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REDUCING WIND DAMAGE IN THE FORESTS OF THE OREGON COAST RANGE

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REDUCING WIND DAMAGE IN THE FORESTS OF THE OREGON COAST RANGE

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SUMMARY

Wind damage is serious in the forests of the Oregon Coast Range. For example, on December 4, 1951, one severe storm blew down 3.7 billion board feet of merchantable timber.

Studies during recent years indicate that on the average, storm winds come from approximately south 30 degrees west.

A survey of blowdown on the borders of clear-cut areas revealed that 93 percent of the wind damage occurred along the north and east boundaries. Losses were much heavier when these north and east cutting boundaries were located on the leeward side of ridges, that is, on the north slopes. An analysis of eight clear-cut tracts showed no correlation between wind damage and the size of the tract, but areas of 2 acres or less sustained considerable losses.

Windfall was studied over a 3-year period in partial cuttings on the Cascade Head Experimental Forest. In stands from which 16 to 24 percent of the volume had been removed in thinnings, the losses averaged 80 board feet per acre per year. Other thinned areas from which most of the dominant and codominant trees had been removed suffered severe blowdown losses in the residual stands.

Preliminary study of the comparative windfirmness of different species indicated that Douglas-fir and Sitka spruce are more windfirm than western hemlock. Trees infected with root rot were particularly susceptible.

Blowdown was more severe on areas with a high water table or very shallow soil.

^{1/} The authors are indebted to many foresters who helped in establishment of this study and review of this paper. They include: Professor David M. Smith, Yale University; Carl M. Berntsen, Elmer W. Shaw, Carl M. Hawkes, and Boyd L. Rasmussen, U. S. Forest Service; and the personnel of the Blowdown and Bark Beetle Survey who collected data on 225 sample plots in the Oregon Coast Range.

In virgin stands, topography influenced wind damage in several ways. The heaviest damage occurred on the lee side of ridges (north slopes, usually), beginning near the crest of the ridge and extending for some distance down the lee slope. Blowdown was also found on small ridges and flats in the lee of higher ridges.

Several recommendations are offered as possible ways to improve management practices and thus reduce wind damage. Some of the suggestions are: cut in progressive strips; select windfirm cutting lines; take full advantage of topography; consider special hazards, such as shallow soils, high water table, defective trees, and root rot; make clearcuts of proper size; plan ahead for salvage; use intermediate harvest cuts to develop windfirmness; and when possible, use young stands, patches of red alder, or understocked areas as cutting boundaries.

INTRODUCTION

Each year storm winds take a high toll in uprooted or broken trees throughout the Oregon Coast Range. Occasionally, as in the winter of 1951-52, the loss caused by a single storm runs into billions of board feet of merchantable timber. For example, the winds of December 4, 1951, blew down 3.7 billion board feet with a stumpage value of some 50 million dollars. Then in the summer of 1952 an additional 455 million board feet of green timber was killed by the Douglas-fir bark beetle (Dendroctonus pseudotsugae Hopk.). The beetle had built up immense populations in blowdown areas, then emerged to attack living trees. Continued heavy losses by beetles are expected for at least the next two years (2).^{2/}

Prompt salvage is necessary, especially in western hemlock and Sitka spruce, to minimize loss from decay in the blowdown and beetle-killed timber, but salvage is often difficult because of the lack of access roads into the damaged areas.

One way to prevent or reduce these losses is to improve the logging plans. In the past, most logging plans have been based on several economic and silvicultural factors. But wind damage has not been well understood and consequently has been given insufficient consideration. It now appears that much of the wind damage associated with cutting can be prevented by avoiding certain conditions which predispose the remaining stand to windthrow.

^{2/} Underlined numbers in parentheses refer to Literature Cited, page 30.

Objectives

The Experiment Station has started a study to determine the best methods of managing coastal forests to minimize wind damage and to provide for efficient salvage of any losses that cannot be prevented. The procedure has been to study the basic pattern of storm damage and the various factors that affect windthrow. This paper is a progress report that describes the characteristics of the damage as observed during the first 4 years of the study. Cutting practices that should minimize losses from storm winds are also recommended.

Scope

Detailed records of the volume and pattern of windfall in a 100-year-old spruce-hemlock stand have been collected on the Cascade Head Experimental Forest since 1948. This is a 10,000-acre tract located 85 miles southwest of Portland, Oregon, and just north of the Salmon River (1). Most of the area lies on an east-west ridge and extends from the precipitous ocean front at Cascade Head inland for 6 miles. The topography is irregular, often abrupt, and dissected by many small canyons. Some flat and gently rolling land occurs along the creeks and at the foot of the slopes. Elevations range from sea level to 1,750 feet. The climate has equable temperatures, much cloudiness, frequent rains except in summer, and fogs even then. The annual precipitation at the Experimental Forest headquarters, almost all in the form of rain, is approximately 90 inches. Along the beach precipitation is known to be considerably less, and on the high ridge it is probably more. The prevailing soils are deep, residual clay loams well watered and moderately well drained. Rock outcrops and stony soils are unusual. The timber type is thrifty, even-aged, 100-year-old Sitka spruce and western hemlock varying from almost pure hemlock to nearly pure spruce. Douglas-fir is a conspicuous associate in some areas, and red alder forms pure or almost pure stands on areas denuded by fire.

Windfall records on the Experimental Forest were taken around the perimeters of staggered clear-cut settings and throughout the areas given commercial thinnings.

During the summer of 1952, additional data on the general characteristics of storm damage were taken on 225 sample plots in the Oregon Coast Range. These plots sampled about 200 miles of the Range, from the north boundary of Polk County to the north boundary of Josephine County. This was the area affected by the severe windstorm of December 4, 1951. The timber type is mostly old-growth and second-growth Douglas-fir merging into spruce-hemlock forests near the coast. These data were supplemented by two days of flying over the blowdown areas to tabulate and photograph the storm damage in relation to topography and logging.

FIELD PROCEDURES

Cascade Head Experimental Forest

The first detailed measurements of storm damage were taken in 1948 around the perimeters of two clear-cut tracts, one of 18 acres (1-C) and another of 11 acres (1-D). Measurements were repeated in 1949 and 1951, and supplemented by additional data from other clearcuts. Storm damage was also recorded in the thinned areas. During the summer of 1952, a 100-percent tally was made of all windfall associated with cutting of 8 tracts on the Experimental Forest (including 1-C and 1-D). The following information was recorded for each tree: species, direction of fall, diameter, number of logs, crown class, and whether the tree was broken-off or uprooted. At the same time notes were taken on all other factors that might logically be correlated with storm damage. These included position of the tree in relation to openings in the stand, presence of decay, soil conditions, and evidence of previous storm damage.

