United States
Department of
Agriculture

Forest Service

**Pacific Southwest
Forest and Range
Experiment Station**

Research Paper
PSW-164

Stem Volume Losses in Grand Firs Topkilled by Western Spruce Budworm in Idaho

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Acknowledgment:

The study reported in this paper was originated by Max Ollieu, Forest Insect and Disease Management Staff, Intermountain Region, Forest Service, U.S. Department of Agriculture, Boise, Idaho.

Cover: The old topkill in this grand fir is visible as the central dead spike issuing from the forked stem.

Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

December 1982

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IN BRIEF . . .

Ferrell, George T.; Scharpf, Robert F. **Stem volume losses in grand firs topkilled by western spruce budworm in Idaho.** Res. Paper PSW-164. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 10 p.

Retrieval Terms: *Abies grandis*, *Choristoneura occidentalis*, *Echinodontium tinctorium*, topkilling, growth loss, decay, volume loss

Two stands, one cutover and one virgin, subjected to western spruce budworm (*Choristoneura occidentalis* Freeman) outbreaks in the years 1922-30, 1952-55, and 1969-78, were sampled in the Little Salmon River drainage of west-central Idaho. Forty mature grand firs (*Abies grandis* [Dougl. ex D. Don] Lindl.) were felled in August 1978, and their stems dissected and analyzed for growth reductions and defects associated with topkilling resulting from the outbreaks. Twenty firs, 14 inches (36 cm) or greater in diameter-at-breast-height (d.b.h.) were randomly selected from the residual overstory of a stand that had been sanitation-logged in the late 1960's; the same number of similarly selected firs was sampled in a nearby virgin stand.

The sample firs were rated for current defoliation, felled, and the stems examined for dead tops, remnants of dead tops, or for indicators of buried dead tops (crooks, forks). Dead tops, or deformities, and adjacent stem segments were dissected to determine the year when topkilled, the basal diameter of the dead top as an indication of the size of top killed, and the extent of any associated decay. Decay-causing fungi were identified in the field or by laboratory culture. Attacks by secondary insects (bark and boring beetles) were identified by their gallery patterns. Internode lengths were measured on the live regrown tops to analyze for height growth reductions. Radial growth was studied by measuring annual ring widths on cross-sections sawn from the lower, middle, and upper regions of the stem.

Growth index analyses were used to estimate reductions in height and radial growth resulting from the outbreak-caused topkilling. The growth indexes expressed annual increment as the percent growth predicted from long-term growth patterns in the trees. For each stand sampled, growth indexes of firs topkilled by each outbreak were compared with those of firs apparently not topkilled by that outbreak. Where percent growth reductions in the topkilled trees were found, they were converted to height or radial growth losses, using increments predicted by regression.

Volume losses were calculated for outbreak-caused topkilling that affected the stems to a minimum 4-inch (10-cm) diameter-inside-bark (d.i.b.). Volume losses resulting from growth reductions were calculated as the difference between existing stem volume and volume expected, if no growth reductions had occurred. Cylindrical volume deductions were made for stem deformities and associated decays. Volume losses were expressed in cubic feet, and as percentages of the stem volume.

Most volume loss was associated with tops killed by the 1922-30 outbreak. From 60 to 70 percent of the sample firs were topkilled by this outbreak and sizable tops, some exceeding 12 ft (3.6 m) in length and 6 inches (15 cm) in basal diameter, were killed. Extensive decay columns, some exceeding 50 ft (15.3 m) in length, were associated with these topkills. Height growth losses in firs topkilled by this outbreak were not measured. Volume losses from stem deformities and decays, although highly variable because of variations in the extent of decay, averaged 9.5 ft^3 (0.3 m^3) or 11.1 percent of stem volume in the sample firs topkilled by this outbreak in the cutover stand. Volume losses in the virgin stand averaged 26.3 ft^3 (0.7 m^3) or 20.5 percent per tree.

Less than 20 percent of the sample firs were topkilled by the 1952-55 outbreak and the basal diameters of the dead tops did not exceed 4 inches (10 cm). Volume losses in firs topkilled by this outbreak averaged 3.3 ft^3 (0.1 m^3) or 5.4 percent per tree in the cutover stand, and 0.5 ft^3 (0.02 m^3) or 0.3 percent in the virgin stand. Volume losses resulted primarily from reduced height growth. Almost no decays were associated with tops killed by this outbreak.

During the 1969-78 outbreak, 65 percent of the firs sampled in the cutover stand were topkilled, but none of the firs sampled in the virgin stand were topkilled. This difference was only partially attributable to differences in defoliation as rated in 1978, but may have resulted from differences in defoliation in earlier years of the outbreak when records were not available. No merchantable volume losses resulted from these topkills as they affected only the stem above the 4-inch (10-cm) diameter limit and no associated decays were found.

