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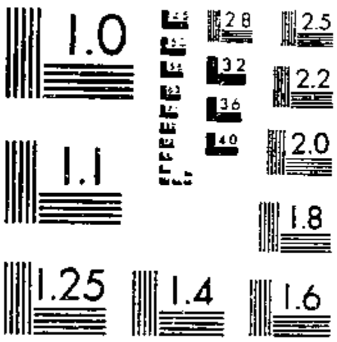

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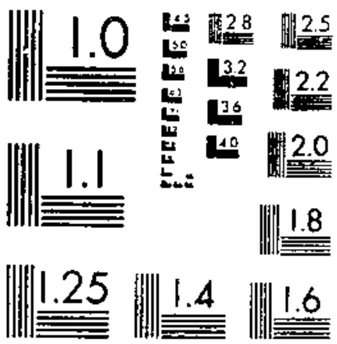

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Decay and Other Volume Losses in Wind-thrown Timber on the Olympic Peninsula, Wash.[1]

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INTRODUCTION

Winds of average velocity may occasionally cause appreciable losses of merchantable timber in stands where cutting has suddenly exposed the trees to their full force, and winds of unusually high velocities, sometimes approaching cyclonic force, not infrequently result in the partial or complete blow-down even of virgin stands over rather extensive areas. A storm of the latter character, the details of which have been presented by Boyce in previous publications,[4] occurred on the west side of the upper Olympic Peninsula of Washington on January 29, 1921. Similar storms had undoubtedly

[1] Submitted for publication January 18, 1940.

[2] The authors are particularly indebted to J. S. Boyce and H. G. Lachmund, formerly pathologists, successively in charge of the Portland (Oreg.) office of the Division of Forest Pathology; to the former for outlining the study herein reported and for supervising the 1926 field examination; and to the latter for directing the 1929 field examination. Acknowledgment is extended to E. G. Mason, professor of forestry at Oregon State College, for his efficient services as chief of party in conducting the field work for the Division in 1926 and 1929. The following men were of valuable assistance in the routine collection and compilation of data: J. W. Kimmey and T. W. Childs, members of the Division of Forest Pathology; D. H. Janzen, A. A. McCready, and C. V. Lovin, formerly of that Division.

[3] Stationed at the branch office maintained at Portland, Oreg., by the Division of Forest Pathology, in cooperation with the Forest Service, U. S. Department of Agriculture.

[4] Boyce, J. S. Losses in wind-thrown timber. Timberman 28 (10): 178, 180, 182, 184, 186. 1927.

——— Deterioration of wind-thrown timber on the Olympic Peninsula, Wash. U. S. Dept. Agr. Tech. Bul. 104, 28 pp., illus. 1929.

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occurred in the area between the coast and the summit of the Cascade Range in Oregon and Washington long before this region was settled by white men. Even more complete but less extensive blow-downs than the historic Olympic one have occurred in western Oregon and Washington in more recent years. Seven such areas of wind-thrown timber are known to the authors and other unreported areas probably exist. It seems logical to conclude, therefore, that destructive windstorms have taken their toll of these forests since time immemorial and that similar storms will occur in future years.

As will be shown later, the volume and also value of salvable wind-thrown timber rapidly decrease with the passage of time because of the inroads made by insects and fungi. At the time of the Olympic blow-down this area was relatively inaccessible and extensive salvage operations were economically impracticable. It was consequently possible for the Division of Forest Pathology to study the progressive deterioration of this timber. By 1926, only 5 years after the storm, sufficient data had been collected to provide the basis for United States Department of Agriculture Technical Bulletin No. 104.[5] Since that time, however, the condition of this wind-thrown timber has altered materially, and the detailed data for the 15-year period immediately following the storm are presented in this bulletin as a guide to those who may be concerned with the problem of salvaging such timber in the spruce-hemlock and Douglas fir old-growth types of the coastal section of Oregon and Washington.

METHOD OF STUDYING LOSSES IN WIND-THROWN TIMBER

All studies were made in the lower valleys of the Calawah, Bogachiel, and Hoh Rivers in the vicinity of Forks, Wash. The species studied were Douglas fir (*Pseudotsuga taxifolia* (Lam.) Brit.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), silver fir (*Abies amabilis* (Loud.) Forbes), and western red cedar (*Thuja plicata* D. Don). General observations were made during August 1921, 1922, 1923, and 1924.[6] The first detailed study was conducted during the summer of 1926, 5 years after the timber was blown down. A similar study was conducted in the summer of 1929, and a third (and perhaps final) detailed examination was made 15 years after the storm.

In conducting the detailed examinations it was necessary to open up the trees for inspection and the required measurements. This was done by chopping into them on both sides, at the points where they would have been bucked in accordance with close utilization practice, to a depth sufficient to permit measuring the extent of decay and of sapwood. The first two butt logs were made 16 feet long, plus trimming allowance in accordance with Forest Service specifications, to avoid excessive errors in computed volume resulting from butt swell. All other logs were from 16 to 32 feet long, plus trimming allowance. In keeping with maximum utilization a top diameter limit of 8 inches inside bark was employed as the limit of mer-

[5] See footnote 4, p. 1.

[6] All observational data were taken by J. S. Boyce. Subsequent discussions of these data, as taken up under individual tree species, are based on the data presented in U. S. Department of Agriculture Technical Bulletin No. 104.

chantability; all portions above this diameter were simply classed as "top" and only linear measurements were taken. Diameters were taken with calipers or a diameter tape as conditions permitted and were recorded to the nearest 0.1 inch. Lengths were measured with a steel tape. All board-foot values were determined from the Scribner Decimal C log rule.

Early in the course of the first detailed examination it became apparent that there were four distinct sources of volume loss in the wind-thrown trees. Losses from breakage and from excessively high stumps were incurred during the storm and have changed but little since that time. The third and fourth sources of loss were insect damage and decay, respectively. From the discussions of these losses for the individual tree species, it will be seen that insect losses were greater than decay losses only during the earliest years of deterioration. The decay loss, in contrast to that from the other sources, ordinarily became much greater with each succeeding year and within a few years overshadowed that caused by insects. In this study it was impracticable to separate insect losses from decay losses; therefore, unless otherwise specified, both sources of loss are included in the decay data as presented throughout the remainder of this bulletin.

Determination of Breakage Losses

Broken portions of trees were treated as would have been done in actual bucking practice. Keeping the adjacent log lengths in 2-foot multiples the hypothetical points of bucking were placed as near the ends of the break as possible. The board-foot volume of this broken section was then determined. For example, if it was found necessary to cut out an 18-foot section having a 28-inch top diameter inside bark (d. i. b.), the volume of this section (650 board feet) was charged as loss from breakage. The total volume lost through breakage was determined by adding the volumes of all broken sections in the tree.

For industries using chipped wood as their raw material, the cubic content of logs more nearly represents their true conversion value than does the board-foot unit. With perfect utilization by such industries there would be no cubic-foot loss resulting from breakage. To permit direct comparison of board- and cubic-foot losses, however, the cubic content of broken sections was also determined. For 1926 this loss was determined by applying Smalian's formula [7] to the sections that would have been bucked out under board-foot methods. In 1929 and 1936 each tree was plotted on Forest Service Form 558a,[8] and the cubic content of broken sections was determined by planimetering the plotted area and multiplying this figure by the proper conversion factor.

Although breakage data were taken at each detailed examination only small differences were found. As the greatest number of trees was sampled in 1926, breakage data for that year only are used throughout the remainder of this bulletin.

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[7] Smalian's formula for cubic-foot content of logs: $(B+b)\frac{h}{2}$, in which B=basal area of the large end of the log in square feet, b=basal area of the small end in square feet, and h=length of the log in feet.

[8] For a discussion of this form and its use, see the following: CHAPMAN, H. H., and D. B. DEMERITT, ELEMENTS OF FOREST MENSURATION. 452 pp., illus. Albany, N. Y. 1932.

Determination of Losses in High Stumps

When the trees blew down they did not fall in an orderly, parallel fashion as though felled by skilled timber fallers, but on the contrary were crisscrossed in every conceivable manner. For this reason it was not always possible to make the theoretical butt cut at what would have been the usual stump height for standing timber. For this study, 4 feet was determined as a representative stump height. Thus, where it would have been necessary to leave a 6-foot stump, 2 feet of the stump was considered as a loss directly attributable to wind throw. The board-foot volume of this stump section was determined by subtracting the volume of the 16-foot butt log from that of a log of the same top diameter inside the bark but whose length exceeded 16 feet by an amount equal to the length of the section wasted in the stump. For example:

	Feet
Lowest height at which stump could be cut	6.0
Usual stump height for standing timber	4.0
Loss in length	2.0
	Board feet
Scale of a 40-inch log, 18 feet (16+2) long	1,350
Scale of a 40-inch log, 16 feet long	1,200
Lost in high stump	150

In computing the cubic-foot volume losses in high stumps for 1926 the entire stump section was treated as a cylinder having a diameter the same as the actual top diameter inside the bark of the stump. For a 6-foot stump 50 inches in diameter the cubic volume lost was considered equivalent to the volume of a cylinder 2 feet long and 50 inches in diameter. In computing the total cubic-foot volume of the trees the volume present in stumps of the usual height was also included. In this example that volume would be equivalent to that of a cylinder 4 feet long and 50 inches in diameter. Obviously there was some volume error involved in this method, but the actual error was considered too small to justify a more precise determination. In 1929 and 1936 the loss in high stumps was computed by planimetering the area of the waste section as plotted on Forest Service Form 558a. The cubic content of the usual 4-foot stump was also determined by planimetering it as a cylinder whose diameter equaled that at the top of the actual stump inside the bark.

Data taken in the different years on the losses from high stumps showed but small differences, due primarily to variations in sampling. Throughout the remainder of this bulletin only the 1926 data for losses in high stumps are presented, as the basis secured in that examination year was larger than in either of the others.