Blowdown and Bark Beetle Survey

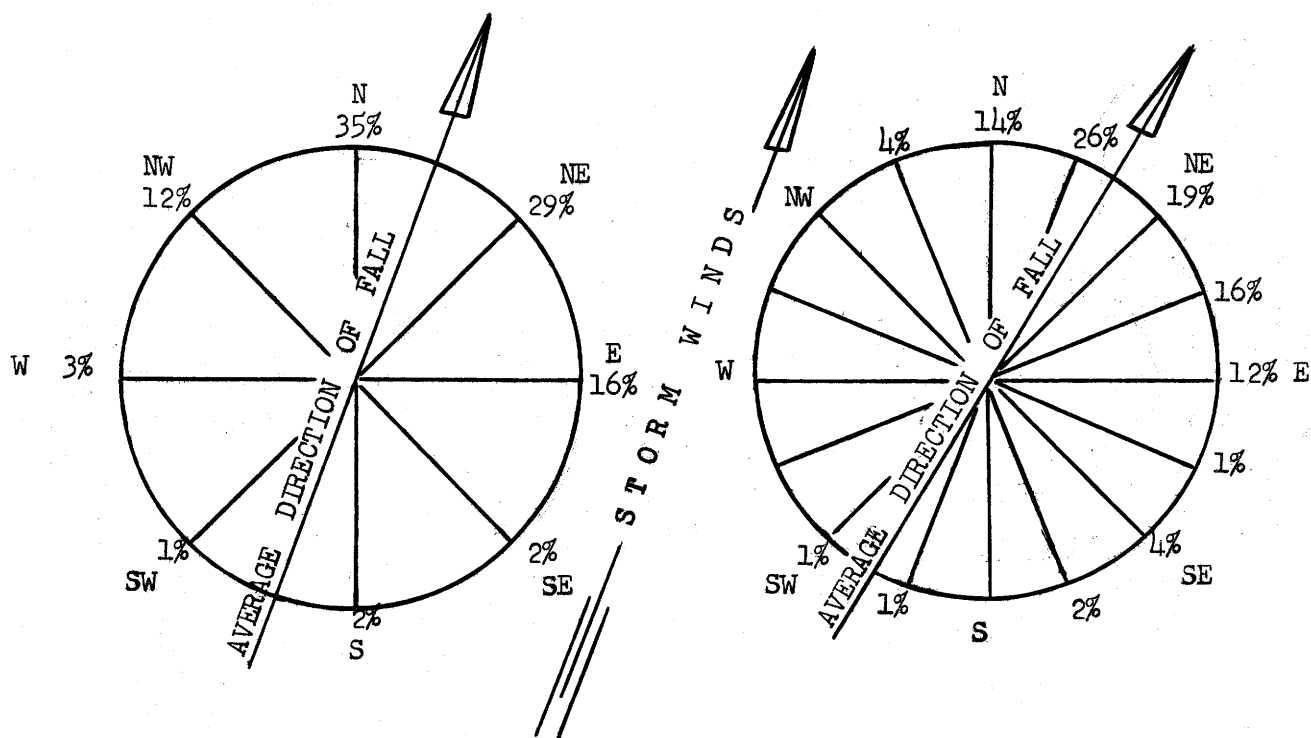
An extensive survey was made during the summer of 1952 to determine the location and volume of timber lost from recent severe windstorms and the associated bark beetle epidemic. The objective was to provide data needed for the development of a salvage program. During the survey, blowdown and bark beetle damage on 10,500,000 acres was mapped from the air by trained observers as they flew on predetermined flight lines. A certain proportion of the blowdown areas was visited later by ground crews who measured the damage on sample plots (2).

Although the survey was conducted primarily to determine the volume and location of losses, it provided an excellent opportunity to investigate other characteristics of storm damage over a wide area. The ground crews cooperated in this effort by recording on a special tally sheet additional information on direction of fall, relation to cutting and to topography, comparative windfirmness of various species and crown classes, and whether trees were broken-off or uprooted.

OBSERVATIONS AND RESULTS

Direction of Fall

At Cascade Head the direction trees fell was recorded as north, northeast, east, southeast, south, southwest, west, or northwest. Trees that had been knocked down by other trees were not recorded because they did not provide an accurate measure of wind direction. At Cascade Head the average tree fell approximately north 20 degrees east (fig. 1), indicating that the damaging storm winds come from south 20 degrees west. Direction of fall as determined for the Oregon Coast Range was recorded on the basis of the average direction of fall for each plot. The average



1-A. Cascade Head Experimental Forest. Basis: 1,233 trees, measured 1948-52. (Numbers show percentage of trees falling in each direction.)

1-B. Oregon Coast Range. Basis: 145 plots, measured 1952. (Numbers show average direction of fall in percent for the total number of plots.)

Figure 1.--Direction of fall.

direction was approximately north 30 degrees east, a pattern very similar to that observed at Cascade Head. The main task of the forest manager, then is to protect his forest against storm winds from the south or southwest.

Storm winds along the coast occur during the winter months. They are usually accompanied by heavy rains, sometimes more than 4 inches in 24 hours. The heavy rains saturate the soil around the roots of the trees at the same time that southwest gales exert a maximum leverage on the root systems. Perhaps it is this combination that often makes storm damage a major management problem.

Relation of Blowdown to Cutting Boundary

Ninety-three percent of the volume loss at Cascade Head occurred along the north and east boundaries of the clearcuts (table 1). On most tracts the losses along the north and east boundaries were more severe near the northeast corner (fig. 2). The southwest winds apparently swept down into the clear-cut tracts and hit these boundaries with full force. Before clear-cutting, the trees along the boundaries had never been exposed to wind stress for their full lengths, and their roots and boles were unable to withstand the blow. The south and west boundaries, where only 7 percent of the losses occurred, apparently were protected from the southwest wind by the uncut stand to windward. This indicates that cutting should be made progressively into the wind to minimize storm damage. Storm winds from the northeast could be expected to cause severe damage along the south and west boundaries of the clear-cut areas, but strong northeast winds are rare along the Oregon Coast.

Data from the Coast Range survey show a similar pattern. On the 55 clear-cut areas where windfall was closely associated with cutting, by far the greatest damage occurred along the north and east boundaries of these clear-cuttings.

Most of the uprooted trees fell back into the uncut stand; only a few fell from the timber edge into the clear-cut area, usually because of some special circumstance such as root rot. In locating cutting lines, then, special attention should be given to windfirmness of the trees that will form the north and east boundaries.

