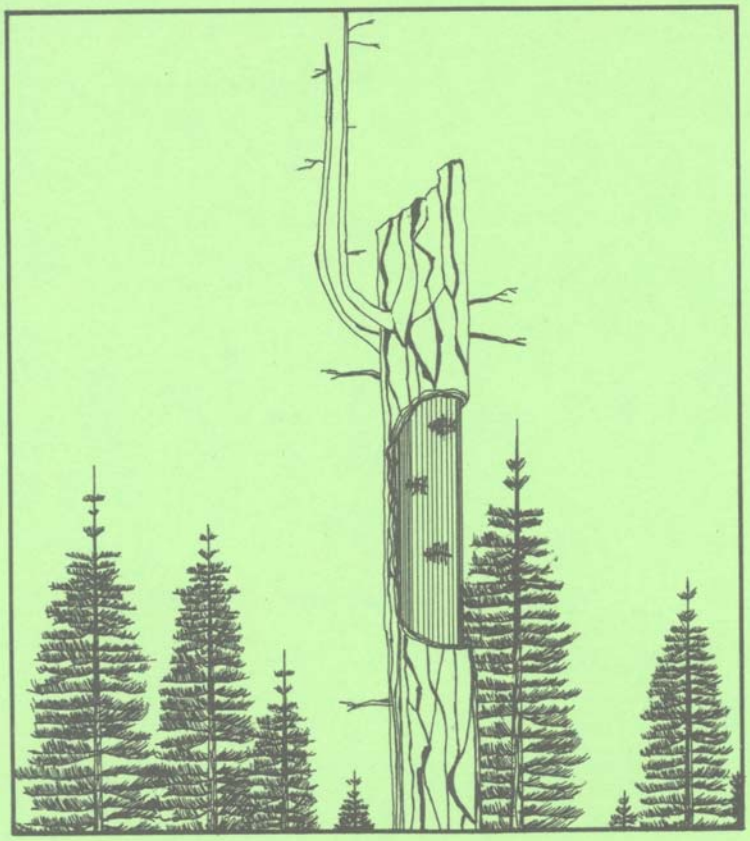
PACIFIC SOUTHWEST Forest and Range Experiment Station.

FOREST SERVICE.
U. S. DEPARTMENT OF AGRICULTURE
P.O. BOX 245, BERKELEY, CALIFORNIA 94701



Stand and Tree Characteristics Influencing Density of Fir Engraver Beetle Attack Scars in White Fir

George T. Ferrell

USDA FOREST SERVICE RESEARCH PAPER PSW- 97 /1973

CONTENTS

SUMMARY

Ferrell, George T.
1973. **Stand and tree characteristics influencing density of fir engraver attack scars in white fir.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 00 p., illus. (USDA Forest Serv. Res. Paper PSW-97)

Oxford: 453–145.7x19.92: 174.7 *Abies concolor.*
Retrieval Terms: Abies concolor; Scolytus ventralis; predator-host relations; damage indexes; attack scars; tree vigor; host resistance; host tree mortality; risk rating; lumber defects.

A total of 530 living white fir was felled along transects through two virgin, old-growth stands in central California, and stem cross-sections were examined for embedded scars resulting from past fir engraver *(Scolytus ventralis)* attacks. An additional 41 living "high-risk" fir, and 32 fir recently killed by the fir engraver were similarly examined within two cutover stands in northern California.

