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

Donald T. Gordon

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Retrieval Terms: Abies magnifica; Abies concolor; wind damage; wind stability; clear-cutting; snow damage: insect damage.

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CONTENTS

The Author

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

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

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

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

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

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

STUDY AREA

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

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

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

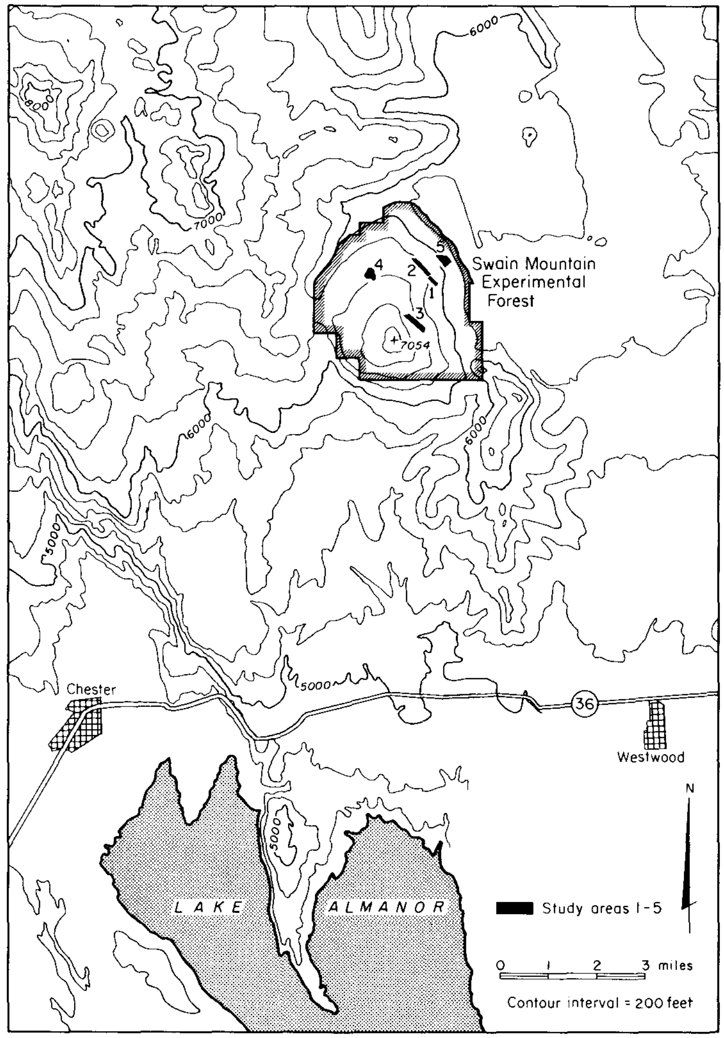

Figure 1–The topography of Swain Mountain Experimental Forest, in northeastern California, and the surrounding area partly determined the amount and kind of damage to trees.

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

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

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

METHODS

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

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

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

1. One strip 3 chains wide by 20 chains long, clearcut through a dense overmature stand in 1958;

2. and 3. Two strips, 5 chains wide by 34 chains long, one clearcut in 1958, the other in 1959, through old stands of heavy to moderate density;

4. One irregularly-shaped 17-acre block, about 17 chains across at its greatest dimension, clearcut in 1958, when the medium density overstory was removed to release an abundant understory.

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

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

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

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

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

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

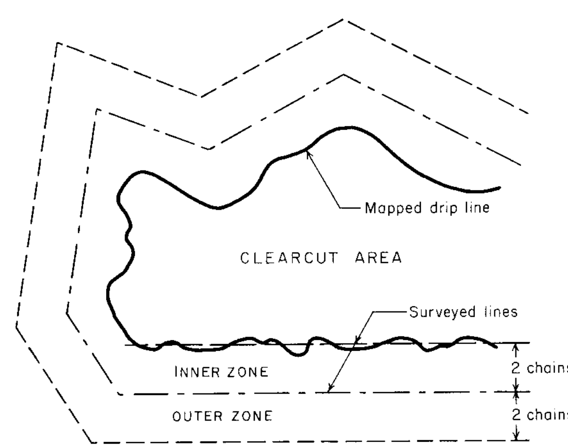

Figure 2–A zoning system was used for classifying locations of observations.