Blowdown on Windward Slopes and Leeward Slopes

Tract 3-B presented a good opportunity to study the influence of aspect on severity of windfall. This 37-acre clear-cut area is irregular in shape and, in effect, has two north boundaries--one on a north slope in the lee of a high ridge and one on the south (windward) slope of the same ridge (figs. 2 and 3). The east boundary extends up and over the high ridge in such a manner that part of this boundary is on the lee side and part on the windward side. The cutting lines on the south (windward) slope proved much more windfirm than those on the north

Table 1.--Windfall loss in relation to cutting boundary on eight clear-cut tracts, Cascade Head Experimental Forest, 1952

Volumes in board feet, Scribner Decimal C

Tract	Area :in acres:	North boundary			East boundary			South boundary			West boundary		
		No. : trees	Gross : volume	No. : trees	No. : trees	Gross : volume	No. : trees	No. : trees	Gross : volume	No. : trees	No. : trees	Gross : volume	Gross : volume
1-A	81.0	68	5,799	1	194	1	90	29	1,476				
1-D	11.0	16	1,621	1	220	1	9	1	105				
1-C	18.0	142	7,935	219	11,776	16	1,154	10	540				
3-A	13.5	5	325	6	728	-	-	-	-				
3-B	37.0	178	14,058	183	12,231	8	505	7	415				
5-A	15.5	-	-	105	8,630	3	117	-	-				
5-B	22.4	13	1,180	1	9	-	-	-	-				
10-A	15.0	39	2,374	52	3,561	-	-	16	516				
Total	213.4	461	33,292	568	37,349	29	1,875	63	3,052				
Percent of total all boundaries		41	44	51	49	3	3	5	4				



Figure 2.--Blowdown on the lee (north) slope of tract 3-B was heaviest near the northeast corner.



Figure 3.--Very little blowdown occurred on this windward (south) slope of tract 3-B. This was in marked contrast to the lee slope (fig.2).

(leeward) slope (table 2). Even when the data are weighted by length of boundary, 92 percent of the north-boundary windfall occurred on the lee slope and only 8 percent on the windward slope. The pattern on the east boundary was about the same with 80 percent of the windfall on the lee slope and 20 percent on the windward.

Clear-cut tract 1-C is rectangular, measuring 1,700 feet north and south by 500 feet east and west with a high east and west ridge through the center. One hundred percent of the blowdown along the east and west boundaries occurred on the lee (north) slope (table 2).

Table 2.--Windfall on north and south slopes, tracts 3-B and 1-C

Tract	Boundary	Aspect	Length : feet	All species		Weighted : percent
				Number : trees	Volume : M bd. ft.	
3-B	North	North	900	162	130	92
		South	900	16	11	8
	East	North	800	174	115	80
		South	200	9	7	20
1-C	East	North	900	217	135	100
		South	800	2	0	0
	West	North	900	5	4	100
		South	800	0	0	0

Since the data from the Coast Range survey were obtained on sample plots, they cannot be compared directly with the Cascade Head findings. However, airplane observations of blowdown on both windward and leeward slopes indicated the pattern was similar throughout the Oregon Coast Range. Even though leeward slopes appear to be better protected, wind damage on these slopes was considerably more severe than on the exposed windward side. For this reason, clearcuts should be located so that north and east boundaries lie on the windward side of the ridge.

Stabilization of Cutting Lines

Windfall was measured during a 4-year period around two clear-cut tracts at Cascade Head, and the data were analyzed to see whether there was a tendency for cutting lines to stabilize. Annual losses were definitely reduced around tract 1-C (table 3). Around tract 1-D the losses continued at about the same rate for 4 years. General observations on other tracts indicated a definite tendency for trees to become more

windfirm following exposure to increased wind stresses. Weidman (11) working in ponderosa pine and Cajander (3) in Finland found that the heaviest blowdown occurred the first few years after exposure. Whether this holds true for Douglas-fir, spruce, and hemlock will be the subject of further study.

Table 3.--Tendency of cutting lines to stabilize

Period after cutting	: Volume of windfall	
	: Tract 1-C	: Tract 1-D
	:(18 acres)	:(11 acres)
	<u>M bd. ft.</u>	<u>M bd. ft.</u>
First winter	111	16
Second winter	50	11
Average of third and fourth winters	35	16

In general the literature agrees that winds impose bending stresses on the roots and boles of trees and thus stimulate growth conducive to windfirmness. Fritzsche (6) reported that accelerated growth occurs on the lee side of conifers but on the windward side of hardwoods. Studying exposed trees, Fritzsche (7) found that all conifer stems had their greatest radius on the lee side. This same characteristic proved to be true for spruce and hemlock trees at Cascade Head. Many trees in exposed positions showed indications of accelerated radial growth on the lee side (fig. 4). Measurements of stumps also showed that radial growth was much faster on the lee side (fig. 5).

It was observed that trees with pronounced buttressing on the lee side, though not immune to wind damage, were definitely more windfirm than those without such support. Hence, trees with well-buttressed boles should be left to form the stand margin whenever practical.

Blowdown in Relation to Size of Clearcut

Analysis of storm damage at Cascade Head was necessarily confined to eight staggered settings. This limited sample (table 4) does not indicate that a correlation exists between size of clearcut and amount of blowdown. If other variables were eliminated, storm damage should theoretically vary directly with the length of cutting line exposed. But since windfall is closely related to other factors such as topography, soil, species, and stocking, these other variables apparently exert more effect than size of clearcut.



Figure 4.--The north side of this tree is buttressed with well developed roots, probably as a result of prevailing southerly winds.

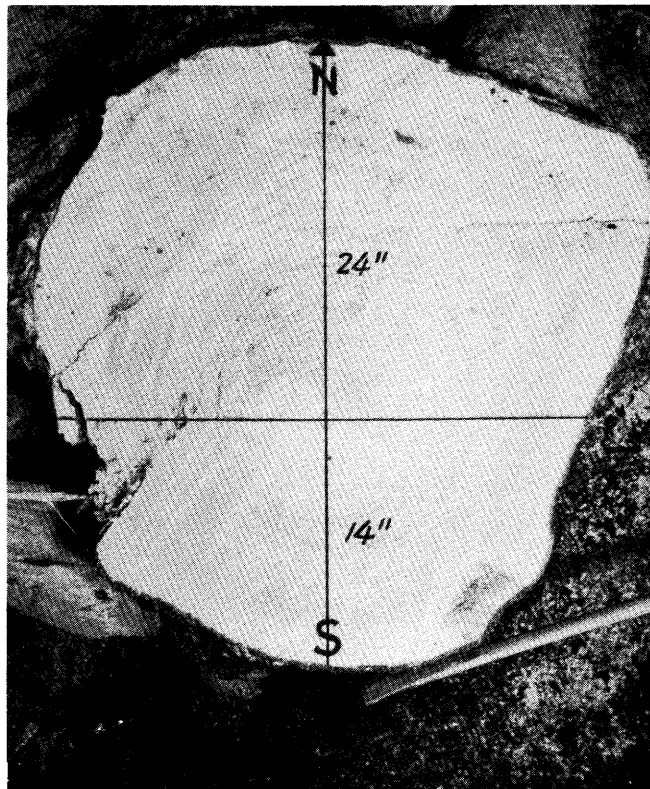


Figure 5.--The stump of the same tree as in figure 4 showing the increased radial growth on the lee (north) side.