Determination of Decay Losses

In this study only decay that had occurred since the trees were wind thrown was considered. Standing timber in the storm area is relatively sound and such decay as is present is confined almost entirely to the central portion of the heartwood. Because decay in the down timber began in the outer sapwood and worked in, little difficulty was experienced in separating this decay from that which was present before the trees were blown down. In computing the losses in this timber the early (incipient) as well as the late (typical) stage of decay was included, as all stages of decay result in either volume or quality losses, or both. From the standpoint of log merchantability it makes little difference which fungi are responsible for the decay; the wood-destroying fungi found active in this wind-thrown timber have, therefore, been discussed in a separate paper.[9]

In board-foot volume computations the loss from decay was figured only in relation to the volume remaining after deducting that lost through breakage and high stumps. That is, decay data were taken only on those portions in which decay was the only source of volume loss. The decay in wind-thrown timber invariably occurred in the peripheral region of the log and usually extended completely around the circumference. Occasionally, however, only a fractional part of the circumference was affected, and the depth of penetration was not always uniform on all sides of the log. When the depth of penetration was not uniform that side of the tree in contact with the ground showed the least decay. In any event, the volume of the sound inner core was scaled by taking its average diameter. Subtracting the volume of this core from the gross volume of the log gave the board-foot loss from decay. Assuming, for example, a 40-inch, 32-foot log with a peripheral zone of decay extending to a depth of 4 inches in the upper half of the circumference and to a depth of but 2 inches in the lower half:

	Board feet
Scale of a sound 40-inch, 32-foot log	2, 410
Scale of the 37-inch sound core (40-inch) $-\left(\frac{\text{4-inch}+\text{2-inch}}{2}\right)$	2, 060
Volume lost through decay	350

Unless, however, it was possible to make a log at least 8 inches in diameter and 16 feet long from the sound core, the entire log was classified as unmerchantable under board-foot standards. Thus a 16-foot log having an 8-inch d. i. b. was automatically classed as unmerchantable if it had as much as 1 inch of circular defect. Total decay was determined by totaling the volume of decay for all the individual sections having that defect only.

In the board-foot computations some error may have been introduced through the handling of fractional inches of diameter. For the sake of uniformity all fractional measurements of 0.5 inch or less were rounded off to the next lower inch and all fractional measurements of 0.6 inch or more were rounded off to the next higher inch. This procedure probably resulted in minor error on the individual log, but when all logs in a tree and all trees in a given diameter class were combined these errors tended to become compensating.

The cubic-foot volume loss caused by decay was figured in relation to the entire volume of the tree, i. e., decay data were taken on broken sections and long stumps as well as on sections otherwise merchantable. In determining the loss from decay the method employed in 1926 was basically the same as for board feet. The gross volume of the log was determined by Smalian's formula. The volume of the sound inner core was similarly determined with its average

[9] BUCHANAN, T. S. FUNGI CAUSING DECAY IN WIND-THROWN NORTHWEST CONIFERS. Jour. Forestry 38: 276-281. 1940.

diameter calculated in the same way as for board feet. The difference between these volumes gave the cubic-foot decay loss. For the 1929 and 1936 data the sound-core volume and the decay volume were computed independently by planimetering the respective areas as plotted on Forest Service Form 558a and applying a correction factor for degree of circular defect. Comparing the planimetered area of the gross volume of the log with the sum of the two component parts provided an excellent check on the accuracy of the computations.

Determination of Total Tree Volume

In board-foot computations the total tree volume included that portion of the tree between the usual stump height (4 feet) and an 8-inch top diameter inside the bark. To determine this value the volumes of all individual sections (including high stumps, broken sections, sound logs, and decayed logs) into which the tree would have been divided under actual bucking practice were combined.

The total cubic-foot content of the tree includes the volume of all sections enumerated above and also that of the usual stump and of the top beyond an 8-inch d. i. b. The top section was treated as a cone in determining its cubic content in 1926, and in other years this volume was determined by planimetering the plotted measurements.

Determination of Sapwood Volume

The sapwood of wind-thrown trees of the species studied is much more susceptible to decay than the heartwood. As decay in such timber almost always enters through the sapwood and must penetrate through that zone before entering the heartwood, it was considered desirable to determine the percentage of sapwood present in the various trees and logs.

The sapwood volume was determined only in 1926, for in subsequent years the progress of decay made accurate measurements impossible. Sapwood measurements were taken only on those trees in which the color demarcation between heartwood and sapwood was distinct and hence the basis of trees employed does not always check with the total number of trees examined. The sapwood volume, both in board feet and in cubic feet, was determined in the same manner as was the decay volume. The sapwood zone was treated just as the decay zone and the heartwood was treated the same as the sound inner core. A slight error was incurred in the cubic-foot volume computations for tops beyond the 8-inch d. i. b. limit by assuming the heartwood to be in the form of a cone whose tip corresponded to the top of the tree.

LOSSES IN WIND-THROWN DOUGLAS FIR

No decay was apparent in the wind-thrown Douglas fir trees when examined 7 months after the blow-down. Sap stain was present only where the ends of the logs had been exposed by cutting to clear roads and trails and in a few trees that had been attacked by ambrosia beetles. By August 1922 there had been a slight increase in the beetle attack and even an occasional tree that had not been so attacked showed slight blue staining. Very slight and superficial decay was noted in a few places where the bark had been knocked off when the trees fell.

In August 1923 60 trees, which had been opened up by wood cutters, were examined and all except 1 were found to be sound. In this tree, decay had penetrated to a depth of 1.5 to 2.0 inches on the top one-fourth of the circumference for a linear distance of about 90 feet. About 15 percent of the trees had been attacked by ambrosia beetles, and these trees showed blue-stained sapwood but only in the vicinity of the insect galleries. The bark was beginning to slip and fungus mycelium was occasionally noted under the bark.

By August 1924 the sapwood was commonly found to be appreciably decayed. This decay was confined largely to the upper half of the circumference of the down trees. The absence of decay on the under sides was particularly noticeable in trees in direct contact with the ground.

Detailed Tree-Volume-Loss Data

Table 1 shows the results, by 4-inch tree diameter classes, and in both board and cubic feet, of the detailed examinations. From this table it is evident that breakage losses in Douglas fir are very definitely influenced by tree size—the larger the tree the greater the percentage loss. The losses in high stumps are much smaller and apparently bear but little relation to the size of the tree. To illustrate more clearly the relationships between sapwood and decay for trees of various diameters these data from table 1 are presented graphically in figures 7, *A*, and 9, *A* (pp. 24 and 26).

It is evident that approximately 35 percent of the gross board-foot volume for the average 20-inch tree is sapwood (fig. 7, *A*). The larger the tree the smaller was the percentage of sapwood, until for trees approximately 78 inches in diameter it made up only 17 or 18 percent of the gross volume. By 1926 decay had caused a loss in merchantability at least equal to the sapwood volume except in trees more than 65 inches in diameter. By 1929 decay had made definite progress in the heartwood of all trees examined. In 1936 trees 70 inches in diameter had suffered a percentage loss from decay equal to that found in 40-inch trees 7 years earlier. In interpreting these board-foot curves it must be borne in mind that logs 16 inches or less in diameter were classed as 100-percent cull if more than one-half decayed and that logs exceeding that diameter were classed as 100-percent cull if more than two-thirds decayed. The decay curves in figure 7, *A*, therefore, represent the effect of decay on tree merchantability rather than on actual sound volume.

To show the percentage of total volume actually decayed, the cubic-foot data from table 1 are presented graphically in figure 9, *A*. The general relationships between percentage of decay and tree diameter are similar to those as found under board feet.

Detailed Log-Decay Data

To show more clearly the relationship of decay to volume units of given diameters the data for the logs that could have been made from the trees of table 1 are presented by 2-inch diameter classes in table 2. Data in this table are for those logs in which decay was the only defect influencing the merchantable volume. The board-foot data in table 2 differ from those in table 1 in that columns have been added showing the actual average percentage of decay in each log-

TABLE 1.—*Losses in wind-thrown Douglas fir trees in 1926, 1929, and 1936*

Diameter breast high		Trees examined			Average height [1]	Average gross volume [1]		Sapwood [2]		Broken in falling [2]		Lost in stump [2]		Loss through decay					
Class (inches)	Average [1]	1926	1929	1936				Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume [3]			Percent of cubic-foot volume		
														1926	1929	1936	1926	1929	1936
	Inches	*Number*	*Number*	*Number*	*Feet*	*Board feet*	*Cubic feet*												
14	14.2	-----	1	-----	125.0	310	75.5	-----	-----	-----	-----	-----	-----	-----	100.0	-----	-----	53.8	-----
18	18.9	1	1	-----	145.2	415	94.5	35.2	29.3	5.6	5.7	0	0	35.2	74.1	-----	30.8	42.9	-----
22	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
26	27.1	1	-----	-----	168.5	1,020	194.6	45.1	35.1	0	0	0	0	45.1	-----	-----	26.2	-----	-----
30	29.8	11	8	-----	174.8	1,600	274.8	30.2	24.3	8.0	9.7	3.3	3.2	32.9	32.7	-----	23.8	23.5	-----
34	34.4	10	9	-----	188.9	2,189	368.3	22.8	18.8	6.5	6.4	3.8	4.1	28.8	34.4	-----	17.9	25.7	-----
38	38.5	19	9	2	192.6	2,782	457.1	24.2	21.4	5.5	6.7	2.1	2.2	25.0	29.3	36.6	17.9	23.2	31.9
42	41.9	12	8	4	196.8	3,413	552.4	22.2	19.6	11.4	12.5	2.5	2.5	24.1	28.8	41.8	17.6	23.3	33.2
46	45.9	10	8	5	205.8	4,428	690.7	22.1	19.7	12.5	13.4	3.9	3.9	23.6	28.6	33.0	18.4	24.6	29.5
50	49.8	13	7	4	214.8	5,379	838.4	20.9	18.6	14.6	14.9	2.6	2.8	21.8	25.1	37.9	17.0	22.0	33.4
54	53.6	11	7	4	217.3	6,491	1,002.9	20.2	18.6	13.4	14.9	3.1	3.3	20.8	28.2	40.0	16.5	25.3	37.2
58	57.6	3	10	5	213.1	7,522	1,159.1	16.7	14.5	12.3	14.6	4.0	4.7	24.7	22.9	30.4	16.3	19.9	30.3
62	61.9	9	9	6	220.7	9,003	1,334.1	19.9	17.2	14.2	16.2	4.3	4.8	19.7	25.0	34.4	16.1	22.8	33.1
66	65.5	6	7	4	226.4	9,934	1,504.4	19.2	17.6	17.5	18.0	3.2	3.4	18.2	20.9	25.5	16.1	18.7	28.3
70	70.1	4	7	5	224.9	11,879	1,732.5	17.9	16.4	16.1	17.0	7.4	7.2	17.3	19.2	36.2	14.2	17.7	24.7
74	73.8	1	1	1	222.9	13,337	1,966.7	12.5	12.4	.4	1.4	1.0	1.0	14.5	19.4	32.9	12.3	19.5	32.1
78	77.5	1	-----	-----	232.1	15,630	2,248.2	17.8	17.8	15.7	17.6	7.7	7.1	18.1	-----	-----	17.8	-----	-----
82	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
86	85.0	-----	-----	1	202.0	12,310	1,806.0	-----	-----	-----	-----	-----	-----	-----	-----	25.8	-----	-----	32.9
90	90.0	-----	-----	1	206.0	14,270	2,140.8	-----	-----	-----	-----	-----	-----	-----	-----	23.5	-----	-----	18.2
Total or average	49.3	112	92	42	205.5	5,715	878.4	20.6	18.5	12.6	13.6	3.6	3.7	24.2	28.2	34.3	16.9	23.0	30.9

[1] Average for all years combined.
[2] Data as of 1926.
[3] Percentage loss in merchantability because of decay.