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

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

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

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

RESULTS

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

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

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

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

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

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

Wind Damage

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

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

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

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

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

[1] Data furnished Sept. 23, 1959 by District Ranger, Almanor Ranger District, Lassen National Forest.
[2] Steady (estimated).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

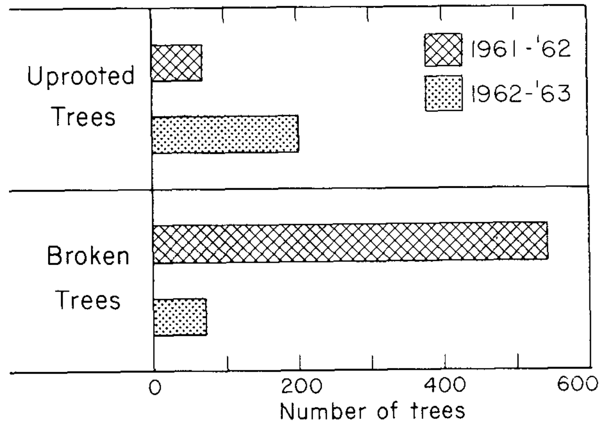

Figure 3–Direct wind action resulted in different kinds of damage in the two most destructive winters.

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

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

[1] Calculated for whole trees 12 inches d.b.h. and larger, or broken pieces of stems on ground (Scribner Scale).
[2] Includes trees down, leaning, and hung up. Leaners and hangups each constituted only 1 percent of direct wind-damaged trees.

Contributory Causes of Wind Damage

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

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

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

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

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

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

Contributory cause	Trees damaged	Trees per acre	Volume per acres	
			Gross	Net
			–*Bd. ft*–.	
Bole rot	99	0.69	1,670	557
Fire scar	63	.44	1,069	457
Root rot	59	.40	750	604
Other:				
Broken (live) bayonet [2]	32	.22	305	35
Dwarf mistletoe in bole	28	.19	361	131
Snow bend	6	.04	0	0
Shallow soil	31[3]	.12	147	140
Logging damage	25	.17	25	19
Total other	330	2.27	4,327	1,943

[1] Calculated for whole trees 12 inches d.b.h. and larger, or broken pieces of stems on ground (Scribner Scale).
[2] Includes both sound and partly decayed broken bayonet tops or forks.
[3] In 14, root growth was restricted at depth of 1 or 2 feet, in the rest at 3 to 5 feet.

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

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

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

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

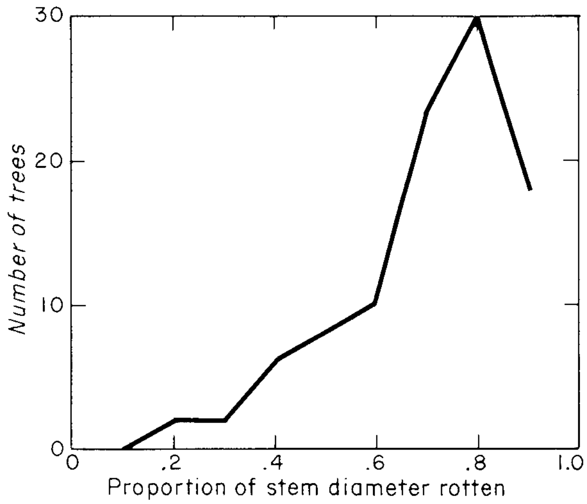

Figure 4–Stem breakage increases with amount of decay.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Relation of Break Height to Crown and Size Class

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

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

For dominant and codominant trees, the height of break anywhere within the first three log lengths appears to be random. The incidence of breakage in the first log is low–l4 percent of breaks in these two crown classes.