Table 4.--Windfall in relation to size of clearcut

Size of clearcut, acres	Annual volume windthrown
	: per acre of clearcut
	<u>Board feet</u>
11.0	1400
13.5	200
15.0	4300
15.5	2800
18.0	3200
22.4	200
37.0	4500
81.0	200

Under current logging methods, it is not practicable to make clear-cut settings small enough to keep the wind from getting in and damaging the trees on the lee side of the opening. At Cascade Head blowdown occurred on the lee side of openings as small as one-half acre. Twenty-five trees were windthrown around the perimeter of a 2-acre clearcut.

If windfall varied directly with the length of cutting line exposed to storm winds, the loss could theoretically be reduced by leaving a minimum of exposed cutting boundary. This has been used as an argument against small clearcuts, in which the perimeter is long in proportion to the area cut. A 40-acre, clear-cut tract, for example, has 1 mile of cutting boundary, compared to only 4 miles of cutting line for a full section with an area 16 times greater. Larger clearcuts do provide more opportunity to place cutting lines in a wind-resistant location, and this may be their greatest advantage.

Blowdown Salvage

If cutting lines gradually stabilize, this tendency should not be reversed by disturbing the cutting line during salvage operations. One of three general procedures could be used:

1. Clear-cut the windfall area if it is practical to move the cutting line back to a more windfirm location.

2. Salvage only the uprooted trees, the broken-topped trees, and the worst leaners in an attempt to develop a wind-resistant border. The boles and roots of the trees that withstood the storm should be protected from further damage or disturbance. Since the standing trees have demonstrated some degree of wind resistance, they can be expected to provide a measure of protection for the stand to leeward. Losses will

probably continue, but on a smaller scale. The wind-resistant trees that are left will, in effect, become an irregular border protecting the main stand. This procedure is applicable only to tractor ground, where repeated salvage is economically feasible.

3. If neither of the above methods is practicable, a third alternative is to clear-cut the trees in the windthrow area and establish a new cutting line. Even though this new line is no more wind resistant than the previous one, there is always the possibility that the damage was caused by an abnormally high wind, and that the winds during the next few years may be less severe. Meanwhile, trees along the new line will have time to become more windfirm.

Windfall in Thinned Stands

Annual windfall losses in the commercial thinnings at Cascade Head averaged only 81 board feet per acre (table 5). Total windfall for a 3-year period was 63,400 board feet, or 244 board feet per acre. These figures are from 4 intermediate cuttings on 260 acres in the 100-year-old spruce-hemlock stand. Sixteen to 24 percent of the original stand volume was removed. The trees cut were mostly in the suppressed and intermediate crown classes although a few of the larger defective or overmature trees were also taken. Care was taken to avoid creating large opening in the crown canopy, but this was not always possible where several defective trees occurred in one group.

Windfall in adjacent unthinned stands (Cascade Head yield plots) averaged only 38 board feet per acre per year over the 5-year period 1945-50, roughly one-half as much as in the thinned acres. However, the removal of suppressed and defective trees from the thinned stands practically eliminated mortality from causes other than wind. In contrast, annual mortality from other causes on the yield plots averaged 499 board feet per acre.

Table 5.--Windfall in intermediate cutting areas, 1949-52

Tract	Area	Stand vol.	Annual windfall
		removed	loss per acre
	<u>Acres</u>	<u>Percent</u>	<u>Board feet</u>
1-B	25	18	250
1-E	100	24	43
3-C	82	20	90
5-C	53	16	30

Because tractor and truck roads had been constructed for the thinning operation, salvage of blowdown timber in the thinned areas has been prompt and economical. Salvage of windfalls in the unthinned stands would not justify road costs unless a commercial thinning were made at the same time.

A high water table in some areas contributed to windfall in the thinned stands. Trees on these sites or around their immediate margins probably should not have been marked.

The Cascade Head thinnings have not sustained large losses even though they were nearing rotation age at the time of the first cut. Experience elsewhere provides strong evidence that early crown thinnings are important in building up the wind resistance of forest trees. Though many American foresters believe that thinnings increase wind losses, European experience strongly indicates that the reverse is true. Heger (8) points out that early and light thinnings increase windfirmness of Norway spruce in Germany. In fact, he recommends a method known as "crown care," largely based on early thinnings as a means of developing wind-resistant protection zones at intervals throughout the forest.

We believe that light and frequent thinnings have an important place in the management of coastal forests, even when started as late in the life of the stand as at Cascade Head. It would have been far more desirable to have begun thinning at a younger age. To minimize wind damage, lighter thinnings probably would have been preferable. Limited observation of heavy partial cuts in the Oregon Coast Range indicates that wind damage to residual stands is usually quite severe, especially when only hemlock or small trees are left. Continued study will help to provide information on better thinning techniques.

Evidence of Old Wind Damage

Old blowdowns can often be traced from evidence which persists on the ground for many years. Mounds of earth, each with an adjoining depression, are good indicators of old windfalls. By locating such mounds, Cline and Spurr (4) found it possible to identify windfalls as old as 150 years.

The length of time this windthrow evidence will persist varies with the character of the soil and with topographic position. The heavy rains at Cascade Head tend to erase such evidence quickly on the finer soils, especially on the steeper slopes along streams. On these sites a uniform slope is restored rapidly after the trees have uprooted. This is also true of swampy spots, which tend to become filled with silt washed down from higher elevations. In contrast, windfall evidence will persist much longer where loose rock is present near the soil surface. Unfortunately, the evidence disappears most rapidly from areas where the blowdown hazard is highest. Evidence of old windthrow should serve as an additional warning in locating cutting lines.

Wood Decay and Wind Damage

Trees infected with rot were observed to be particularly susceptible to wind damage. Too many down trees were included in the study to permit detailed examinations for defect. Since only the obvious cases were noted, it is probable that only a fraction of the total decay was recorded. This was also true of the field data obtained by the Coast Range survey, which showed that defect caused by old snowbreak, ice damage, butt rot, and fire scars contributed heavily to both windthrow and wind breakage on 15 percent of the plots. Sufficient data for a numerical evaluation of this relationship is not available, but it is recommended that trees with definite indications of decay should not be left along the borders of clearcuts or in thinned stands.