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TABLE 2.—*Decay losses in logs otherwise salvable from wind-thrown Douglas fir trees in 1926, 1929, and 1936*

Diameter inside bark at small end		Basis of logs			Sapwood [2]		Loss through decay								
Class (inches)	Average [1]	1926	1929	1936	Percent of board-foot volume	Percent of cubic-foot volume	Percent of actual board-foot volume			Percent of merchantable board-foot volume [3]			Percent of cubic-foot volume		
							1926	1929	1936	1926	1929	1936	1926	1929	1936
	Inches	*Number*	*Number*	*Number*											
8	8.1	24	35	26	37.5	38.6	39.4	73.7	85.8	46.2	100.0	96.4	38.2	46.9	67.1
10	10.8	11	15	------	47.9	34.0	42.7	69.6	------	57.3	100.0	------	33.7	42.8	------
12	12.5	21	20	5	38.7	30.7	35.9	45.0	72.0	43.9	69.1	100.0	31.8	32.1	50.2
14	14.5	28	22	4	37.1	30.0	34.5	42.9	65.6	39.5	61.5	87.8	29.5	32.8	64.8
16	16.6	35	26	10	30.9	24.9	31.7	39.2	67.7	35.7	40.9	85.9	23.6	30.8	50.0
18	18.6	38	34	9	31.7	22.6	30.1	34.5	58.0	30.1	34.5	58.0	22.6	26.6	50.0
20	20.6	46	40	15	26.0	21.0	26.4	23.9	53.8	26.4	33.9	58.1	20.6	24.9	41.8
22	22.6	46	37	14	21.9	20.2	20.5	28.0	48.0	20.5	28.0	48.0	18.3	23.5	37.7
24	24.6	43	31	10	23.1	20.9	21.7	29.6	37.8	21.7	29.6	37.8	18.4	24.9	32.1
26	26.4	36	30	22	23.4	18.5	22.0	31.1	40.5	22.0	31.1	40.5	17.3	23.8	31.5
28	28.4	37	34	13	19.2	20.7	18.8	26.2	42.9	18.8	26.2	42.9	17.9	22.6	29.7
30	30.5	33	27	18	17.9	17.1	16.1	23.1	30.8	16.1	23.1	30.8	14.9	20.6	26.2
32	32.5	28	21	9	16.8	15.5	16.3	21.3	29.1	16.3	21.3	29.1	16.3	21.2	25.7
34	34.5	20	22	13	14.7	16.6	14.8	17.9	29.3	14.8	17.9	30.1	14.2	19.8	31.3
36	36.6	18	19	10	19.3	15.4	18.3	24.2	33.3	18.3	24.2	34.9	14.6	20.7	29.6
38	38.5	17	15	10	17.2	14.3	15.9	22.1	27.1	15.9	22.1	27.1	13.2	18.0	23.2
40	40.5	12	15	7	16.8	14.2	16.2	19.8	33.5	16.2	19.8	33.5	14.2	17.4	22.1
42	42.3	9	9	12	12.7	12.1	8.9	19.7	27.6	8.9	19.7	27.6	9.3	14.9	23.5
44	44.4	7	7	4	16.7	14.5	14.2	20.8	24.7	14.2	20.8	24.7	11.8	17.7	20.8
46	46.5	6	7	7	12.8	13.9	11.5	14.2	19.7	11.5	14.2	19.7	13.2	14.4	20.3
48	48.5	4	1	4	13.3	12.6	12.2	15.6	14.0	12.2	15.6	14.0	9.9	10.5	15.3
50	50.4	2	2	4	13.0	11.9	13.0	13.5	19.7	13.0	13.5	19.7	11.9	13.3	21.8
52	52.2	4	4	4	13.6	11.2	11.4	15.6	15.9	11.4	15.6	15.9	9.5	13.6	13.5
54	54.4	1	2	4	14.1	16.4	14.1	12.1	16.9	14.1	12.1	16.9	16.4	8.9	20.3
56	56.5	1	1	1	10.4	9.5	10.4	20.0	20.4	10.4	20.0	20.4	9.1	18.0	28.4
Total or average	25.8	527	476	235	24.6	21.3	23.6	33.5	43.6	25.1	38.9	46.9	20.1	25.9	35.6

[1] Average for all years combined.
[2] Data as of 1926.
[3] Logs not meeting merchantability requirements classed as totally decayed.

diameter class irrespective of whether or not the individual logs met the prescribed merchantability limits. This table, then, shows the average actual decayed volume as determined in board-foot and cubic-foot units, as well as the effect of this decay on log merchantability according to board-foot standards.

From the data in table 2 it is evident that a definite decrease in percentage of decay accompanies an increase in log diameter. This relationship is brought out more clearly by the curved values for actual decay as shown in board feet in figure 1. In this figure the line marked "Limit of merchantability" is placed at 50 percent for logs 8 to 16 inches in diameter and at 67 percent for logs exceeding 16 inches in diameter. All portions of the decay curves that extend above this line represent diameters in which the average log is unmerchantable. Inspection of figure 1 shows that average logs of all diameters were still merchantable in 1926; average logs 10 inches or less in diameter had been rendered unmerchantable by decay in 1929; and the average log over 16 inches in diameter was still merchantable in 1936, 15 years after the windstorm.

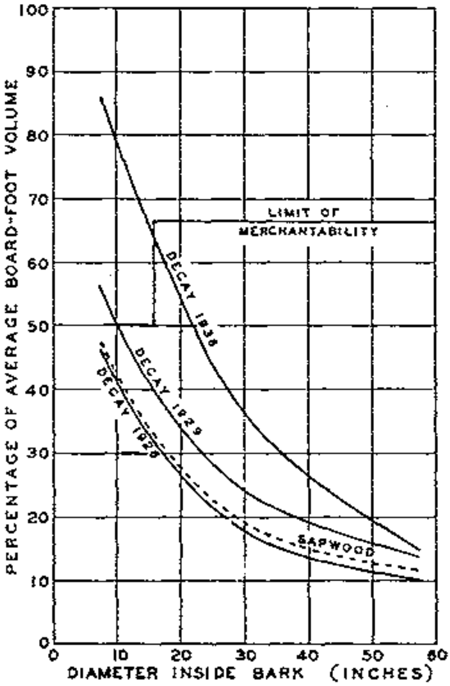

FIGURE 1.—Smoothed curves illustrating the percentages of sapwood and actual decay in logs otherwise salvable from wind-thrown Douglas fir trees, based on volume in board feet.

It should be emphasized, however, that the decays in wind-thrown timber result in exterior defects and hence render worthless those portions of the log from which the clear and other high-grade, high-value lumber is manufactured. The limits of merchantability (figs. 1 and 4) prescribe the amount of allowable defect in any log. These limits, however, are based primarily on interior defects, i. e., defects such as heart rot, lowering the gross volume but destroying only the central portion of the log from which the lower grades of lumber are manufactured. In ordinary application, then, a log just meeting merchantability requirements has suffered a volume loss somewhat greater than its value loss. In wind-thrown timber with exterior defects the situation is just the reverse; the log value is decreased by the presence of decay proportionately more than is the log volume. Logs from wind-thrown trees may, therefore, still meet volume requirements and yet not have a sufficient conversion value to justify their removal from the woods.

Figure 2 presents the cubic-foot data from table 2. Figures 1 and 2 thus afford a direct comparison between board- and cubic-foot decay percentages for the complete range of log-diameter classes and for each of the years in which detailed data were taken.

The rate at which decay reduced the percentage of sound volume can be determined from figure 3 for representative log diameters available from wind-thrown Douglas fir trees. These curves were derived by cross-plotting the decay data from figure 1. The curves do not originate at 0 years but rather at 2 years after wind throw, the time at which decay first became apparent in the logs. It is evident that decay progressed very rapidly during the first years after the storm, as only the relatively susceptible sapwood was being attacked, but the rate of decay noticeably decreased thereafter because further progress was necessarily in the more durable heartwood. Fifteen years after the storm, decay was still progressing fairly rapidly in 16-inch logs but quite slowly in 56-inch logs. Projection of the 8- to 15-year line for logs of the latter diameter indicates that such logs will have a high percentage of sound volume for many years to come.

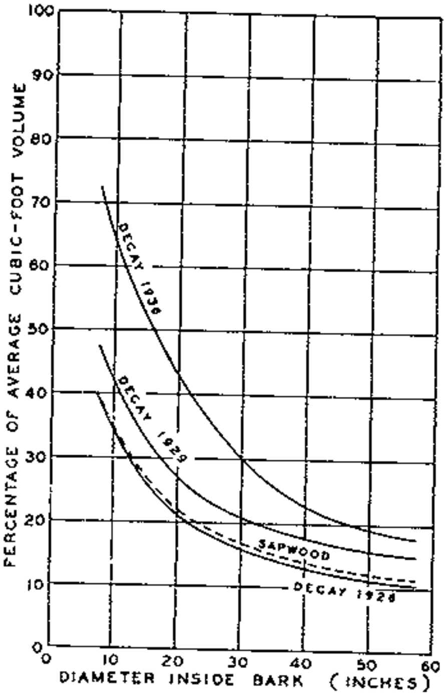

Figure 2.—Smoothed curves illustrating the percentages of sapwood and decay in logs otherwise salvable from wind-thrown Douglas fir trees, based on volume in cubic feet.

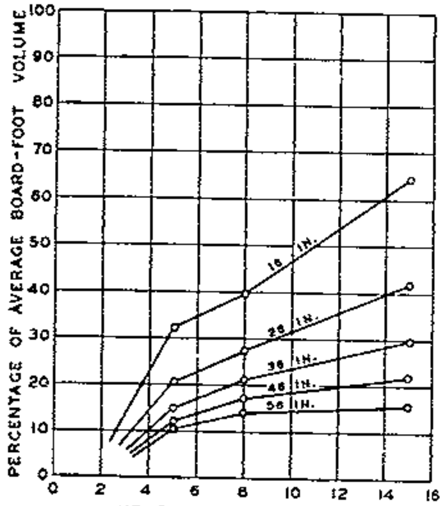

Figure 3.—Rate of decay in logs of representative diameters otherwise salvable from wind-thrown Douglas fir trees.

The rate of decay in logs of all diameters will probably be even slower as time goes on. Each succeeding year the brush cover becomes denser and the crown canopy more nearly closed. This tends to keep the moisture content of the logs sufficiently high to inhibit materially the activity of the fungi causing decay.