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

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

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

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

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

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

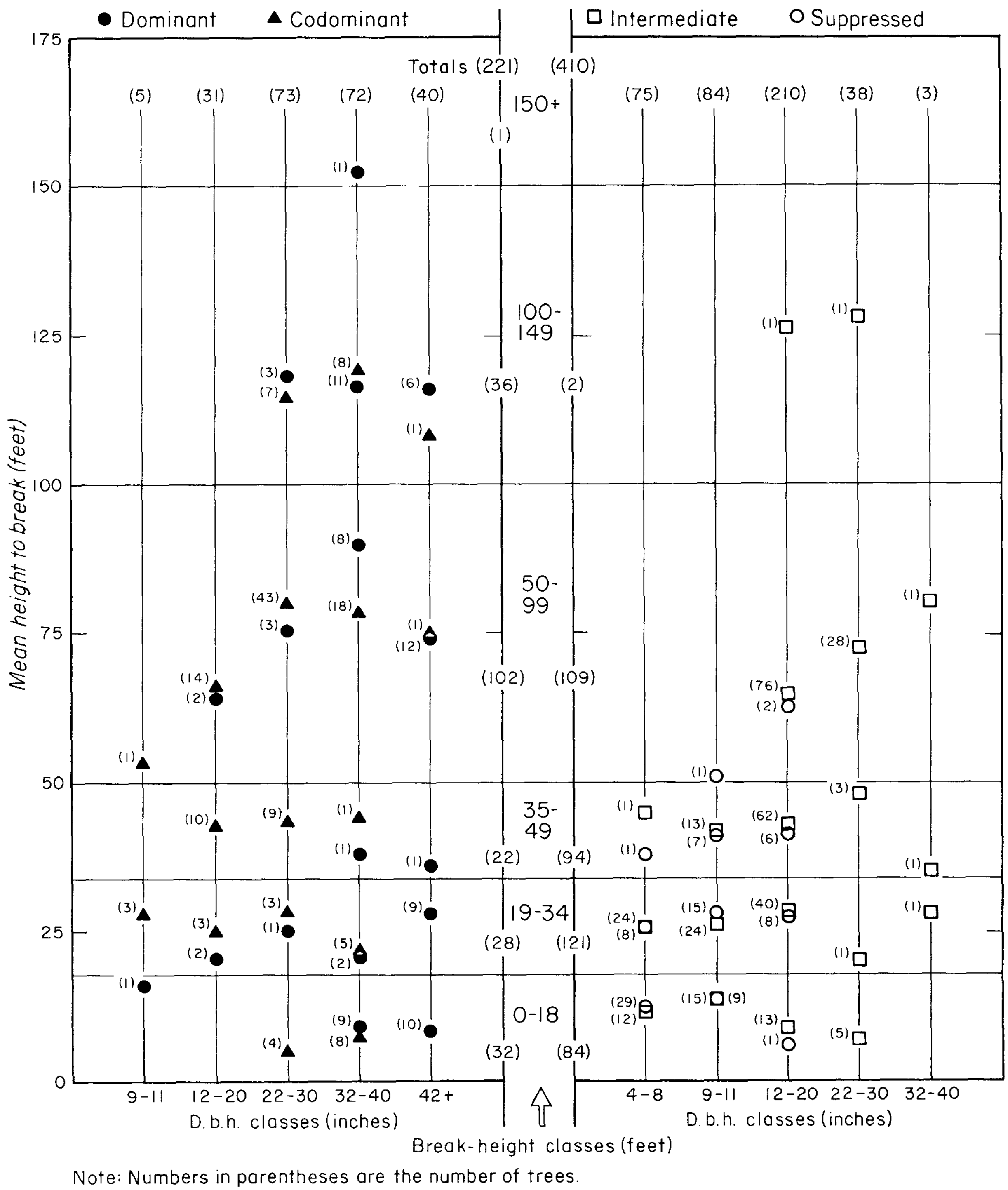

Figure 5–The mean height of wind-caused breaks, when plotted for tree diameter classes, shows a trend in some break height classes. **Left**, in dominant and codominant trees, breakage in the 50- to 100-foot class shows an upward trend with increasing diameter. **Right**, in intermediate and suppressed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