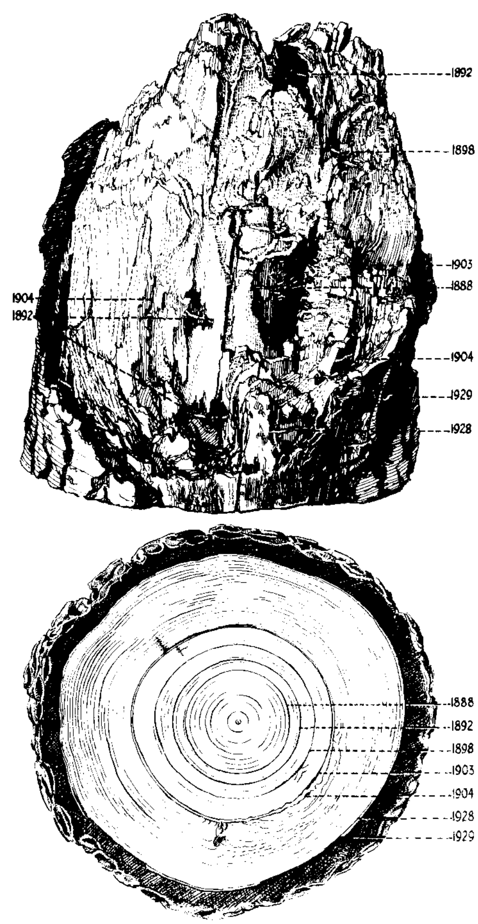
The mean density of scars formed per 10 cu. ft. per decade was obtained by dividing the number of scars found in each cross-section by its volume and age. Mean scar densities were compared in fir according to crown class, whether trees were living or killed by fir engravers, quality of growing site (site class), and percentage of the stand removed by past logging.

Mean scar densities were found to be directly related to percentage of mature stand removed by logging. An inverse relationship was found between scar density and site quality.

Mean scar densities were higher in suppressed and intermediate trees compared to dominant trees, so that inverse relationships with the following characteristics associated with crown class were evident: diameter, height, age, volume, and mean growth rate.

The highest scar densities were found in intermediate and suppressed fir recently killed by the fir engraver in a heavily cutover stand growing on the lowest quality site studied (Site II-III). High density of the scars was interpreted to be primarily an indication of decreased resistance to fir engraver attack in the past.

It appears possible to develop a risk rating system for identifying white fir with decreased resistance to fir engraver attack, based on tree and stand characteristics such as growth rate, crown class, site class and logging history. Such a system would allow selective removal of high risk fir, thus reducing future mortality from fir engraver attacks. Another possible use might be the identification of fir with large amounts of lumber defects caused by high scar density.



The fir engraver *(Scolytus ventralis* Lec.*)* attacks the main stems of true fir *(Abies* spp.*)* in western North America. This bark beetle mines and oviposits in the cambial zone of standing trees and in recently cut logging slash. Heavily attacked trees usually die, but often only the top, or strips and patches of the bole, are killed. If the tree survives the attack, the invasion of the insect and associated microorganisms results in a necrotic lesion that is healed over by the surrounding living tissues. The attack scar is visible in stem cross sections as a darkly stained segment of the annual ring, so that the year of attack is readily determinable. The embedded attack scars provide a long-term record of fir engraver attack activity, as the scars are often numerous in individual fir, indicating that the tree has been repeatedly attacked over many years of its life *(fig. 1)*.

Analysis of the scars embedded in living and recently killed fir indicated that fluctuations in scar abundance were directly correlated with trends in the volume of fir timber killed by the fir engraver over a 15-year period. This suggested that the scars could be used as an index to past levels of fir damage and fir engraver populations where such data are lacking (Ferrell 1973). The analysis also provided insight into the causes of fir engraver outbreaks. The scars were more abundant in years of drought when fir growth rates were below normal or declining, especially when the stands were being logged under these conditions. Also, the scars in the dead trees rapidly increased in frequency in the narrow annual rings formed in the last few years before the fir were killed by the insect. These results agreed with those of Felix *et al.* 1971, who found that the embedded attack scars were more abundant in tops of fir heavily infected by true mistletoe, especially during drought years, than in uninfected fir. These observations support the conclusion that the scars provide a long-term record of the interaction between the beetles and their host.

In addition to providing information on past levels of host resistance, beetle populations, and host tree mortality, the old fir engraver attack scars cause lumber defects such as stain, ring-shake, and decay (Johnson and Shea 1963; Struble 1957). Knowledge of the scar distribution promises to be useful in predicting the amount of these defects to be expected from various trees and stands.

Both Struble (1957) and Stevens (1971) suggested that silvicultural methods of controlling the fir engraver seemed most promising, but indicated that this is presently impractical because it is difficult to identify those fir most vulnerable to the beetles before they are killed.

This paper reports the distribution of fir engraver attack scars in relation to stand and tree characteristics of white fir in California. The purpose of the study was to develop methods of identifying fir particularly vulnerable to fir engraver attack and the resulting stem defects.