LOSSES IN WIND-THROWN SITKA SPRUCE

When examined in late August 1921, wind-thrown Sitka spruce trees showed no evidence of decay but did show a somewhat heavier beetle infestation and more blue staining than did Douglas fir. In August 1922 the condition of Sitka spruce was closely comparable to that of Douglas fir.

An examination of 30 trees was made in 1923. Beetles had infested 60 percent and superficial decay was apparent on the upper sides of 25 percent of these trees. One tree had decayed to a depth of about 3 inches over a limited area where the bark had been knocked off. When examined in 1924 it was apparent that decay had progressed materially in the sapwood, particularly on the upper surfaces of the down trees.

Detailed Tree-Volume-Loss Data

Table 3 shows the results, by 4-inch diameter classes, and in both board and cubic feet, of the detailed examinations. From this table it is evident that breakage in falling was not so definitely related to tree size as was true of Douglas fir, nor was the loss from this source nearly as great in Sitka spruce as in trees of comparable size in the former species. The loss in high stumps again shows no definite relation to tree size, but the percentage loss from this cause is very slightly higher than in Douglas fir. To illustrate more clearly the relationships between sapwood and decay for trees of various diameters these data from table 3 are presented graphically in figures 7, *B*, and 9, *B* (pp. 24 and 26).

It is shown that sapwood makes up about 47 percent of the average gross board-foot volume of trees 20 inches in diameter (fig. 7, *B*). With larger trees the percentage of sapwood becomes smaller, 80-inch trees being only about 16 percent sapwood and 115-inch trees only about 10 percent sapwood. It is of interest to note that the sapwood comprises a larger percentage of the total volume in small trees of Sitka spruce than it does in Douglas fir trees (fig. 7, *A*), whereas the two species seem to be very similar in this respect in the larger diameter classes.

By 1926, decay had caused a board-foot loss in Sitka spruce far in excess of the sapwood volume in trees of all diameters. This loss in merchantability amounted to about 93 percent for the average 10-inch tree and approximately 19 percent for the average 110-inch tree. Eight years after the storm, decay had rendered worthless, on the average, trees less than 30 inches in diameter and even the largest trees measured (88 inches) showed a loss in merchantability slightly over 35 percent. Fifteen years after being wind thrown, Sitka spruce trees of all sizes were so badly decayed as to be almost completely unmerchantable. Trees less than 50 inches in diameter were completely valueless and trees even 88 inches in diameter had lost 80 percent of their merchantable volume.

TABLE 3.—*Losses in wind-thrown Sitka spruce trees in 1926, 1929, and 1936*

Diameter breast high		Trees examined				Average height[1]	Average gross volume[2]		Sapwood[2]		Broken in falling[2]		Lost in stump[2]		Loss through decay					
Class (inches)	Average[1]	1926		1929	1936				Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume[3]			Percent of cubic-foot volume		
		Total	Sapwood												1926	1929	1936	1926	1929	1936
	Inches	*Number*	*Number*	*Number*	*Number*	*Feet*	*Board feet*	*Cubic feet*												
10	11.1	5				64.1	58	21.9			13.8	8.3	0	0	92.0			63.7		
14	14.5	9	1			113.0	179	50.5	63.2	44.3	0	0	1.9	1.8	89.2			67.4		
18	17.9	14	3			116.4	320	78.3	45.7	42.9	1.6	1.7	1.5	1.4	87.9			[illegible]		
22	22.3	11	2			130.4	560	124.9	50.0	37.0	2.9	2.8	3.0	2.6	83.1			59.7		
26	25.9	11	3			148.1	1,050	205.6	30.3	25.1	9.5	8.5	.3	.2	73.1			57.0		
30	30.0	7	3	1	1	184.9	1,711	301.0	35.3	28.2	8.4	9.9	1.7	1.9	68.3	96.2	100.0	52.2	76.9	100.0
34	33.2	8	2	2		172.9	2,072	357.2	35.3	26.8	.5	1.0	5.6	5.2	59.0	100.0		39.6	63.7	
38	38.8	6	5	5		193.7	3,116	513.8	24.2	21.6	4.6	4.2	5.9	5.4	39.4	90.2		29.6	59.5	
42	42.6	7	6	4	1	200.8	3,841	607.1	27.5	24.0	7.5	8.4	4.0	3.6	58.4	81.9	100.0	40.9	60.6	90.0
46	46.1	11	7	7	3	204.8	4,367	699.7	22.7	21.1	5.8	6.4	3.5	3.6	41.9	73.0	100.0	33.8	54.7	97.7
50	50.3	5	1	11	4	209.1	5,984	934.6	20.2	18.3	8.1	8.9	5.4	5.6	48.9	62.0	100.0	32.9	47.8	71.9
54	54.6	9	3	11	4	206.4	6,050	982.3	22.3	21.4	2.6	3.2	5.3	4.4	40.8	64.5	100.0	30.4	49.7	95.4
58	57.6	7	4	9	2	231.1	8,416	1,259.3	19.4	17.0	11.1	10.6	3.9	4.1	38.1	64.8	100.0	28.5	51.7	93.8
62	61.3	2		10	4	225.6	9,707	1,457.6			2.3	3.3	4.9	4.6	43.1	62.6	96.4	41.2	48.0	82.1
66	66.1	11	7	11	6	228.9	10,137	1,469.[illegible]	18.1	16.3	4.0	4.7	4.4	4.3	31.9	45.2	86.0	25.6	36.9	77.6
70	70.0	3	1	2	1	222.1	8,366	1,333.9	23.0	20.7	2.5	2.9	6.6	7.5	49.1	34.2	67.3	35.6	30.8	61.0
74	75.4	1		6	4	209.9	10,004	1,663.2			2.6	2.7	3.7	5.2	24.9	42.8	100.0	25.6	33.4	78.6
78	77.9	2	2	1	1	197.0	9,067	1,374.3	25.7	21.0	19.2	18.7	12.1	10.7	27.9	46.1	100.0	27.1	35.1	76.0
82	81.6	2	2	3	2	231.7	13,674	2,040.3	16.9	14.8	6.7	6.3	8.1	10.3	22.9	37.0	78.1	15.9	32.6	68.6
86	87.[illegible]	1		1	1	223.2	17,770	2,684.1			12.2	11.0	1.1	2.7	44.4	42.3	94.4	33.5	37.3	67.8
90																				
94	95.0	1				231.1	16,260	2,943.7			3.3	3.8	1.9	1.5	11.9			7.7		
98																				
102	101.0	1				242.9	20,830	3,123.0			.3	1.1	6.5	6.4	15.9			12.7		
106																				
110																				
114																				
118	117.0	1	1	1		253.1	19,920	2,925.6	8.3	11.6	8.9	7.8	7.5	7.3	29.5	37.7		22.5	27.8	
Total or average	48.9	135	53	85	34	194.6	5,856	908.3	20.9	19.1	5.7	5.9	4.7	4.6	59.0	61.7	94.7	31.2	47.2	82.1

[1] Average for all years combined.
[2] Data as of 1926.
[3] Percentage loss in merchantability because of decay.

To show the percentage of total volume actually decayed, the cubic-foot data from table 3 are presented graphically in figure 9, *B*. The general trends and relationships between percentage of decay and tree diameter are found to be similar to those for board feet. From this figure it is apparent that considerable heartwood had been decayed by 1926, after only about 3 years (1923–26) of perceptible fungus activity. Judging by the curves, decay progressed almost as rapidly in the heartwood of Sitka spruce as it did in the sapwood. By 1936 the average Sitka spruce tree less than about 30 inches in diameter was completely decayed and trees as large as 88 inches in diameter averaged nearly 70 percent decayed. Practically all of the sound volume remaining at that time was confined to the small sound core found in the first few butt logs, the logs from the central and top portions having been almost completely decayed.

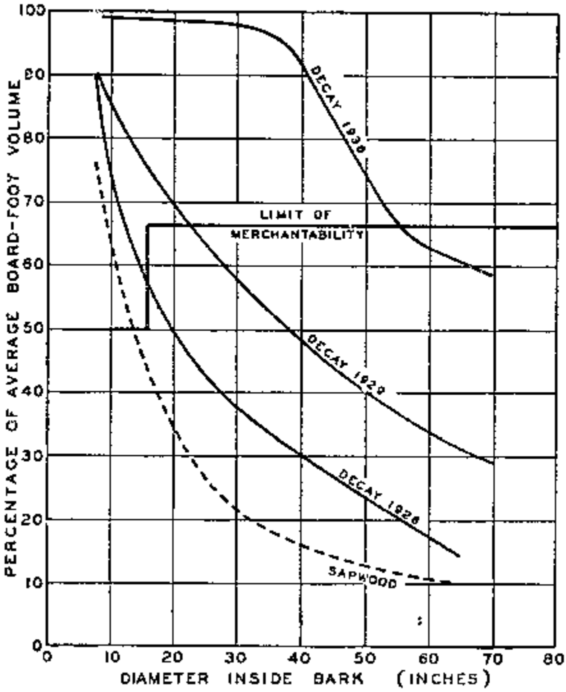

FIGURE 4.—Smoothed curves illustrating the percentages of sapwood and actual decay in logs otherwise salvable from wind-thrown Sitka spruce trees, based on volume in board feet.

Detailed Log-Decay Data

To bring out more clearly the relationship of decay to volume units of given diameters, the data for the logs that could have been made from the trees in table 3 are presented by 2-inch diameter classes in table 4. Data in this table are for those logs in which decay was the only defect influencing the merchantable volume. The board-foot data of table 4 differ from those of table 3 by the addition of columns showing the actual average decay percentage in each log-diameter class without consideration of whether or not the individual logs met prescribed merchantability limits. This table, then, shows the average actual decayed volume as measured in board- and cubic-foot units as well as the effect of this decay on log merchantability according to board-foot standards.