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

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

Influences on Wind Damage

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

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

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

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

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

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

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

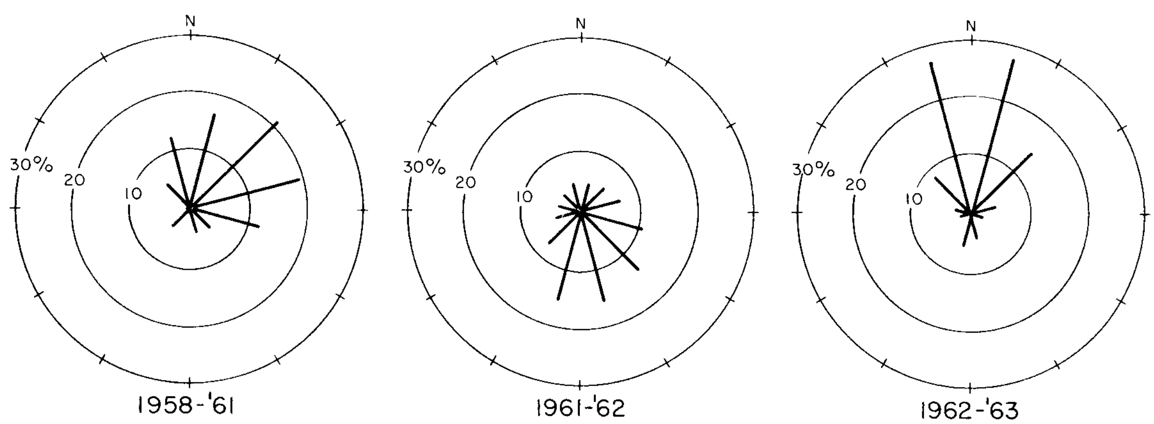

Figure 6–Direction of fall of trees or broken pieces of stems was unusual during heavy storm periods. The percent of total direct wind damage is shown for the first three winters combined, and for the following two winters separately. Bars are at centers of 30 azimuth classes.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[1] See map, figure 1.
[2]Calculated for whole trees 12 inches d.b.h. and larger, or broken pieces of stem, on ground (Scribner Scale).
[3]Combined data from removal of five trees and two and one-half trees per acre.

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

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

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

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

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

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

[1] Inner zone: up to 2 chains from edge; outer zone: 2 to 4 chains from edge.
[2] Uprooting difference, by zones, significantly different at the 5 percent level; breakage difference, by zones, not statistically significant.

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

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

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

Insect Damage

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

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

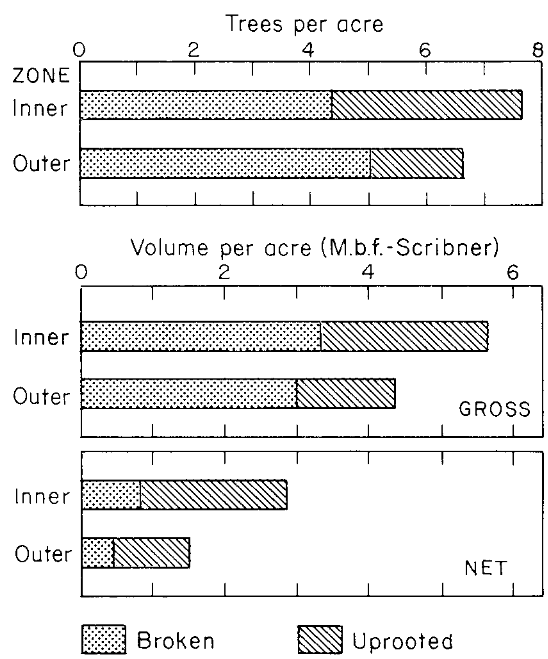

Figure 8–At any distance from cutting edge, more trees were broken than uprooted. But uprooting and its effects were more prevalent close to cutting edges than at greater distances.