STUDY SITES

Four plots, differing in site quality, in the extent of past logging activity, and in the criteria used for selecting sample trees, were established in uneven-aged mixed conifer stands, with white fir *(Abies con-color* [Gord. and Glen.] Lindl.*)* as a major component.

Old-Growth Plots

Two sites were sampled more than 50 years ago by pathologists of the California (now Pacific Southwest) Forest and Range Experiment Station, who were investigating stem defects in white fir on the west slope of the Sierra Nevada. The two plots were located near Shaver Lake, Fresno County, California at elevations of 5,200 to 6,600 feet (Wagener 1970). The plots at Madson Mill (90 acres) and Ellis Meadow (120 acres) were virgin when sampled (1921 and 1917, respectively). All age and size classes were represented, with large, mature trees predominating. Comparison of the height-age relationships of the dominant white fir on these plots, with site classifi-

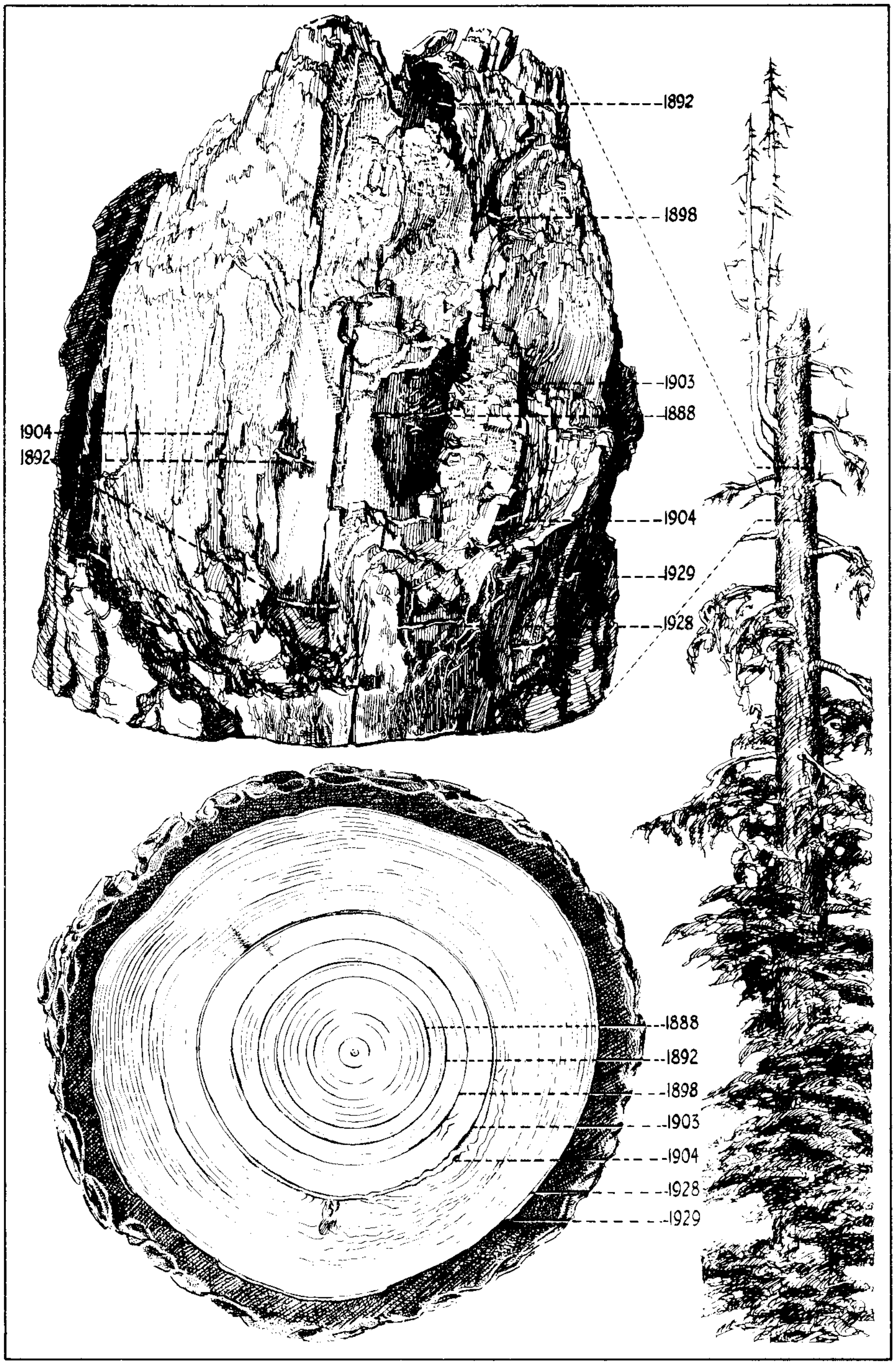


Figure 1—Scars embedded in the stem of a living white fir resulted from periodic *Scolytus ventralis* attacks during the years 1888-1929.

cation curves for white fir in Sierra Nevada mixed conifer forest (Maul 1958), indicated that both Madson Mill (Site I), and Ellis Meadow (Site II), were good growing sites for white fir. In addition to white fir, varying proportions of ponderosa pine *(Pinus ponderosa* Laws*)*, sugar pine *(P. lambertiana* Dougl.*)*, Jeffrey pine *(P. jeffreyi* Grey. and Balf.*)*, incense-cedar *(Libocedrus decurrens* Torr.*)*, and California black oak *(Quercus kelloggii* Newb.*)* were present. Levels of fir engraver activity on these plots were not estimated during sampling, as this was outside the scope of the defect study.

Cutover Plots

Two plots, differing in proportion of mature stand removed by past logging, and in current levels of fir engraver activity, were sampled 4 miles apart at Dersch Meadow and Beal's Place on the west slope of Mount Lassen in Northern California in 1970. The associated tree species were the same as on the old-growth plots except, that Jeffrey pine was absent and Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco*)* was present. The first cycle of logging on both plots (1949-1957) had removed approximately 50 percent of the volume of mature sawtimber. An additional 47 percent of the original sawtimber volume was removed during the years 1958-1968 on the Dersch Meadow plot (4,000 feet elevation, 1,440 acres), leaving scattered clumps of young or formerly suppressed and intermediate trees interspersed with openings in which shrubs and forbs predominated. Firs recently killed by the fir engraver were scattered throughout this plot in 1970. The forest cover was more complete on the Beal's Place plot (4,500 feet elevation, 1,280 acres) before the second cycle of logging in 1970. No recent fir mortality attributable to the insect was observed on this plot in 1970. Beal's Place was a good growing site for white fir (Site II), while Dersch Meadow was somewhat poorer (Sites II and III).

