	1.54	.27	.8029
0–8	.0526	.0066		1.0895	2.28	.24	1.0965

[1]3-YHG = Height growth in feet for the 3 years before thinning.
[2]PLC • CD = Product of live crown in percent and crown diameter in feet.
[3]ID = Initial d.b.h. (inches).

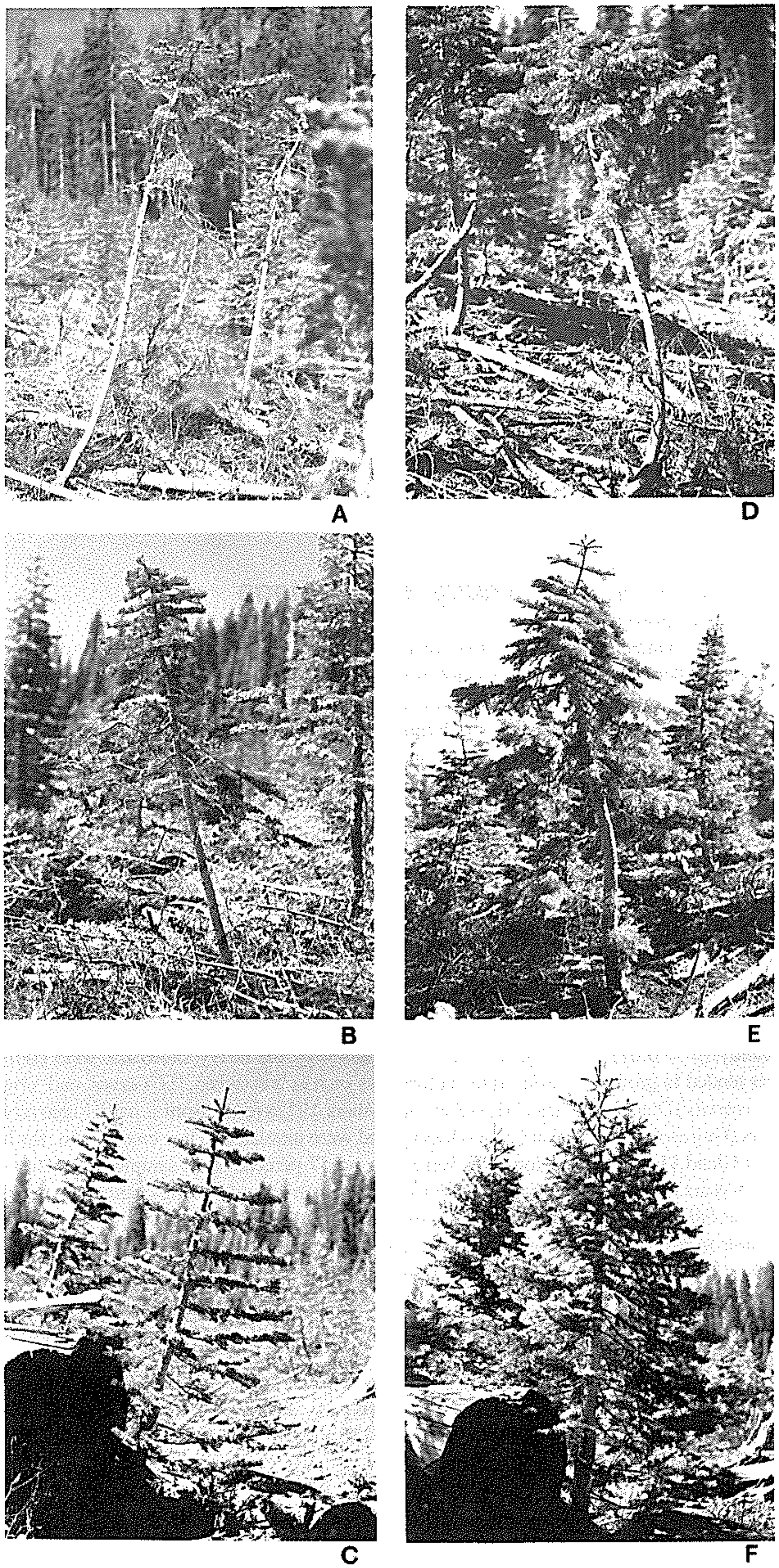

Figure 1—Growth response of California red fir saplings was related to percent live crown (PLC) and 3-year height growth before thinning (3-YHG). Immediately after thinning, (A) PLC was 10 percent and 3-YHG was 0.1 ft, (B) PLC was 50 percent and 3-YHG was 0.5 ft, and (C) PLC was 80 percent and 3-YHG was 1.1 ft. Six years later, these same trees had grown in diameter at breast height (d.b.h.) and in height: (D) 0.4 inch in d.b.h. and 0.2 ft in height, (E) 0.9 inch in d.b.h. and 1.4 ft in height, and (F) 1.3 inches in d.b.h. and 3.3 ft in height.