Comparative Windfirmness of Different Species

A knowledge of the comparative windfirmness of Douglas-fir, spruce, and hemlock is important if cutting lines are to be located so that the most windfirm species will be left to form a more stable border. To determine relative windfirmness, both down and standing trees in the windthrow area on the lee slope of clear-cut tract 3-B were examined and measured (table 6). On a volume basis, 16 percent of the hemlock, 28 percent of the spruce, and 27 percent of the Douglas-fir withstood the wind. Although 26 percent of the number of trees in all species remained standing, they contained only 20 percent of the original volume. This resulted from two factors: 1. Most trees 30 inches d.b.h. and larger were windthrown; 2. remaining trees were below average height. Apparently hemlock is the least windfirm. Spruce and Douglas-fir were about equal in this respect. Each species was reasonably well distributed over the area and occurred over a wide range of slope and soil conditions.

Table 6.--Stand before and after windthrow on north slope of clear-cut tract 3-B (volumes board feet Scribner)

Time of observation	Hemlock		Spruce		Douglas-fir		All species	
	No. :	Volume	No. :	Volume	No. :	Volume	No. :	Volume
	trees:		trees:		trees:		trees:	
Before windthrow	307	181,080	100	80,890	41	29,660	448	291,630
After windthrow	65	28,370	36	22,320	16	8,140	117	58,830
Percent of original stand remaining	21	16	36	28	39	27	26	20

Because most field plots examined during the survey were in pure stands, information on relative windfirmness of species is not available for the Douglas-fir type. However, on all five plots representing the spruce-hemlock type, spruce was found to be the more windfirm species.

Effects of crown class on windfirmness were also studied. An analysis of Cascade Head data failed to show a positive correlation, probably because the effects of crown class were obscured by several other factors.

Hazards in Poorly Drained Areas

Observations at Cascade Head showed that the uprooting of trees is definitely greater on poorly drained soils. On almost all of the areas studied, the windfall was concentrated in very moist areas and often on steep banks immediately above streams. Skunkcabbage (Lysichiton camtschatcensis) is an excellent indicator of these sites. Impeded drainage had caused most of the trees to develop very shallow root systems (fig. 6). It is important to recognize the fact that swampy spots are not confined to the valley bottoms. They are often found in the draws and the more gentle terrain of higher elevations (fig. 7), where they present a serious windfall hazard. Smith (9) states that windthrow is frequent where a high water table, a hard impenetrable soil, or shallow soil results in shallow root development. He further points out that in many situations soil conditions may be fully as important as topography in determining the risk of windfall.

In locating cutting lines the best procedure is to avoid areas where the trees have been forced to develop abnormally shallow root systems because of physiologically or mechanically shallow soil.

One often hears the statement, "Sitka spruce and western hemlock are shallow-rooted species." Heavy windthrow in the spruce-hemlock type is, in turn, often attributed to shallow rooting alone. There is no doubt that these species are shallow-rooted in areas with very shallow soils or a high water table. Observations at Cascade Head, however, indicate that both species will develop root systems about as deep as Douglas-fir if soils are deep and reasonably well drained. The few uprooted trees found on well-drained areas left holes up to 4 feet and more in depth (fig. 8). Broken roots in the bottom of the holes indicated an even greater penetration. Perhaps it is not correct to label the two species as "shallow-rooted" in view of the apparent variability in root development.

Windfall in Virgin Stands

The blowdown and bark beetle survey afforded an excellent opportunity to examine the characteristics of windthrow in virgin stands over the large area of the Oregon Coast Range. On 59 plots in virgin stands a tabulation was made of the windfall in relation to topographic



Figure 6.--An uprooted Sitka spruce 34 inches d.b.h., showing how root penetration was restricted by a high water table. Deepest root penetration of this tree was about 10 inches.



Figure 7.--Blowdown was heavy in this flat, poorly drained area with a high water table. Blowdown was negligible on the higher ridge top east of this point.



Figure 8.--Uprooted Sitka spruce 48 inches d.b.h. that grew on moderately well-drained soil. Broken roots indicate that root penetration was more than 4 feet.

position. Most of the damage occurred on the ridge tops, upper slopes, and middle slopes, as the following tabulation shows:

<u>Position</u>	<u>No. of samples</u>
Ridge top	27
Upper slope	34
Middle slope	29
Lower slope	11
Creek bottom	6

In many situations the blowdown losses were distributed over several of these positions. For that reason the total number of samples is greater than the total number of plots.

The tendency for damage to occur on ridge tops and upper slopes is described and explained in the literature. French (5) states:

The general effects of a strong wind over a mountain barrier are an accelerated wind speed and reduced pressure over the crest, and turbulence and relatively low pressure on the lee side.....Also, the increase of wind velocity over the crest is likely to be greater over a ridge when the wind is blowing at right angles to it than over an isolated peak, as in the latter case much of the air can escape around the peak and does not have to be lifted over the peak.

Smith (9) describes how a southwest wind blowing against a mountain would cause the most damage on the northwest and southeast sides and in the lee of the crest of the mountain. The damage in the lee of the crest occurs because of the constriction of the air channel in the vertical plane. He states that a southwest wind blowing across a ridge would cause damage in the immediate vicinity of the crest, both to leeward and to windward.

We spent several days flying over the Oregon Coast Range to observe the general characteristics of the storm damage. It was possible to obtain an excellent view of the larger windfall areas and to check their relation to specific topographic features, for it is much easier to evaluate wind damage from the air than on the ground. A definite and fairly consistent relation between windfall and topography was apparent. By far the largest volume of wind damage in the Oregon Coast Range was on the lee slopes. The damage usually started at the ridge top and extended for some distance down the lee slope (fig. 9). This was true for 11 of 17 large areas of windfall that were observed and described from the air.

Downslope winds on lee slopes usually caused little damage if the slopes were steeper than 70 percent. Apparently these slopes were too steep for the wind to adhere to them although several 70 percent slopes had some damage. Smith (9) stated that where valleys were deep and narrow, winds blowing at right angles to the valleys caused little damage either



Figure 9.--Very heavy blowdown in the Cape Creek drainage of the Siuslaw National Forest. The wind blew up the main drainage from right to left. The damage is most severe on lee slopes of secondary ridges.

in the bottoms or on the lower slopes. Writing about New England forests, he concluded that gusts of wind in excess of 75 miles per hour are necessary to rupture the supporting roots of a forest tree enough that the tree can be blown over by steady winds of lower velocity.