COLLECTION AND MEASUREMENT OF SAMPLES

Old-Growth Plots

A total of 530 living white fir were felled along meander-line transects through the old-growth plots. The pathologists conducting the defect study attempted to include a representative sample of all age and size classes present. Only the lower 50 to 70 percent of the bole merchantable as sawlogs was sampled, as follows: The bole of each tree was sawn into logs 16 feet in length. The minimum diameter at the uppermost cut was about 10 inches; thus the upper log often measured less than 16 feet in length. The number of logs per tree varied from 2 to 14, depending on tree height. Data collected included diagrams of all defects (decay, fir engraver attack scars, etc.) visible on the cut surface at the lower end of each log; measurements of height, diameter, and age at stump for each tree; and measurements of the radius and age of each sample cross section. The crown class of each sample tree was noted as dominant, intermediate or suppressed (Ford-Robertson 1971). Sample sizes within each crown class were:

	Trees	*Bole cross sections*
		(No.)
Plot and crown class:		
Madsen Mill		
Suppressed	29	131
Intermediate	35	190
Dominant	195	1,558
Ellis Meadow		
Suppressed	48	202
Intermediate	58	260
Dominant	165	854

Cutover Plots

The method of sampling on these plots was similar to that used for the virgin plots. The 32 fir sampled at Dersch Meadow had been killed by the fir engraver in 1969, however, and were selected for convenient proximity to roads. The minimum diameter at the uppermost cut was 4 inches, and a 1-inch-thick cross section, or disk, was removed at each cut, resulting in 3 to 5 disks per tree and a plot total of 118 disks. The 41 fir sampled at Beal's Place were living when felled, and were selected by foresters as vulnerable to the insect (high-risk trees) based on an appearance of poor vigor. The lowest log was about 32 feet long. From these trees 116 disks were obtained. One surface of each sample disk was sanded with both coarse and fine grit papers to increase the visibility of both small fir engraver scars and the annual rings. The data recorded were the same as for the old-growth plots, except that crown classification of individual sample trees on these plots was not attempted because stand structure had been altered by logging. The small size of these trees in relation to the remaining overstory trees indicated they were formerly of the suppressed or intermediate crown classes.