The data of table 4 show that a definite decrease in percentage of decay accompanies an increase in log diameter. This relationship is brought out more clearly in figure 4, in which the curved values for

TABLE 4.—*Decay losses in logs otherwise salvable from wind-thrown Sitka spruce trees in 1926, 1929, and 1936*

Diameter inside bark (small end)		Basis of logs				Sapwood [2]		Loss through decay								
Class (inches)	Average [1]	1926		1929	1936	Percent of board-foot volume	Percent of cubic-foot volume	Percent of actual board-foot volume			Percent of merchantable board-foot volume [3]			Percent of cubic-foot volume		
		Total	Sapwood					1926	1929	1936	1926	1929	1936	1926	1929	1936
	Inches	*Number*	*Number*	*Number*	*Number*											
8	8.1	83	30	24	8	85.1	45.1	88.8	79.7	92.5	93.6	89.0	92.5	63.7	60.7	91.4
10	10.4	21	5	17	5	57.1	46.1	75.4	85.3	100.0	83.4	96.2	100.0	66.5	65.8	100.0
12	12.0	45	19	9	3	45.7	35.5	59.9	69.6	100.0	79.1	82.9	100.0	57.1	51.4	100.0
14	14.2	49	17	18	4	43.4	34.1	62.1	83.5	100.0	78.5	97.5	100.0	53.6	63.4	100.0
16	16.2	34	18	13	6	40.6	29.8	57.3	68.6	89.7	69.7	79.1	100.0	49.4	48.1	86.7
18	18.3	34	10	23	7	36.5	23.2	54.3	72.9	100.0	58.1	89.7	100.0	44.4	59.4	100.0
20	20.2	31	17	23	10	33.8	25.0	58.2	69.1	100.0	64.0	80.1	100.0	39.2	60.9	100.0
22	22.2	35	23	17	3	31.5	24.3	43.9	67.6	100.0	46.5	77.5	100.0	38.6	57.2	100.0
24	24.2	39	15	20	11	26.1	20.9	44.1	70.2	100.0	47.9	81.7	100.0	38.1	57.6	89.3
26	26.2	24	15	22	7	26.1	21.0	40.4	62.9	100.0	43.6	73.6	100.0	32.7	54.3	100.0
28	28.3	26	13	25	11	20.3	18.6	43.4	57.2	97.4	49.7	64.5	100.0	36.1	49.5	93.6
30	30.2	37	23	24	8	20.2	18.9	36.4	56.1	98.2	40.5	65.1	100.0	33.2	49.3	96.5
32	32.3	17	9	28	11	19.9	19.4	33.9	56.5	96.9	33.9	63.9	100.0	32.1	47.7	93.9
34	34.3	17	7	20	8	15.5	16.7	35.4	46.9	97.0	37.2	48.8	97.1	33.6	43.8	90.8
36	36.4	20	11	18	10	21.6	18.4	33.7	59.8	97.8	33.7	67.9	100.0	28.1	55.7	93.7
38	38.3	16	7	26	10	20.5	15.6	30.2	53.2	92.6	30.2	62.2	100.0	27.1	44.6	83.3
40	40.4	17	8	22	11	13.4	12.3	30.3	48.6	88.1	30.3	49.5	91.5	22.6	40.5	80.4
42	42.2	10	7	16	8	17.4	15.9	23.6	47.1	83.6	23.6	50.9	90.3	20.1	38.9	70.5
44	44.3	11	3	13	7	16.5	14.2	33.5	44.2	87.7	33.5	44.2	100.0	28.3	39.8	74.4
46	46.3	6	2	15	7	12.0	12.7	28.9	40.1	81.0	28.9	40.1	93.6	26.6	34.8	77.7
48	48.2	6	3	8	4	13.1	12.7	26.9	33.6	73.2	26.9	33.6	84.6	23.9	29.0	57.3
50	50.0	1	1	4	3	11.7	10.7	11.7	36.9	80.7	11.7	36.9	85.7	12.9	32.8	77.6
52	51.9	2	......	4	3	......	......	24.4	37.0	42.1	24.4	37.0	42.1	25.6	34.7	36.1
54	54.4	3	2	3	2	12.7	12.0	22.2	39.1	70.4	22.2	39.1	100.0	16.0	32.3	70.0
56	56.5	......	......	2	2	......	......	......	38.1	73.3	......	38.1	100.0	......	33.9	71.1
60	60.0	1	......	1	1	......	......	10.0	39.3	67.4	10.0	39.3	100.0	10.8	36.2	66.9
62	62.0	......	......	1	1	......	......		40.5	69.6		40.5	100.0		37.8	68.8
64	64.0	2	1	2	1	9.4	8.0	13.6	29.9	76.3	13.6	29.9	100.0	13.7	25.1	74.7
66	65.8	1	......	1	1	......	......	2.8	37.1	61.7	2.8	37.1	61.7	3.6	37.3	46.1
68	69.0	......	......	2	2	......	......		40.9	64.5		40.9	76.1		34.2	38.6
Total or average	25.9	588	266	430	175	35.4	25.8	52.6	60.4	91.7	58.8	68.3	96.2	43.4	50.4	87.0

[1] Average for all years combined.
[2] Data as of 1926.
[3] Logs not meeting merchantability requirements classed as totally decayed.

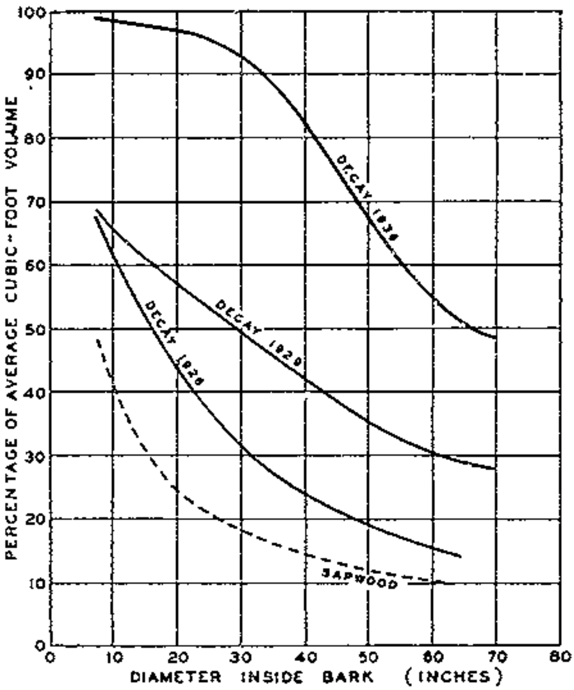

FIGURE 5.—Smoothed curves illustrating the percentages of sapwood and decay in logs otherwise salvable from wind-thrown Sitka spruce trees, based on volume in cubic feet.

actual board-foot decay percentages are shown. The line showing limit of merchantability is placed in the same position as it was for Douglas fir logs (fig. 1). Inspection of this curve shows that Sitka spruce logs became unmerchantable through the activity of decay much more rapidly than did Douglas fir logs. By 1926 the average log less than 16 inches in diameter was no longer merchantable. Three years later the average log less than 22 inches in diameter was unmerchantable. By 1936, logs averaging less than 55 inches in diameter would not meet merchantability requirements and larger logs would barely meet those requirements. Within 15 years after being wind thrown, Sitka spruce logs are, for all practical purposes and regardless of size, no longer merchantable. This is especially true since the high-grade portions have been decayed and the sound volume remaining consists of the knotty, wide-ringed core.

Figure 5 presents the cubic-foot data from table 4. Figures 4 and 5 thus afford a direct comparison between board-foot and cubic-foot decay percentages for the complete range of log-diameter classes and for each of the years in which detailed data were taken. From these curves it will be noted that a considerable portion of the heartwood was

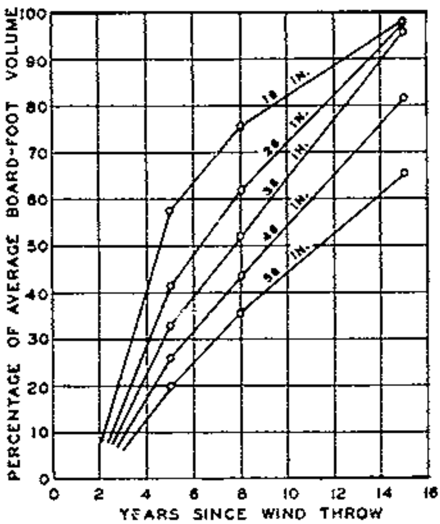

FIGURE 6.—Rate of decay in logs of representative diameters otherwise salvable from wind-thrown Sitka spruce trees.

decayed by 1926, only 5 years after wind throw and only 3 years after decay was first evident.

The rate at which decay reduced the percentage of sound volume can be determined from figure 6 for representative log diameters available from wind-thrown Sitka spruce trees. These curves were derived by cross-plotting the decay data from figure 4. The curves do not originate until 2 years after wind throw, the time at which decay probably first caused any volume loss. With the exception of the smaller logs,[10] the rate of decay in Sitka spruce has remained reasonably constant during the 13 years of its apparent activity. If the decay continues at this rate (and the trend to date indicates that it will) it is obvious that Sitka spruce logs of all sizes will be almost completely decayed in a very few more years. After comparing the Sitka spruce log curves of figure 6 with similar curves for Douglas fir shown in figure 3, it is strikingly evident that Sitka spruce logs decay much more rapidly than do Douglas fir logs of similar size.

LOSSES IN WIND-THROWN WESTERN HEMLOCK

An examination of wind-thrown western hemlock in August 1921 showed that decay was not yet evident. The sapwood, however, was occasionally slightly blue stained, and those trees attacked by ambrosia beetles showed heavy blue staining. The following year there had been some increase in beetle infestation and blue staining, but no decay was noted.

In August 1923 40 western hemlocks were examined and 90 percent were found to be heavily infested by ambrosia beetles and blue stained throughout the sapwood. Early decay, extending to a depth of not more than 1.5 inches, was noted on the upper sides of 50 percent of the down trees. By August 1924 decay had made definite progress in the sapwood of western hemlock. As was true in Douglas fir and Sitka spruce, the decay in hemlock was confined largely to the sides and upper surfaces of the wind-thrown trees.

Detailed Tree-Volume-Loss Data

Table 5 gives the results, by 4-inch tree diameter classes, and in both board and cubic feet, for 1926 and 1929, the only years in which hemlock trees were examined in detail. With this species, breakage loss apparently bore no definite relationship to tree diameter, but the actual percentage loss from this source was a little greater than in Douglas fir and considerably greater than in Sitka spruce trees of similar size. The percentage volume lost in high stumps was somewhat less than in Douglas fir or Sitka spruce trees of similar size. Figures 8, *A*, and 10, *A* (pp. 25 and 27), present the data of table 5 to illustrate more clearly the relationships between sapwood and decay for trees of various diameters.

[10] The smaller logs were mostly from the tops of the trees. As decay advanced the tops settled down onto the wet, swampy ground where the excessive moisture retarded the further progress of decay in those portions.