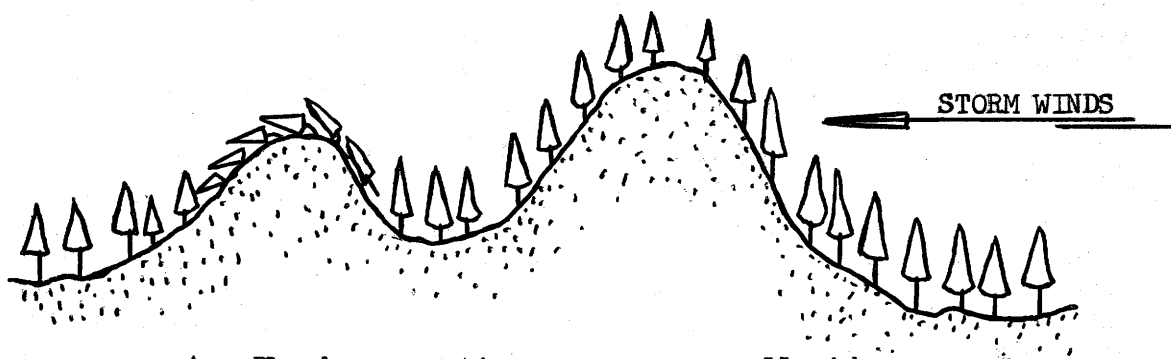
Of the six large blowdown areas that were not in the lee of the crest of a ridge, two were located on tops of smaller ridges that were in the lee of a main ridge (fig. 10-A). One of these areas contained scattered patches of windfall on small ridges and flats, all in the lee of a high main ridge to the southwest. In three areas the damage was on a flat in the lee of a long steep slope (fig. 10-B). In the sixth area, losses occurred in the lee of a saddle in a main ridge. This is one location where serious storm damage can be expected. According to Smith (9), the greatest damage occurs where the wind is concentrated into gaps between hills.

Where storm winds parallel a main ridge, the winds apparently funnel up the valley at high speeds. According to Smith, storm winds tend to assume a direction parallel to the valley, especially when the valley has steep high sides. As wind flows up a valley, lines of airflow become more and more concentrated and the force increases. At Cape Creek, one of the largest blowdown areas observed, the wind blew over a ridge, then funnelled up the main valley and caused severe blowdown on the tops and lee slopes of secondary ridges that were at right angles to the wind. Three other windfall areas were observed where the wind funnelled up the main valley. In one, the creek forked and severe damage occurred on the ridge between forks.

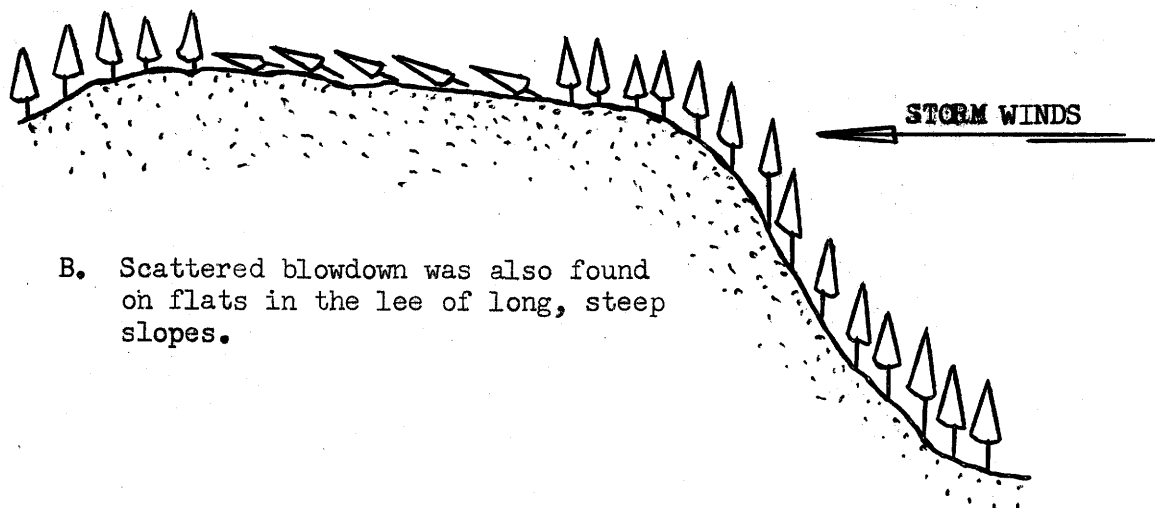
During a full day of observing windfall from the air, not a single case was noted where isolated conifers growing as scattered dominants in stands composed predominantly of red alder had been windthrown. The long crowns and exposed position of open-grown conifers evidently foster exceptionally high resistance to windthrow.

Protection Zones and Stand Borders

Protecting growing forests against wind damage is a primary objective of much European silvicultural practice. A method recommended by Heger (8) and others is the establishment of wind-resistant protection zones. These are made by planting the most wind-resistant hardwoods and conifers in belts about 100 feet wide; zones are placed at the edge of the forest, and at frequent intervals within the stand, and they are always at right angles to the prevailing winds. Mixed stands are more windfirm than pure stands--on this point the literature is in agreement. Protection zones are planted after the mature stand is cut and the trees for the next rotation are being established. Long crowns are maintained through early and frequent thinnings (termed "crown care") which delays natural pruning of lower branches.



A. Blowdown sometimes occurs on small ridges in the lee of a high main ridge.



B. Scattered blowdown was also found on flats in the lee of long, steep slopes.

Figure 10.--Position of blowdown in relation to topography.

According to Heger, building up protection zones is possible only in young stands, although older stands can be made more windfirm by planting an understory of tolerant species. Protection zones should be started when cutting and regenerating the mature forests so that the zones will protect the next generation.

A method of increasing wind resistance similar to that of establishing protection zones is to develop stand borders that will gradually lift the strong winds up to the level of the main forest canopy (fig. 11). This protects the edge of the main stand and also lessens the danger of turbulent downdrafts toppling trees in the interior of the stand. Heger (8) states that the stand borders should be thinned frequently to keep the trees windfirm, long crowned and growing rapidly.

Measures of this kind require far more intensive forest management than may be practiced in the Oregon Coast Range for many years to come. Nevertheless, these measures should be considered for certain windswept sites along highway strips and other areas of high scenic and recreational value. The techniques could be developed on these sites so that they would be available to future forest managers when more intensive practices come into wider use. Meanwhile, the forester and logger should recognize and use natural stand borders and protection zones wherever they occur.