Two additional expressions of the size and vigor of fir on all plots were calculated from measurements of tree diameter, height, and age: (a) stem volume (cubic feet), expressing both tree diameter and height, obtained by the formula for a paraboloid frustum, a common bole form for conifers (Bruce and Schumacher 1935); and (b) mean annual volume increment, or growth rate (cubic feet per year), expressing average lifetime vigor, obtained by dividing the tree's volume by its age.

I reasoned that if the beetles had attacked the trees at random, larger and older fir could be expected to contain more scars than smaller or younger trees, by virtue of having a larger bole surface exposed to the beetles over a greater period of years, all else being equal. To eliminate or reduce this possible source of bias, the density of scars per unit of disk volume and age was calculated. Volume was chosen as an expression of the sum of all past surface areas. The number of scars visible on the sample surface of each cross section was considered to represent the number present in a 1-inch-thick cross-sectional disk. The result, referred to as a disk's "attack scar density," was expressed as scars per 10 cubic feet per decade for convenience of scale.

The trees were grouped by crown class on the virgin plots, and by plot on the cutover sites where the crown classifications could not be made due to stand alteration. Mean and variance in attack scar density were calculated for all sample disks from each tree grouping. Variance-to-mean ratios were large and increased disproportionately as mean attack density increased, indicating the scars were distributed in highly aggregated fashion among the sample disks. Such a distribution was not unexpected in light of the aggregated distribution of fir engraver attacks in response to the attraction produced by the mining beetles (Ashraf and Berryman 1969; Ferrell 1971). I wanted to determine if the variation in scar density between the groups of firs so defined was significant compared to variation within the groups, and if so, to test differences between group means. To satisfy the assumptions underlying these analyses, it was necessary to stabilize the variance-to-mean ratios, which was accomplished by transforming the scar densities (log x + 1). The value of one was added so that a definite logarithm could be obtained for disks for which the scar density was zero. Differences between means were compared with least significant differences (Lsd) at the 5 percent level. The mean ± 2 standard errors ($\bar{x} \pm t s_{\bar{x}}$ = approximate 95 percent confidence interval) was calculated for tree diameter, height, volume, age, and growth rate of the sample trees grouped by crown class and plot. Nonoverlap of confidence intervals was used as an approximate method for identifying significant differences between means as this criterion is conservative, with actual confidence limits usually well above the stipulated 95 percent level (Lidicker 1962).

RESULTS

Variation in scar density among the fir grouped by crown class and plot was significant ($F = 82.81$, df = 7 ,3422, $p < .01$).

Mean attack scar densities in living fir were higher in suppressed and intermediate than in dominant trees, and on Site II than on Site I plots. Also, in all crown classes, mean scar densities were at least twice as high in trees on the Site II plots, which had attained lesser diameters, heights, volumes, and growth rates than trees on the Site I plot *(table 1)*. The highest mean scar density occurred in the suppressed and intermediate fir at Dersch Meadow. These trees were growing in a heavily logged stand on the poorest site studied (Sites II and III). These conditions probably contributed to poor tree vigor as expressed by low growth rates, and to the eventual loss of the trees to the beetles. Apparently, the relatively light logging at Beal's Place was unimportant, as the growth rates and scar densities in these fir were similar to those of comparable crown classes (intermediate, suppressed) and site class (II) at Ellis Meadow which had not been logged. Fir growing on the best site (Madsen Mill) had the lowest scar densities and the greatest volumes and growth rates. Tree age was not an important factor. Although there was some tendency for younger trees to have high scar densities, this relationship was not evident on the old-growth plots, where there was little difference between the average ages of fir in the various crown classes and suppressed fir contained about four times the scar density of dominants.