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

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

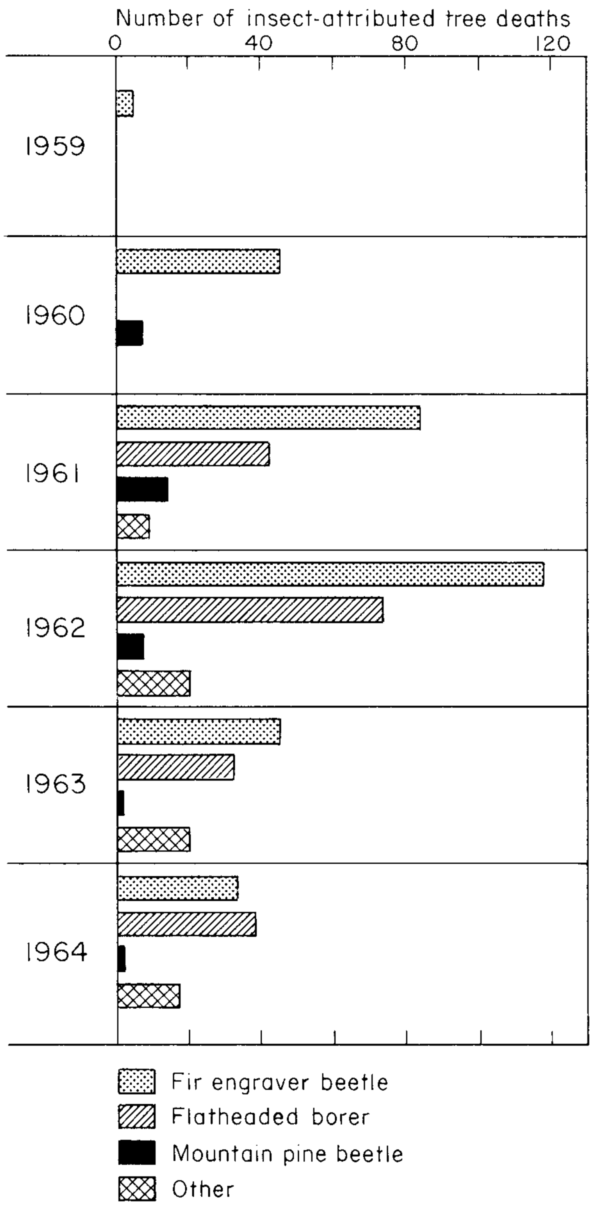

Figure 9–Tree mortality attributed to insect attack fluctuated during the study years. When 1962 storms made slash available for breeding, insect pressure on live trees may have lessened.