TABLE 5.—*Losses in wind-thrown western hemlock trees in 1926 and 1929*

Diameter breast high		Trees examined			Average height [1]	Average gross volume [1]		Sapwood [2]		Broken in falling [2]		Lost in stump [2]		Loss through decay			
Class (inches)	Average [1]	1926		1929				Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume	Percent of cubic foot volume	Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume [3]		Percent of cubic-foot volume	
		Total	Sapwood											1926	1929	1926	1929
	Inches	*Number*	*Number*	*Number*	*Feet*	*Board feet*	*Cubic feet*										
10	10.6	9	4	------	89.6	65	23.0	66.1	53.1	6.4	4.2	0	0.6	95.7	------	70.1	------
14	14.3	20	7	------	116.4	218	54.0	82.2	63.8	15.1	12.0	.6	.3	95.5	------	68.6	------
18	18.0	38	5	------	134.4	491	102.4	67.6	57.6	9.3	9.4	1.0	.8	95.8	------	62.8	------
22	22.1	42	7	------	146.3	831	167.7	64.2	56.3	16.7	15.3	1.6	1.4	96.2	------	60.8	------
26	25.7	29	7	------	157.4	1,163	216.1	57.7	49.2	6.7	7.0	3.4	2.7	94.4	------	52.5	------
30	30.0	15	5	------	163.8	1,770	297.8	49.2	37.4	13.4	14.4	2.7	2.2	90.0	------	51.2	------
34	34.5	12	3	------	173.1	2,163	374.3	54.7	44.1	12.4	12.6	4.4	3.9	83.7	------	50.8	------
38	38.3	6	2	1	180.2	2,706	463.8	52.6	43.3	8.6	8.3	.8	.8	87.0	100.0	45.9	81.9
42	42.1	------	------	4	169.5	3,453	555.4	------	------	------	------	------	------	------	100.0	------	91.9
46	45.4	2	------	4	178.0	4,127	658.6	------	------	10.4	13.6	3.0	3.0	71.6	100.0	43.5	86.7
50	49.9	------	------	1	182.0	4,290	732.0	------	------	------	------	------	------	------	100.0	------	77.3
Total or average	23.6	173	40	10	145.0	1,103	198.7	57.0	47.6	11.5	11.5	2.4	2.1	93.7	100.0	54.8	87.1

[1] Average for both years combined.
[2] Data as of 1926.
[3] Percentage loss in merchantability because of decay.

It is evident that sapwood makes up about 80 percent of the board-foot volume of the average 10-inch tree and roughly 45 percent of the volume of the average 40-inch tree (fig. 8, *A*). The average sapwood volume in hemlock trees is thus found to be considerably higher, to some extent because of their younger age and hence more rapid growth, than in Douglas fir or Sitka spruce trees of equivalent size. By 1926 decay had caused a loss in merchantability ranging from 95 percent in the smallest trees measured to about 75 percent in trees averaging 45 inches in diameter. By 1929 the largest hemlocks measured (50 inches d. b. h.) had been so decayed as to be rendered unmerchantable. The curves of figure 8, *A*, show the effect of decay on tree merchantability rather than actual sound volume. For lumbering purposes western hemlock trees up to 50 inches in diameter were unmerchantable by 1929, i. e., 8 years after being wind thrown.

The cubic-foot data from table 5 are presented in figure 10, *A*, to show the percentage of total volume actually decayed in wind-thrown hemlock trees. The general relationships are the same as were found with the board-foot data. From this figure it is evident that decay penetrated considerably beyond the extensive sapwood during the 3 years after first becoming apparent and during the next 3 years it progressed nearly as rapidly. In 1929 data were taken only on the largest trees that could be found, it being obvious that smaller trees were completely decayed. No data were taken on this species in 1936, for casual inspection showed trees of all sizes to be not only completely decayed but badly disintegrated.

Decay data for logs otherwise salvable from wind-thrown western hemlock trees are not given because it is evident from the tree data that no logs would be merchantable for more than 4 or 5 years after the trees were wind thrown.

LOSSES IN WIND-THROWN SILVER FIR

Data on the losses and deterioration of silver fir were taken only in 1926 and are summarized in table 6. Percentage losses from breakage in falling were a little lower than in Douglas fir and western hemlock but were slightly higher than in Sitka spruce trees of similar size. The percentage loss in high stumps was practically the same as for western hemlock and somewhat lower than in either Douglas fir or Sitka spruce. To illustrate more clearly the relationships between sapwood and decay for trees of various diameters, these data from table 6 are presented in figures 8, *B*, and 10, *B* (pp. 25 and 27).

It is evident that sapwood makes up approximately 70 percent of the board-foot volume of the average 10-inch tree and about 20 percent of the volume of 51-inch trees (fig. 8, *B*). These values are somewhat lower than found for western hemlock trees of similar size but are appreciably higher, especially in the smaller diameter classes, than were found for Douglas fir and Sitka spruce. Here again the high percentage of sapwood is probably, to some extent at least, related to the youth and rapid growth of the trees studied. By 1926 decay had caused a 98-percent loss in the merchantability of trees 10 inches in diameter. The loss for larger trees was relatively smaller, amounting to about 30 percent, on the average, for trees 55 inches d. b. h.

TABLE 6.—*Losses in wind-thrown silver fir trees in 1926*

Diameter breast high		Trees examined		Average height	Average gross volume		Sapwood		Broken in falling		Lost in stump		Loss through decay	
Class (inches)	Average	1926	Sapwood				Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume[1]	Percent of cubic-foot volume
	Inches	*Number*	*Number*	*Feet*	*Board feet*	*Cubic feet*								
10	11.3	5	4	72.7	50	19.7	63.2	45.5	0	0	0	0	84.6	57.4
14	14.1	6	3	97.4	157	42.8	65.4	51.0	1.7	1.3	2.2	1.6	91.9	71.5
18	17.7	13	2	110.7	306	74.0	65.1	54.3	6.6	5.6	1.0	1.1	97.6	69.5
22	21.7	10	5	124.1	629	131.5	44.6	36.0	5.2	4.0	1.4	1.3	90.1	52.5
26	26.0	15	7	135.7	918	181.0	37.0	30.4	15.3	14.4	1.5	1.3	88.7	53.4
30	29.4	12	3	138.3	1,048	204.0	43.0	34.7	5.4	5.3	2.6	2.5	93.1	56.6
34	33.9	12		158.8	1,942	332.0			4.1	5.1	3.5	3.2	86.4	54.8
38	38.7	11	2	161.7	2,333	407.4	38.2	29.4	9.0	8.3	1.4	1.6	77.2	46.1
42	42.1	3		165.4	3,132	513.8			7.5	3.0	1.4	2.0	59.0	39.8
46	46.3	7	2	171.3	3,590	594.0	22.8	21.1	12.7	12.4	3.6	4.3	55.3	31.6
50	48.4	2		180.9	3,470	586.7			6.5	7.7	3.8	4.2	66.6	38.3
54	53.2	2		183.6	5,313	847.4			10.1	12.5	2.2	3.1	32.8	30.4
58	56.8	2	1	183.5	6,073	980.3	20.5	18.8	5.7	6.9	2.7	3.0	28.5	23.4
Total or average	28.4	100	29	135.2	1,418	253.4	32.9	28.7	8.4	8.3	2.5	2.6	83.0	44.9

[1] Percentage loss in merchantability because of decay.

To show the percentage of total volume actually decayed, the cubic-foot data from table 6 are presented in figure 10, *B*. The relationship between decay and sapwood is very similar to that found with board feet. By 1926 decay had penetrated through the sapwood and for a considerable distance into the heartwood. This curve practically coincides with the corresponding curve for western hemlock (fig. 10, *A*). It seems probable, then, that decay progresses in much the same manner in these two species. For this reason no data were taken on silver fir in 1929 or 1936, the data for western hemlock for those years being considered sufficiently indicative of conditions in silver fir.

LOSSES IN WIND-THROWN WESTERN RED CEDAR

Detailed data on the losses in and the deterioration of wind-thrown western red cedar were taken only in 1926. These data are summarized in table 7. Comparing trees of equivalent size (up to 50 inches d. b. h.) the average percentage of volume lost through breakage was a little greater than in Sitka spruce and somewhat less than in any other species. In diameters exceeding 50 inches, however, western red cedar broke up worse than any other species studied. The percentage of volume lost in high stumps averaged greater than in any other species except Sitka spruce. To illustrate more clearly the relationships between sapwood and decay for trees of various diameters these data from table 7 are presented graphically in figures 8, *C*, and 10, *C* (pp. 25 and 27).

It is evident that sapwood makes up a smaller percentage of the total board-foot volume in western red cedar than in any other species studied (fig. 8, *C*). This relationship holds true irrespective of tree size. From this figure it will be noted that by 1926 decay had not yet caused a loss of merchantable volume equal to the sapwood volume. The actual loss from decay ranged from an average of about 20 percent in the smallest trees examined to somewhat less than 5 percent for trees 70 inches d. b. h.

The cubic-foot data from table 7 are presented graphically in figure 10, *C*, to show the percentage of total volume actually decayed. Decay had caused no log having as much as an 8-inch heartwood core to be unmerchantable under board-foot standards, as might be inferred from a comparison of the curves in figures 8, *C*, and 10, *C*. Data are not given by log classes because general observations made in 1929 and 1936 showed that decay had not advanced beyond the sapwood in western red cedar. For these years, then, sapwood percentages can be used equally well to indicate the percentages of decay. The inherent durability of western red cedar is so well known that it seems reasonable to expect the heartwood of wind-thrown trees of this species to remain sound for many more years and to decay only very slowly when finally attacked. As this species typically occurs on the wetter sites, the rapid development of a dense brush cover serves to keep the moisture content of the down trees at a high level and thus provides an additional retardant to decay.

TABLE 7.—*Losses in wind-thrown western red cedar trees in 1926*

Diameter breast high: Class (inches)	Diameter breast high: Average	Trees examined	Average height	Average gross volume		Sapwood: Percent of board-foot volume	Sapwood: Percent of cubic-foot volume	Broken in falling: Percent of board-foot volume	Broken in falling: Percent of cubic-foot volume	Lost in stump: Percent of board-foot volume	Lost in stump: Percent of cubic-foot volume	Loss through decay: Percent of board-foot volume [1]	Loss through decay: Percent of cubic-foot volume
	Inches	*Number*	*Feet*	*Board feet*	*Cubic feet*								
14	14.8	3	82.1	123	37.4	21.3	21.6	0	0	0	0	21.6	20.1
18	16.3	1	72.4	60	33.7	16.7	13.0	0	0	0	0	16.7	16.7
22	22.2	4	99.6	330	93.1	17.4	19.1	2.3	3.7	0	0	17.8	14.6
26	24.8	4	99.4	370	106.1	11.5	14.6	0	0	1.4	1.3	11.0	13.5
30	30.2	3	114.0	680	158.2	17.6	13.6	1.0	1.5	10.3	8.9	17.1	14.2
34	33.8	8	125.1	1,048	233.2	18.5	13.0	7.2	6.6	2.7	2.4	18.7	11.4
38	38.5	6	132.9	1,195	257.5	15.6	13.6	2.8	3.3	4.2	4.6	14.7	12.0
42	41.9	6	137.7	1,895	380.0	14.4	11.5	7.7	8.5	1.5	1.8	12.1	9.8
46	45.0	1	144.6	2,610	480.8	11.6	12.5	0	0	0	0	8.6	11.5
50	49.6	5	145.7	3,258	587.6	7.6	8.0	9.9	10.2	4.3	4.6	6.2	6.8
54	54.0	2		3,460	611.7	10.7	8.2	9.5	9.8	8.1	7.8	14.9	9.7
58	59.4	1	142.7	5,000	879.1	5.1	7.4	7.2	6.0	7.4	7.3	4.7	7.4
62	62.0	2		7,190	1,087.9	6.5	5.8	10.4	8.5	3.3	3.6	5.5	5.7
66	65.2	1		5,670	972.5	4.4	4.6	51.1	32.9	1.8	.1	3.0	4.1
70	69.2	2	166.7	6,420	1,193.6	3.8	4.9	11.5	11.6	7.7	9.2	3.4	4.9
Total or average	38.4	49	123.2	1,978	370.7	9.7	9.3	10.7	9.1	4.3	4.4	7.9	8.5

[1] Percentage loss in merchantability because of decay.