DISCUSSION

The density of scars formed in white fir in response to past fir engraver attacks was inversely related to tree vigor as expressed by crown class, growth rate, and quality of growing site (site class). These results agree with other studies reporting increased abundance of the scars in annual rings formed by white fir in years of drought and reduced radial growth (Ferrell 1973), and in white fir heavily in-

Table 1–*Stand and tree characteristics related to fir engraver attack scar densities in white fir, by crown class, at four locations in northern and central California*

Crown class	Mean ± 2 standard errors[1] per tree					Mean (standard error)
	Stump diameter (in.)	Height (ft.)	Volume (cu. ft.)	Stump age (yrs.)	Growth rate (cu. ft./yr.)	Scar density[2] (cu. ft./yr.)
	Madsen Mill (Site I, virgin old-growth, live sample trees)					
Suppressed	25 ± 3	98 ± 9	193 ± 51	159 ± 9	1.2 ± 0.3	10.2 (2.6) d
Intermediate	31 ± 2	123 ± 7	360 ± 66	178 ± 13	2.0 ± .3	6.7 (1.4) d
Dominant	45 ± 1	159 ± 4	971 ±69	185 ± 7	5.3 ± .3	2.8 (.3) e
	Ellis Meadow (Site II, virgin old-growth, live sample trees)					
Suppressed	21 ± 2	90 ± 5	128 ± 37	175 ± 9	.7 ± .2	29.2 (3.9) b
Intermediate	28 ± 1	116 ±4	254 ± 32	180 ± 12	1.4 ± .1	10.7 (1.6) c
Dominant	34 ± 1	132 ± 3	451 ± 37	178 ± 8	2.5 ± .2	6.6 (.8) d
	Beal's Place (Site II, cutover, live, high-risk sample trees)					
Suppressed and intermediate	22 ± 1	75 ± 6	110 ± 17	126 ± 10	.9 ± .1	21.5 (5.0) c
	Dersch Meadow (Site II-III, heavily cutover, sample trees killed by fir engraver)					
Suppressed and intermediate	15 ± 1	63 ± 4	44 ± 8	100 ± 7	.4 ± .2	180.3 (58.4) a

[1] Approximate 95 percent confidence interval.

[2] Number of scars per 10 cubic feet per decade, sample disk basis. Differences between transformed means followed by dissimilar letters exceeded least significant difference at 5 percent level.

fected by mistletoe, especially in drought years (Felix, *et al.* 1971). The lower scar densities observed in more vigorous fir may be attributable to more rapid resinous responses of the host tissues to the attacks. Such high host resistance causes some attacks to fail to penetrate to the cambium and hence to form scars in the xylem; other attacks that do penetrate produce only small scars (Berryman 1969). Small scars would probably be less frequently detected on the surfaces of stem cross sections, the method of sampling used in this study.

In addition to variations in resistance associated with host vigor, other circumstances could have contributed to the observed variations in scar density. Logging slash on the cutover plots may have increased fir engraver populations on these plots by providing an abundance of nonresistant host material; the fir engraver readily attacks and reproduces in logging slash. Nevertheless, although previous study established that scar frequency increased in annual rings formed during logging operations at Beal's Place (Ferrell 1973), mean scar densities in these trees did not differ from those in fir of the same crown classes in the virgin stand at Ellis Meadow. (The two plots were similar in quality of growing site; both were Site II.)

Another possible source of variation in scar density was that some fir may have been selectively attacked because they were more attractive to the beetles. The possible role of attraction was not assessed, as this would require a representative sample of all fir engraver attacks within a given fir stand. The sampling methods used in this study did not represent the full spectrum of fir engraver attacks. Only a portion of the attacks form scars in the annual rings as discussed above, and attacks in fir killed by the beetles in years long past could not be sampled because the resulting snags had since fallen to the forest floor and decomposed.