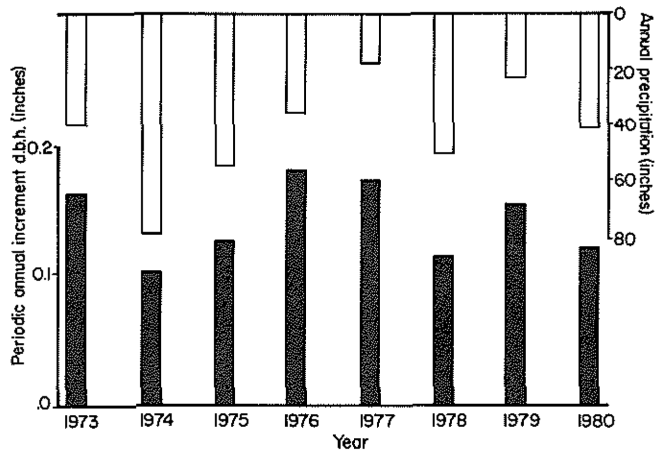

Figure 2—When annual precipitation was less, California red fir saplings grew more in diameter at breast height (d.b.h.), at Swain Mountain Experimental Forest, 1973–1980.

The variables explained more of the variation, and the standard error of the estimates was less when the growth period after thinning was short. For the first 2 years after thinning, the variables explained 60 percent of the variation in d.b.h. growth. Explained variation fell steadily to 33 percent and the standard error of the estimate rose steadily with longer periods after thinning.

These measures of fit were similar for height growth. For the 2 years after thinning, the variables explained 65 percent of the variation. Explained variation fell to 24 percent and the standard error of the estimate rose with longer periods after thinning. Although coefficients of multiple correlation were significant ($p < 0.01$), the variables explained only about one-fourth of the variation in height growth, and the standard error of the estimate increased to more than 0.8 ft (0.24 m) for periods longer than 4 years after thinning.

Total ages of red fir saplings ranged from 10 years, for some trees originating after the overstory was removed, to 97 years. The age of the vast majority (71 pct) of the saplings, however, ranged from 50 to 70 years. Age was significantly ($p < 0.01$) correlated with growth measures. Younger trees tended to grow faster than did older trees. Neither grand fir (*A. grandis* [Dougl. ex D. Don]) in northern Idaho older than 30 years (Ferguson and Adams 1980) nor white fir (*A. concolor* [Gord. & Glend.] Lindl. ex Hildebr.) in northern California older than 45 years (Helms and Standiford 1985) responded to release as well as did younger trees. Nevertheless, age was not chosen as a variable in the equations for two reasons: it was correlated with two of the chosen variables, 3-YHG and PLC; and, age is difficult to measure in the field. Determining age of suppressed saplings is difficult even under ideal conditions because annual rings often are narrow.

Precipitation and Diameter Growth

One uncontrollable variable that accounts for some of the unexplained variation in growth response is precipitation. From the sample of 200 best crop trees measured yearly for d.b.h., annual precipitation was correlated ($r = 0.79$, $p < 0.05$) with mean growth, as expected; but, the correlation was negative—more precipitation was associated with less growth in d.b.h. (*fig.* 2).

The reason for this startling result is not clear, but length of growing season seems likely to be the cause. In the study area, the snowpack often lingers into early summer, delaying the start of growth of sapling red fir. The approximate date when height growth starts, which immediately follows the start of cambial activity, was observed in 3 of the 8 years of the study. In 2 years with above-normal precipitation, shoot growth was delayed until July 10 (1974) and July 1 (1975). Whereas in 1979, a dry year, shoot growth began a month earlier on June 8. Upland conifers tend to require a photoperiod longer than 12 hours for active growth,[1] and a growing season of at least 3½ months for maximum d.b.h. growth (Fowells 1941). A delay in growth initiation until July may cause the growing season to be truncated by short days because effective day length becomes shorter than 12 hours in less than 3 months.

Mortality and Damage

Eight trees died during the 8 years of the study. Cause of death often was not determined but probably was the result of several factors. The most prevalent predisposing factor probably was shock from thinning around weak trees. All but one of the dead trees had live crowns of 20 percent or less.