CONCLUSIONS AND RECOMMENDATIONS

Although present information on wind damage is far from complete, there is no doubt that damage associated with clear-cutting in the Oregon Coast Range can be substantially reduced through improved cutting practices. Blowdown has been a major cause for concern, but its prevention has seldom been considered in the cutting plan because the factors that effect blowdown have not been known.

The following recommendations are made in an effort to fill this need. Some are based on fairly complete data, some need to be strengthened or modified by further research, and others are based entirely on general observations.

Cut in Progressive Strips

Since wind damage is concentrated along north and east boundaries of clear-cut areas, the key to control is to eliminate those boundaries. There is nothing new in this method or its variations. It is the basis for the European schemes of progressive strip cutting and the "wedge system" described by Troup (10). Modification of these systems, when geared to western logging practice, should work equally as well in Oregon as in Europe.

A logging plan applying progressive cutting into the wind on the Cascade Head Experimental Forest is shown in figure 12. The first cut could be in staggered clear-cut tracts spaced along the 3-mile strip of pasture and cut-over lands which form the northern boundary of this unit. Storm damage should be held to a minimum because the winds will pass off into the pasture and cutover.

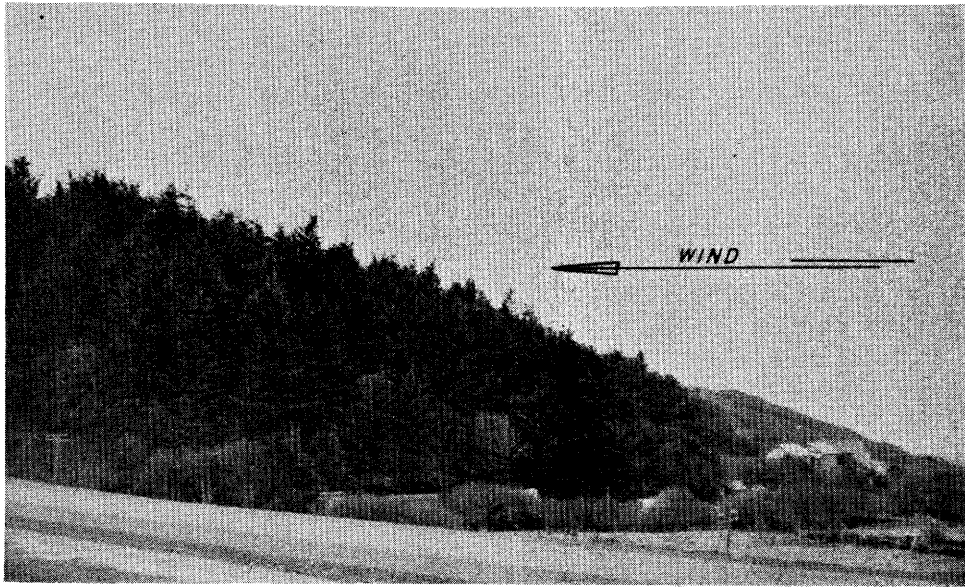


Figure 11.--A natural stand border, stabilized against storm winds along the Oregon Coast.

The second step would be to cut the leave units along the same road level, eventually resulting in a long clear-cut strip.

Then staggered settings would be cut along successively higher road levels so that cutting would progress slowly to the southwest. Cutting would thus proceed up the lee (north) slope of the main ridge and down the windward (south) slope without leaving a north or east boundary exposed to storm winds.

Assuming that a complete rotation will be required for cutting the unit, a series of age classes will be developed with the youngest stands on the windward side, and the oldest stands on the leeward side (fig. 13). The step-like formation of age classes will tend to lift the wind up and over the stand and windfall losses associated with clear-cutting should be minimized.

Where to start progressive cuttings poses an important question. Ideally, the best choice would be a large natural opening, such as a pasture, a cut over, or an area supporting reproduction or brush. Red alder stands also provide good starting boundaries because alder is relatively windfirm. Lacking any of these, a logical starting point would be along the north and east boundaries of the ownership. If neither north nor east boundaries can be used, cutting could begin on a windward slope where a cutting line should stabilize more quickly and with less windthrow than on a leeward slope.

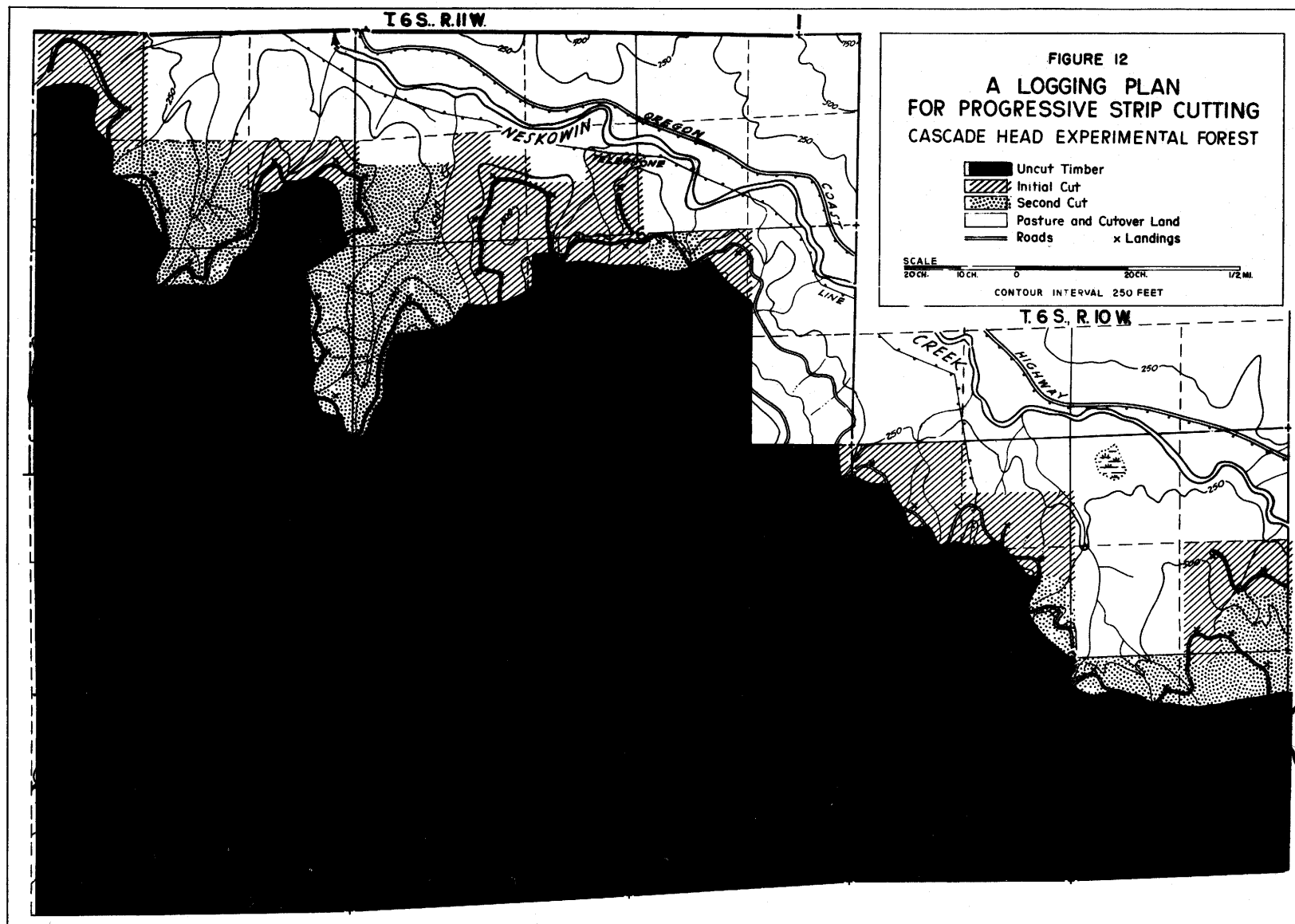
Large scale progressive strip cutting would probably create a number of regeneration and fire protection problems. No attempt will be made to analyze them here, but we do want to emphasize that it would be an advantage to have the cuttings progress slowly to windward and thereby allow adequate time for regeneration. This would also tend to reduce the fire hazard. In large ownerships this type of cutting could be done by having several progressive strips--each one as long as practicable.