It was possible to distinguish less resistant fir with high densities of embedded attack scars by observable characteristics such as crown class and growth rate. These results suggest that a risk rating system could be developed for white fir. Such a risk rating, if reliable and followed by selective removal of vulnerable fir (sanitation-salvage logging), would allow forest managers to reduce stand hazard and tree mortality from the fir engraver. Risk rating systems, using visible age and vigor characteristics, have been developed for ponderosa and Jeffrey pine stands in northeastern California subject to attack by subcortical insects (Salmon and Bongberg 1942), and have been successful in reducing subsequent timber loss caused by these insects (Wickman and Eaton 1962). The development of such a risk rating system for white fir requires further investigation of the characteristics of white fir killed by the fir engraver. An important byproduct of such mortality studies would be an assessment of the impact of the fir engraver upon the growth, stocking, and yield of both second- and old-growth stands.

Results of this study also indicate that lumber from white fir of low vigor (suppressed, intermediate, and high-risk trees) contains greater densities of stem defects produced by the embedded scars. This fact suggests that fir trees could be visually rated for the quality of wood products they would produce.

LITERATURE CITED

Ashraf, Muhammad, and A. A. Berryman.
1969. **Biology of *Scolytus ventralis* (Coleoptera: Scolytidae) attacking *Abies grandis* in northern Idaho.** Melanderia 2: 1-23.

Berryman, Alan A.
1969. **Responses of *Abies grandis* to attack by *Scolytus ventralis* (Coleoptera: Scolytidae).** Can. Entomol. 101: 1033-1041.

Bruce, D., and F. X. Schumacher.
1935. **Forest mensuration.** 360 p. New York: McGraw-Hill Book Co.

Felix, Leonard S., E. Uhrenholdt, and J. R. Parmeter, Jr.
1971. **Association of *Scolytus ventralis* (Coleoptera: Scolytidae) and *Phoradendron bolleanum* subspecies *pauciflorum* on *Abies concolor*.** Can. Entomol. 103: 1697-1703.

Ferrell, George T.
1971. **Host selection by the fir engraver, *Scolytus ventralis* (Coleoptera: Scolytidae). Preliminary field studies.** Can Entomol. 103: 1717-1725.

Ferrell, George T.
1973. **Weather, logging, and tree growth associated with fir engraver attack scars in white fir.** USDA Forest Serv. Res. Paper PSW-92. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 11 p., illus.

Ford-Robertson, F. S. (Ed.)
1971. **Terminology of forest science, technology practice and products.** Multilingual forestry terminology series No. 1. Washington, D. C. Society of American Foresters. 349 p.

Johnson, Norman E., and K. R. Shea.
1963. **White fir defects associated with attacks by the fir engraver.** Weyerhaeuser Co. For. Res. Note 54. 8 p.

Lidicker, William Z., Jr.
1962. **The nature of subspecies boundaries in a desert rodent and its implications for subspecies taxonomy.** Syst. Zool. 11: 160-171.

Maul, David C.
1958. **Silvical characteristics of white fir.** U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 25.22 p.

Salmon, K. A., and J. W. Bongberg.
1942. **Logging high-risk trees to control insects in the pine stands of northeastern California.** J. For. 40: 533-539.

Stevens, Robert E.
1971. **Fir engraver.** USDA Forest Serv. For. Pest Leafl. 13.7 p.

Struble, George R.
1957. **The fir engraver.** USDA Forest Serv. Prod. Res. Rep. 11.18 p.

Wagener, Willis W.
1970. **Frost cracks ... a common defect in white fir in California.** USDA Forest Serv. Res. Note PSW-209. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 5 p.

Wickman, Boyd E., and C. B. Eaton.
1962. **The effects of sanitation-salvage cutting on insect-caused mortality at Blacks Mountain Experimental Forest, 1938-1959.** U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. Tech. Paper 66.39 p.

GPO-794-474/4617

Ferrell, George T.
1973. **Stand and tree characteristics influencing density of fir engraver attack scars in white fir.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 8 p., illus. (USDA Forest Serv. Res. Paper PSW-97)

Density of embedded scars resulting from old fir engraver *(Scolytus ventralis* Lec.*)* attacks was assessed in 3,430 bole cross sections cut from 603 white firs growing in both cutover and in virgin old-growth stands in northern California. Mean scar density was directly related to percentage of mature stand removed by logging and was higher in suppressed and intermediate, compared to dominant, fir. Inverse relationships were found between scar density and site quality, tree diameter, height, age, volume, and mean growth rate. A risk rating system based on tree and stand characteristics appears possible and would be useful in identifying for removal white fir with decreased resistance to beetle attacks. Such trees might also have a high probability of lumber defects caused by high scar densities.