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

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

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

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

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

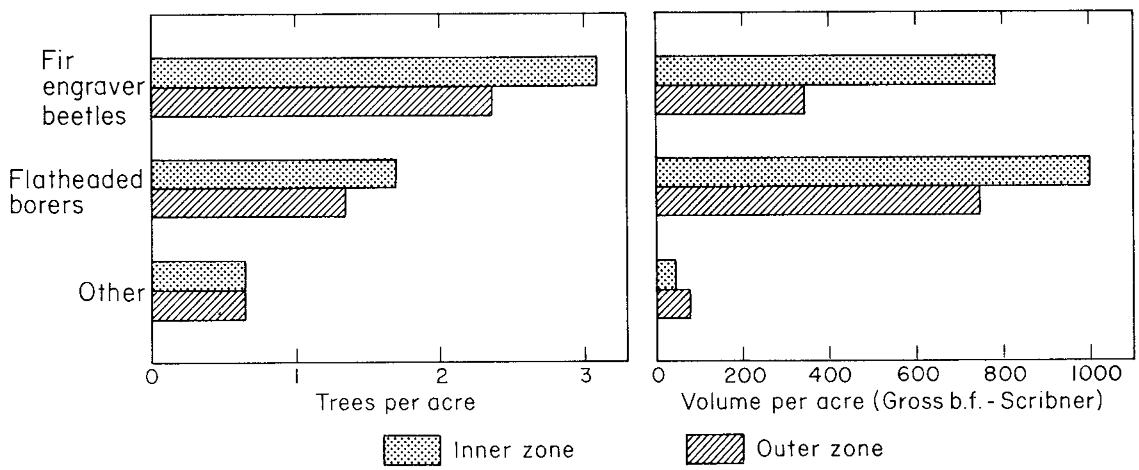

Figure 10–Fir engraver beetles apparently killed more trees than any other insect, but board-foot mortality assigned to flatheaded borers was greatest. Tree numbers and volume lost were higher near clearcut edges (inner zone) than at greater distance (outer zone).

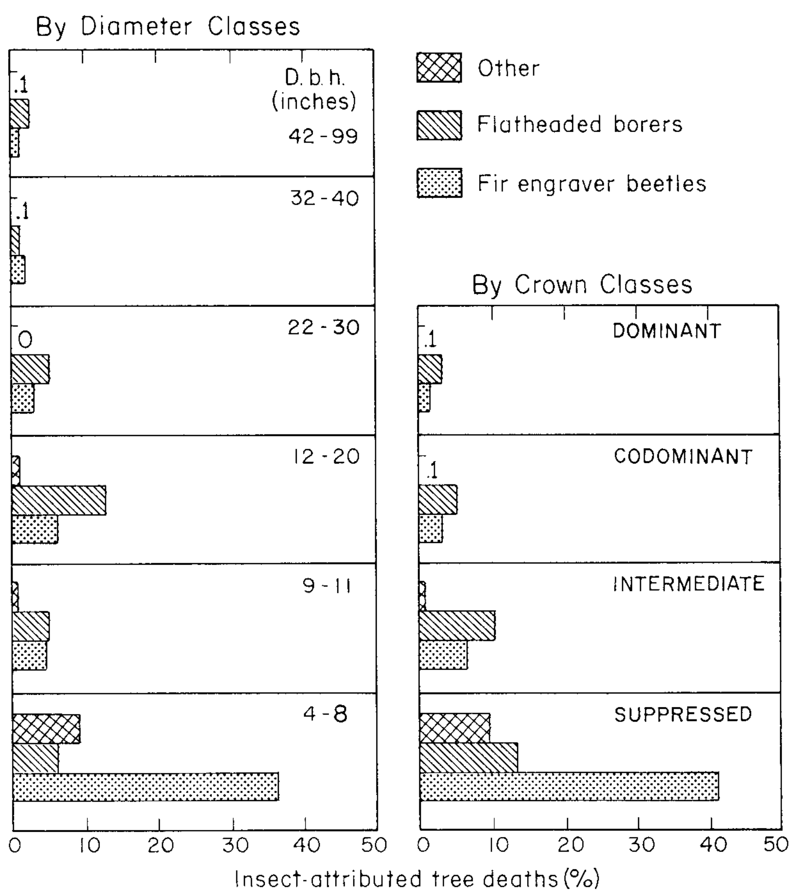

Figure 11–Tree mortality assigned to different insect species varied by tree diameter classes, but showed a common trend. By tree crown classes, the trend is more consistent.

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

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

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

Snow Damage

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

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

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

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

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

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

Other Primary Damage

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

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

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

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

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

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

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

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

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

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

Salvage and Potential Losses

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

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

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

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

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

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

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

DISCUSSION

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

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

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

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

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

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

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

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

[1]Index = Damaged trees per acre in uncut stand divided by related cutting area acreage.
[2]Combined data from removal of five trees and two and one-half trees per acre.

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

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

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

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

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

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

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

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

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

Retain these kinds of trees:

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

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

SUMMARY

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

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

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

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

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

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

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

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

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

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

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

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