COMPARATIVE LOSSES IN WIND-THROWN TREES

To permit a ready comparison of the losses in wind-thrown trees of all species studied, the detailed decay data are presented in figures 7 and 8 on a board-foot basis and in figures 9 and 10 on a cubic-foot basis. From table 8, in which the summary data are presented, it is apparent that decay, with the possible exception of that in western red cedar, is eventually the most important source of loss in wind-thrown timber.

Some breakage loss occurs even when skilled fallers cut standing timber and hence not all of the breakage loss shown should have been charged directly to wind throw. Except for Douglas fir, data are not available on the amount of breakage in operations in standing timber and hence no correction figure could be applied here to the losses from this source. In a previous study Boyce [11] found a breakage in felling on smooth ground, amounting to 7.5 percent of the board-foot volume for trees averaging 38 inches in diameter breast high. On rough ground, felling resulted in a 9.5-percent breakage loss for trees averaging 36 inches in diameter. In the blow-down study trees of that species that averaged 49 inches in diameter showed a 12.6-percent breakage loss. It seems probable, then, that at least a small part of the breakage should be charged directly to the storm.

TABLE 8.—*Comparative losses in the five species of wind-thrown trees for the years in which detailed data were taken on the Olympic blow-down*

Species and year examined	Trees examined	Average diameter breast high	Average height	Total volume		Broken in falling		Lost in stump		Loss through decay	
						Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume	Percent of cubic-foot volume	Percent of board-foot volume [1]	Percent of cubic-foot volume
	Number	*Inches*	*Feet*	*Board feet*	*Cubic feet*						
Douglas fir:											
1926	112	46.6	208.2	599,020	91,662	12.6	13.6	3.6	3.7	24.2	16.9
1929	92	48.9	203.4	505,220	77,844					28.2	23.0
1936	42	57.2	202.8	301,640	44,167					34.3	30.9
Sitka spruce:											
1926	135	40.6	177.4	519,940	88,761	5.7	5.0	4.7	4.6	59.0	31.2
1929	85	57.8	209.8	669,580	101,840					61.7	43.5
1936	34	61.7	216.7	315,490	48,688					94.7	82.1
Western hemlock:											
1926	173	22.7	146.6	175,240	31,963	11.5	11.5	2.4	2.1	93.7	54.8
1929	10	44.0	165.1	35,000	5,826					100.0	87.1
Silver fir:											
1926	100	28.4	137.2	151,440	26,906	5.4	8.3	2.5	2.0	83.9	44.9
Western red cedar:											
1926	40	38.4	123.2	96,900	18,165	10.7	9.1	4.3	4.4	7.8	6.6

[1] Percentage loss in merchantability because of decay.

[11] BOYCE, J. S. DECAY AND OTHER LOSSES IN DOUGLAS FIR IN WESTERN OREGON AND WASHINGTON. U. S. Dept. Agr. Tech. Bul. 286, 60 pp., illus. 1932.

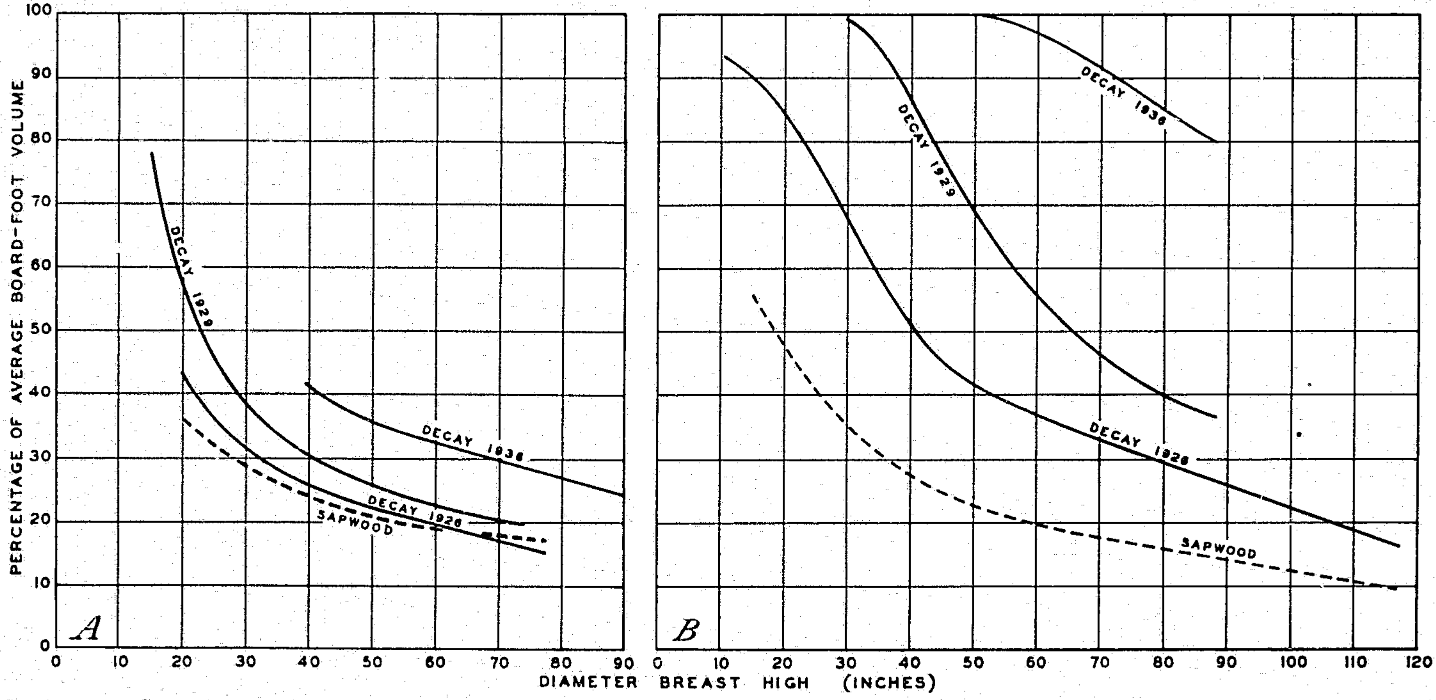

FIGURE 7.—Smoothed curves illustrating the percentages of merchantable volume lost through decay and the percentages of sapwood in wind-thrown trees, based on volume in board feet: *A*, Douglas fir; *B*, Sitka spruce.

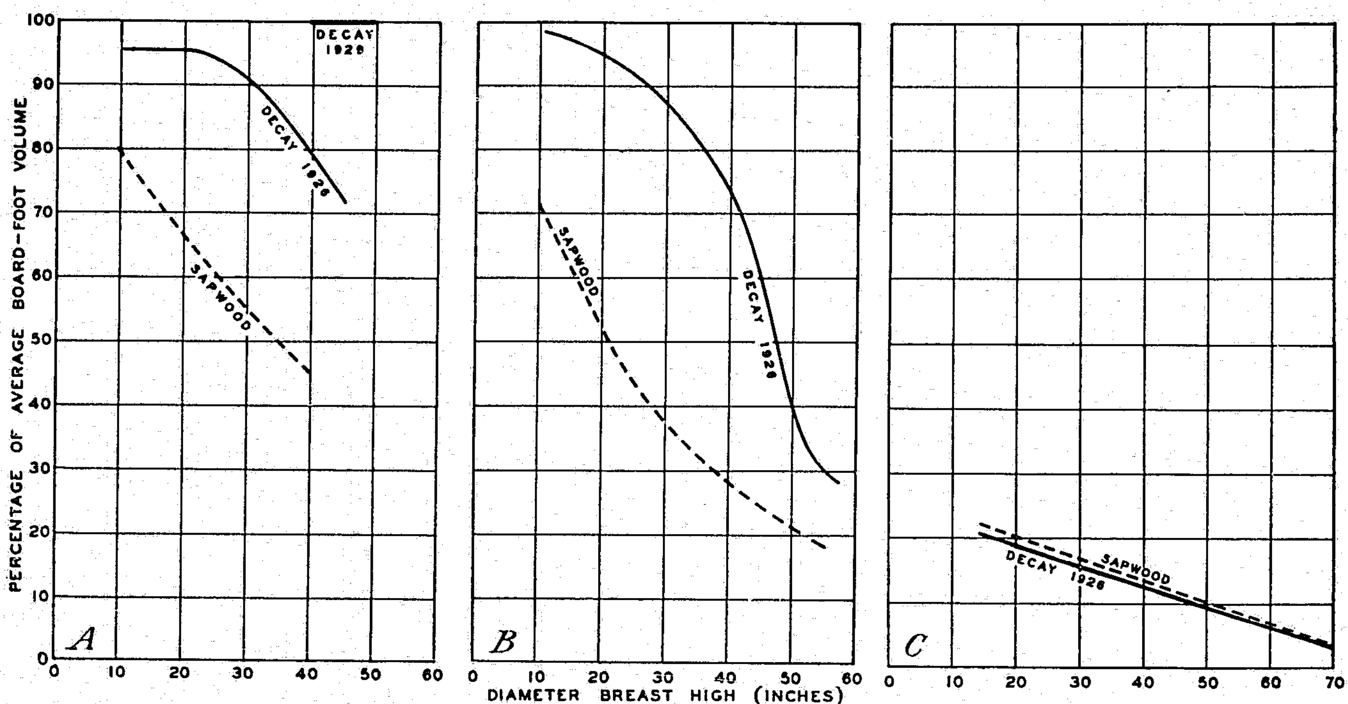

FIGURE 8.—Smoothed curves illustrating the percentages of merchantable volume lost through decay and the percentages of sapwood in wind-thrown trees, based on volume in board feet: *A*, Western hemlock; *B*, silver fir; *C*, western red cedar.