Oxford: 453–145.7x19.92: 174.7 *Abies concolor.*
Retrieval Terms: Abies concolor; Scolytus ventralis; predator-host relations; damage indexes; attack scars; tree vigor; host resistance; host tree mortality; risk rating; lumber defects.

Ferrell, George T.
1973. **Stand and tree characteristics influencing density of fir engraver attack scars in white fir.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 8 p., illus. (USDA Forest Serv. Res. Paper PSW-97)

Density of embedded scars resulting from old fir engraver *(Scolytus ventralis* Lec.*)* attacks was assessed in 3,430 bole cross sections cut from 603 white firs growing in both cutover and in virgin old-growth stands in northern California. Mean scar density was directly related to percentage of mature stand removed by logging and was higher in suppressed and intermediate, compared to dominant, fir. Inverse relationships were found between scar density and site quality, tree diameter, height, age, volume, and mean growth rate. A risk rating system based on tree and stand characteristics appears possible and would be useful in identifying for removal white fir with decreased resistance to beetle attacks. Such trees might also have a high probability of lumber defects caused by high scar densities.

Oxford: 453–145.7x19.92: 174.7 *Abies concolor.*
Retrieval Terms: Abies concolor; Scolytus ventralis; predator-host relations; damage indexes; attack scars; tree vigor; host resistance; host tree mortality; risk rating; lumber defects.

Ferrell, George T.
1973. **Stand and tree characteristics influencing density of fir engraver attack scars in white fir.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 8 p., illus. (USDA Forest Serv. Res. Paper PSW-97)

Density of embedded scars resulting from old fir engraver *(Scolytus ventralis* Lec.*)* attacks was assessed in 3,430 bole cross sections cut from 603 white firs growing in both cutover and in virgin old-growth stands in northern California. Mean scar density was directly related to percentage of mature stand removed by logging and was higher in suppression and intermediate, compared to dominant, fir. Inverse relationships were found between scar density and site quality, tree diameter, height, age, volume, and mean growth rate. A risk rating system based on tree and stand characteristics appears possible and would be useful in identifying for removal white fir with decreased resistance to beetle attacks. Such trees might also have a high probability of lumber defects caused by high scar densities.

Oxford: 453–145.7x19.92: 174.7 *Abies concolor.*
Retrieval Terms: Abies concolor; Scolytus ventralis; predator-host relations; damage indexes; attack scars; tree vigor; host resistance; host tree mortality; risk rating; lumber defects.

Ferrell, George T.
1973. **Stand and tree characteristics influencing density of fir engraver attack scars in white fir.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 8 p., illus. (USDA Forest Serv. Res. Paper PSW-97)

Density of embedded scars resulting from old fir engraver *(Scolytus ventralis* Lec.*)* attacks was assessed in 3,430 bole cross sections cut from 603 white firs growing in both cutover and in virgin old-growth stands in northern California. Mean scar density was directly related to percentage of mature stand removed by logging and was higher in suppression and intermediate, compared to dominant, fir. Inverse relationships were found between scar density and site quality, tree diameter, height, age, volume, and mean growth rate. A risk rating system based on tree and stand characteristics appears possible and would be useful in identifying for removal white fir with decreased resistance to beetle attacks. Such trees might also have a high probability of lumber defects caused by high scar densities.

Oxford: 453–145.7x19.92: 174.7 *Abies concolor.*
Retrieval Terms: Abies concolor; Scolytus ventralis; predator-host relations; damage indexes; attack scars; tree vigor; host resistance; host tree mortality; risk rating; lumber defects.

The Author

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

ACKNOWLEDGMENTS

I am indebted to the late Willis W. Wagener, Pacific Southwest Forest and Range Experiment Station, for permission to analyze data collected by him and his associates, and to William Beatty Associates, Consulting Foresters, Redding, California, for logging and site information on the study plots.

The Forest Service of the U.S. Department of Agriculture

. . . Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

. . . Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

. . . Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.