Select Windfirm Cutting Lines

Whatever the method of clear-cutting--by progressive strips, staggered settings, or variation of these methods--the cutting lines selected should be as windfirm as possible. Some important points in choosing the most windfirm location are:

1. If practical, locate the north and east boundaries on windward slopes where the trees have already been exposed to storm winds throughout their lives and developed a degree of windfirmness. Windfirm trees usually have crowns with a windswept appearance, boles with more than normal taper, and enlarged leeward prop roots.

2. Leave only sound trees along the cutting line. Defective trees are usually poor windfall risks. This is especially true of trees with butt rot or root rot.



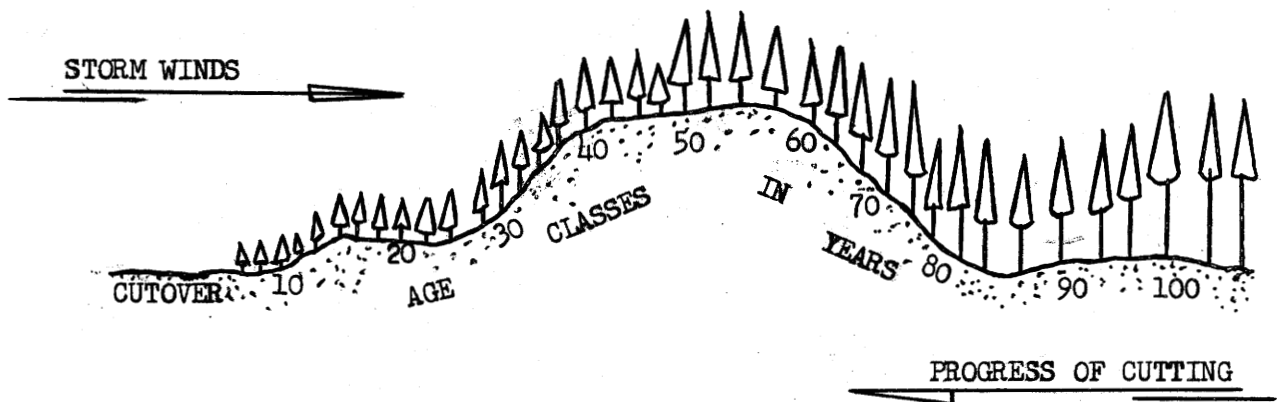


Figure 13.--Progressive strip cutting would result in this distribution of age classes at the end of the first rotation.

3. Leave poorly stocked stands as borders. Open stands are usually more windfirm than dense stands because individual trees have developed windfirmness.

4. Avoid areas of high water tables, or shallow or moist soils when selecting cutting lines. Trees on such sites are highly susceptible to windthrow because of shallow root development. Remember that these areas are not confined to the valley bottoms, but are often found on upper slopes.

5. Avoid leaving hemlock as a stand border tree; it is believed to be less windfirm than either Douglas-fir or Sitka spruce.

6. Choose red alder stands or stands of mixed alder and conifers as stand borders. Very little blowdown was observed in these stands, and in case of damage the economic loss would be less than in a pure conifer stand.

7. Choose young stands (under 50 years) as stand borders. Young stands are often more windfirm. They also have the ability to develop increasing windfirmness when exposed to wind.

Make Clearcuts Large Enough

Blowdown often occurs around clear-cut tracts of 1 acre or less. Clearcuts small enough to eliminate this loss are impractical in most parts of the Oregon Coast Range. Other factors, such as economic yarding distance, seed source, and fire hazard probably should govern the size of clearcuts. The larger tracts now in general use allow for greater flexibility in selecting windfirm cutting lines.

Plan Ahead for Salvage

Some windthrow will take place in spite of all precautions. Most of the losses will be along the north and east boundaries of the clearcuts. It is very important to locate roads and cutting lines so that salvage will be practical. Maintenance of a permanent forest road system will greatly facilitate periodic salvage operations.

Use Intermediate Cuttings to Develop Windfirmness

Light intermediate cuttings, if started at an early age and repeated frequently, should increase the windfirmness of residual stands. The literature strongly supports this view. At present, the experimental evidence at Cascade Head is limited to a three-year thinning record. Observations of the greater windfirmness of stands with naturally low density also emphasize this point.

Continue Wind-Damage Studies

Much remains to be learned about wind damage in coastal forests and about ways to reduce or prevent the damage. Specific studies should be made to answer the following questions:

1. How much blowdown can be eliminated by progressive strip cutting?
2. What is the effect of progressive cutting on natural regeneration and fire hazard?
3. Can wind damage be reduced by light, frequent thinnings in young stands?
4. What are the characteristics of windfirm trees?
5. How can windfirm trees be recognized in the woods?
6. What is the relative windfirmness of the different species in the Oregon Coast Range?
7. What is the best way to establish a windfirm stand border?

Meanwhile, this preliminary report should serve as a helpful guide until better methods of reducing wind damage are developed.

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