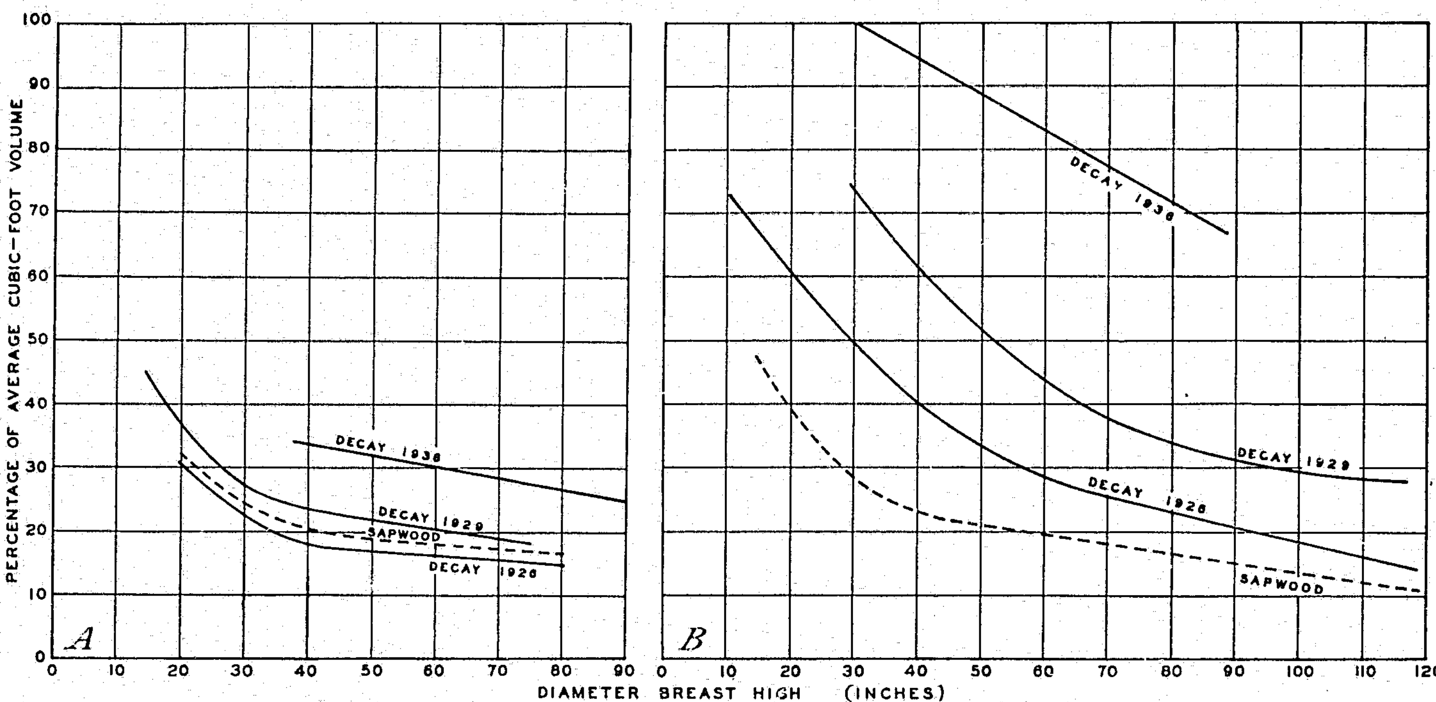

FIGURE 9.—Smoothed curves illustrating the percentages of decay and sapwood in wind-thrown trees, based on volume in cubic feet: *A*, Douglas fir; *B*, Sitka spruce.

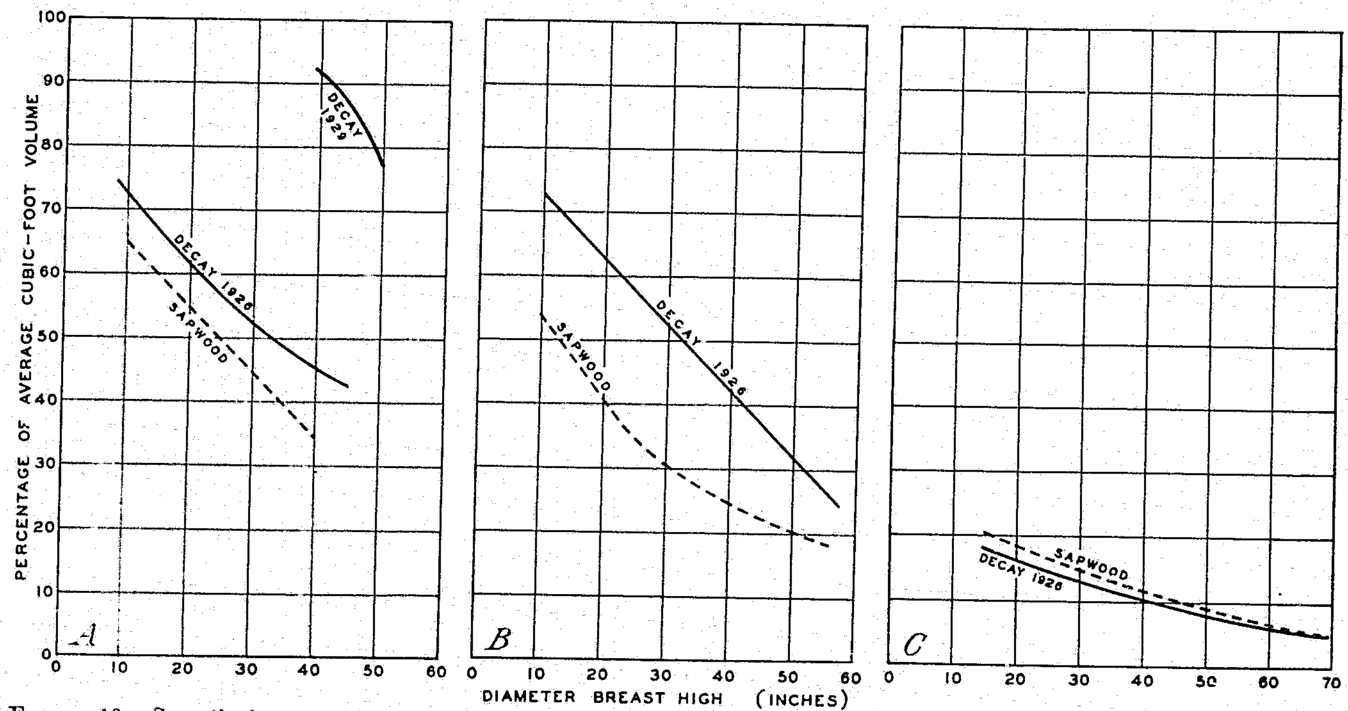

FIGURE 10.—Smoothed curves illustrating the percentages of decay and sapwood in wind-thrown trees, based on volume in cubic feet: *A*, Western hemlock; *B*, silver fir; *C*, western red cedar.

The losses from breakage and high stumps will vary greatly from area to area, depending upon many factors, the most important of which are the steepness and roughness of the ground. Data for losses from these sources, therefore, are not directly applicable to other areas of wind-thrown timber. Losses caused by decay vary somewhat between individual trees, depending on just how they contact the ground and on the density of the surrounding brush cover, which aids in maintaining a high moisture content inhibitive to decay. In general, however, the percentage losses caused by decay as given in this bulletin should not result in erroneous conclusions when applied to trees in other blow-downs of known age in the spruce-hemlock and Douglas fir old-growth types, typical of the fog belt of the Oregon and Washington coast.

SUMMARY

In the vicinity of Forks, on the Olympic Peninsula of Washington, data were taken on the condition of Douglas fir, Sitka spruce, western hemlock, silver fir, and western red cedar trees that had been blown down by the catastrophic storm of January 29, 1921. General observational data were taken in 1921, 1922, 1923, and 1924 and intensive detailed examinations were made in 1926, 1929, and 1936.

At the beginning of the detailed studies it became apparent that there were four sources of loss in wind-thrown timber, namely, breakage, high stumps, insect damage, and decay. Volume losses from these last two sources were determined by cutting into the trees at the points where they would have been bucked in accordance with close utilization practice. Losses from the first two sources were apparent immediately after the trees fell and have not changed materially since. Data on these two losses, therefore, are presented only for the year 1926. No loss from decay was noted until at least 2 years after the storm. After once becoming evident decay progressed at varying rates until loss from this source soon exceeded that from any of the other three in all species except western red cedar. All data, including percentages, are presented on both board- and cubic-foot bases to make them usable by industries utilizing either saw logs or chipped wood as raw material.

The high-grade, high-value lumber is manufactured from the sapwood and adjacent heartwood of logs. This zone was the first to be invaded by decay, and data were taken to show the relationships between decay and the sapwood. Western hemlock and silver fir, the two species having the highest percentage of sapwood and the least durable heartwood, decayed most rapidly. Sitka spruce did not decay so fast as these species but much faster than either Douglas fir or cedar. The sapwood of Douglas fir decayed rather rapidly but the heartwood showed a high degree of durability. Western red cedar, with its narrow ring of sapwood and highly durable heartwood, suffered least from decay.

The data indicate that if wind-thrown trees in the spruce-hemlock and Douglas fir old-growth types of the Washington and Oregon coast are to be salvaged before suffering any decay loss it must be done within 1 or 2 years following blow-down. Douglas fir trees decay rather rapidly until at least the bulk of the sapwood is destroyed, but the heartwood decays very slowly. Trees of this species still contain

considerable merchantable volume even 15 years after being blown down. Most of this sound volume, however, is found in trees over 30 inches in diameter. In Sitka spruce trees little difference is found between the rate of decay in sapwood and heartwood. Thus decay progresses at a uniform rate and practically all sound wood, irrespective of tree size, is destroyed within 15 years. Both western hemlock and silver fir trees, irrespective of size, are rendered worthless by decay within 8 years after being blown down. Even after lying on the ground for 15 years the decay loss in western red cedar does not exceed the original sapwood volume. Indications are that heartwood of this species will remain sound for many years to come.

Operators are cautioned against applying the data for losses from breakage and high stumps, as presented throughout this bulletin, directly to wind-thrown timber on other areas. Losses from these sources, breakage in particular, will vary greatly depending upon topographic conditions. The decay data, however, are believed to be generally applicable in determining the salvable volume on other areas of wind-thrown timber in the spruce-hemlock and Douglas fir old-growth types of the fog belt of the coastal region of the Northwest.

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