Much of the advance regeneration was unavoidably damaged in logging the overstory. When the study began 12 years later, open basal wounds were still common, especially on saplings with live crowns of 40 percent or less. Of all such saplings sampled, 31 percent had open wounds. These wounded saplings represented two-thirds of all wounded trees in the study. At the end of the study, 8 years later, incidence of sample trees with open wounds had declined to 7 percent, overall, from the initial 18 percent. Of the trees with logging wounds still open, 85 percent were in live crown classes of 40 percent or less.

Stem deformities caused by the heavy snowpack were common. Many deformities such as butt sweep, "S" curves, and "dog legs" (Leaphart and others 1972) result from a partial recovery from snow damage and were unrelated to live crown ratio. Such deformities were seen on 37 percent of all sample trees. However, recent snow bend, which caused leaning or prostrate trees, was related to live crown ratio. Of the sample trees with live crowns of 30 percent or less, leaning trees averaged 14 percent at each measurement—nearly four times the sample proportion found for trees with live crowns of 40 percent or more.

The original overstory of old-growth red fir was decadent. Many stumps showed rot. And conks of *Heterobasidium annosum* root disease were identified in cavities of stumps with heart rot. Because infection can spread to nearby regeneration through root contacts, I suspected root disease might inhibit

[1]Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Redding, California.

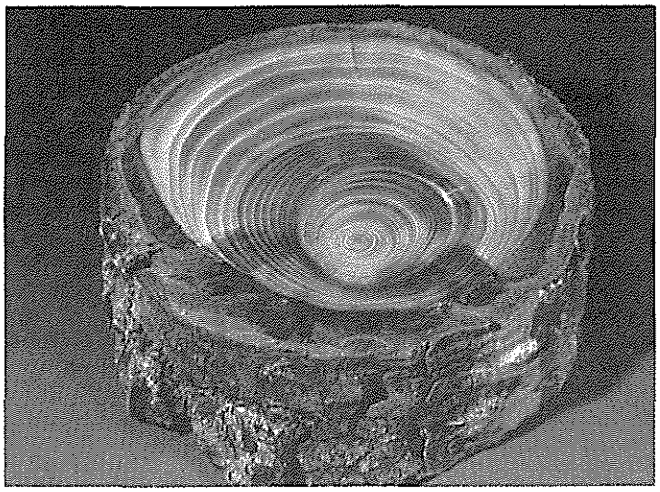

Figure 3—Sunscald immediately kills the cambium, but the bark remains nearly intact and would seem to provide a favorable environment for rapid fungal growth.

growth in some trees. Distance from old-growth stumps, however, was not correlated with measured growth.

Thinning dense stands of trees with short live crowns suddenly exposes many stems to insolation. The cambium on the south and southwest sides of thin-barked trees, such as sapling red fir, often dies when exposed suddenly to full insolation (Levitt 1980). In this study, sunscald and epicormic branching were common and were related significantly ($p < 0.01$) to percent live crown. It explained 82 percent of the variation in sunscald and 77 percent of that in epicormic branching. About one-fourth of the sample trees with less than 20 percent live crowns suffered sunscald. For trees with larger crowns, incidence of sunscald fell to an unimportant 5 percent or less for trees with live crowns of 70 percent or larger.

Sunscald causes an immediate stem defect because the cambium is killed, but the long-term defect can be more serious. Sunscald wounds would seem to be ideal entry points for rot fungi. The bark cracks, allowing spores to enter the wound, and because the bark remains nearly intact (*fig. 3*), the wound provides a moist environment for rapid fungal growth. Also, retention of bark over the wound impedes callus formation. Fungi were not isolated from sunscald wounds, however.

A common response to release of the more severely suppressed red fir saplings was epicormic branching. And those trees with restricted cambial activity, i.e., suppressed trees, are especially prone to such branching (Kozlowski 1971). White fir produces epicormic branches so profusely that pruning to improve lumber quality is not feasible (Cosens 1952). Epicormic branching—to my knowledge—has not been previously reported in red fir. Indeed, pole-size and larger crop trees of red fir may produce epicormic shoots only rarely. The epicormic shoots I observed on suppressed saplings may be ephemeral only. Many shoots were dying 8 years after thinning.

The proportion of saplings exhibiting epicormic branching in the sample was summarized by live crown classes. About 70 percent of all saplings with live crowns of 60 percent or less produced epicormic shoots. Incidence of shoots dropped to less than 25 percent for saplings with full crowns.

DISCUSSION AND CONCLUSIONS

The variables did not explain adequately the observed variation in growth of red fir advance regeneration after thinning. Even in the best equations, those for the initial 2-year period after thinning, the variables explained less than two-thirds of the variation in d.b.h. and height growth.

Explanations of growth increase in usefulness with time after release and thinning. Ideally, the land manager would wish to know the growth of saplings up to time of first commercial entry. But in the study reported here, the variance increased with length of period after thinning: for the 8-year period, the 95 percent confidence limit about the mean was 0.5 to 2.4 inches (1.3 to 6.1 cm) for diameter growth and 0.1 to 4.5 ft (0.03 to 1.37 m) for height growth. This range of values is of little use to the land manager. Growth of well-spaced, suppressed grand fir saplings after overstory removal in central Oregon also could not be reliably explained (Seidel 1980).

I found both tree age and precipitation to be strongly correlated with growth. But age of advance regeneration is difficult to measure in the field and precipitation cannot be known in advance.

The easily measured independent variables that were most strongly correlated with growth—pretreatment height growth and percent live crown—were found to be strongly correlated, either singly or in combination, with growth in similar studies of true fir in the West (Ferguson and Adams 1980, McCaughey and Schmidt 1982, Scharpf 1979, Helms and Standiford 1985). Although widely used, these variables may be too crude to identify the potential vigor and photosynthetic capacity of suppressed saplings in some situations. Further investigations will be necessary to develop adequate predictive equations.

Although the equations were unreliable, growth during the 8-year period averaged by percent live crown classes suggest that PLC may be a rough but useful guide for selecting leave trees when thinning. Minimum rates of growth for nonsuppressed red fir on sites of similar indices in northern California seem to be 0.15 inch (0.4 cm) in d.b.h. and 0.3 ft (0.01 m) in height, annually (Gordon 1973, Powers 1979).[1] Of the trees in this study with PLC of 30 or less, only 30 percent exceeded this minimum rate for d.b.h. growth and only 5 percent exceeded this minimum rate for height growth during the 8-year period. Deeper crowned sample trees (PLC of 40 and greater) grew more rapidly. Many sample trees reached or exceeded these minimum values for periodic annual increment (PAI): 56 percent for diameter and 41 percent for height. Growth rates found elsewhere may not apply to the trees in this study because slope direction and steepness as they affect depth and movement of snowpack may result in different growth rates for red fir saplings (Leaphart and others 1972, Williams 1966). These site differences are of less consequence to larger trees such as those measurable for site index. Nevertheless, these minimum PAI's provided rough target growth rates for evaluating the performance of the sample trees in this study.

Aside from growth, sample trees with larger live crowns withstood the sudden exposure resulting from thinning with less snow bending, and were sufficiently vigorous to heal more logging wounds during the study period than were sample trees with smaller live crowns. Nevertheless, many healed wounds—particularly at ground line—may be infected with rot fungi as were about half of the wounded grand fir and white fir examined in Washington and Oregon (Aho and Filip 1981). Sunscald was linearly related to PLC. In the study reported here, if only those trees with PLC of 40 or more had been chosen as potential crop trees, incidence of sunscald injury would have been 19 percent or less.

Saving advance regeneration for the next crop can shorten the rotation length compared with that required after establishing new trees. Observations of height growth of nonsuppressed saplings that originated in skid roads after overstory removal suggest that about 12 years may be saved by retaining the better advance regeneration as future crop trees. These saplings reached the same height—6.8 ft (2.1 m)—as the initial height of sample trees with PLC of 40 or more, in 12 years. Despite savings in rotation length, site preparation, and planting costs, advance regeneration requires costly precommercial thinning and poses the threat of future decay—especially if crop trees have been wounded. A final decision on whether to use advance regeneration for the next crop must consider both these advantages and disadvantages.

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Oliver, William W. **Growth of California red fir advance regeneration after overstory removal and thinning**. Res. Paper PSW-180. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1985. 6 p.

Overstory removal and thinning can reduce competition and increase growth of advance regeneration under old-growth California red fir (*Abies magnifica* A. Murr.). To guide selection of leave trees, land managers need to know which tree characteristics are associated with growth after release and thinning. Periodic growth in diameter and height was tested for its relationship to stem and crown characteristics of about 200 red fir saplings in a stand in northeastern California. Strongest correlations were between growth and the independent variables percent live crown and 3-year pretreatment height growth. Although the correlations were statistically significant ($p < 0.01$), unexplained variation was too high for reliable predictions. Lacking a more precise guide, virgorous, well-formed dominants and codominants with a percent live crown of 40 or greater are suggested for potential crop trees in similar stands.

Retrieval Terms: California red fir, *Abies magnifica*, advance regeneration, tree growth, damage, mortality