Radial growth was evidently not affected by the topkilling. Although radial growth of all sample firs decreased during the 1922-30 and 1969-78 outbreaks, no appreciable difference was found between the radial growth of firs topkilled and those not topkilled.

Galleries of bark beetles and flathead borers were found in some of the dead tops, but most of the older dead tops were missing or were too decomposed to allow the incidence of attack to be determined.

Stem decays, caused mainly by Indian paint fungus (*Echinodontium tinctorium* Ell. and Ev.), caused most of the volume losses associated with topkilling. Almost all the decay was associated with the larger tops killed by the 1922-30 outbreak. Little decay was found unless the top was killed more than 30 years ago and had a basal diameter exceeding 3 inches (8 cm).

Although based on relatively few trees, these results indicate that substantial volume losses can be expected in mature grand firs topkilled by the 1922-30 western spruce budworm outbreak in this region.

Extensive outbreaks of western spruce budworm (*Choristoneura occidentalis* Freeman) have repeatedly defoliated conifer forests of the American Northern Rocky Mountain and Intermountain Regions during the last six decades. The chronology and geographic extent of the outbreaks, as well as effects on host trees, have been reviewed (Johnson and Denton 1975). During these outbreaks, grand firs (*Abies grandis* [Dougl. ex D. Don] Lindl.), both a major component of these forests and an important host tree for this budworm, have often been extensively defoliated, resulting in radial growth reductions and considerable topkilling. Losses of height growth in grand firs topkilled by western spruce budworm outbreaks have been reported by Bousefield (1980) and Williams (1967) as the length of stem and years of growth involved in the diebacks. The dead tops frequently are replaced by upturned lateral branches. Little information is available, however, about potential height growth reduction resulting from the shorter internodes formed on these regrown tops. Also, potential reductions in radial growth in the living stem below the killed top, resulting from loss of the killed portion of the tree crown, have received little study. Furthermore, although studies of stem defect in grand firs in this region have indicated that topkills, of whatever cause, frequently result in stem deformities (spikes, crooks, forks) and are associated with stem decays (Aho 1977, Aho and others 1979, Maloy and Gross 1963), the extent of such defects resulting from budworm-caused topkilling has not been documented. Stem defects associated with these topkills need further assessment so that forest managers and pest management specialists can estimate losses and determine the possible benefits of preventing topkilling from future outbreaks.

This paper reports a study to assess growth reduction and stem defects in mature grand firs that were topkilled by one or more of several outbreaks of western spruce budworm in west-central Idaho during the last six decades. Stem volume losses associated with topkilling resulting from each outbreak are estimated and related to the size of the tops killed, the period of years elapsed since the outbreak, and the duration of the outbreaks and associated droughts. Both a cutover and a virgin stand were sampled to obtain an indication of the volume loss that might be expected in each.

METHODS

Tree Sampling

Mature grand firs were felled and their stems dissected and examined in two stands—one cutover, one virgin—located in the Boulder Creek drainage, tributary to the Little Salmon River, in west-central Idaho. Firs in both stands had been subjected to western spruce budworm outbreaks in the years 1922-30 (Johnson and Denton 1975), 1952-55 (Furniss 1957), and 1969-78 (Ollieu and others 1977). Many of the firs had spike tops and stem deformities (crooks, forks) indicating they had been topkilled by the budworm. The cutover stand had received a sanitation cut in the late 1960's, which removed the firs with the most serious stem deformities, including those resulting from topkilling during the two earlier budworm outbreaks. The virgin stand, located about 2 mi (3 km) from the cutover stand, was sampled to obtain a more complete representation of firs that had suffered extensive stem diebacks during these two outbreaks.

Twenty grand firs were felled in each stand by a sampling procedure that selected the first four overstory firs 14 inches (36 cm) or greater in diameter-at-breast-height (d.b.h.) on each of five, randomly located, one-chain-wide strips extending into each stand.

The study began in August 1978, after defoliation and tree growth for that year were essentially completed. With a method developed previously (Ferrell 1980), current defoliation of each test tree was estimated visually. Separate defoliation ratings were made for both the current year's, and older, foliage at three crown levels—lower, mid, and upper. On the basis of percent foliage consumed or destroyed, the ratings were 0 (none), 1 (<50 percent), 2 (50 to 90 percent), and 3 (>90 percent). Foliage ratings were weighted by factors of 1 (for current) and 4 (for older), on the basis of visual estimates of the contribution of new and old foliage to the crown biomass, and then averaged to obtain a defoliation rating for the entire crown. Ratings averaging <1.0 were considered light (<50 percent), 1.0 to 1.5 medium (50 to 70 percent), and >1.5 heavy (>70 percent) defoliation.

After rating for defoliation, each tree was felled and measured for *diameter-at-breast-height* to the nearest 0.1 inch (0.3 cm), *total stem length* to the nearest 0.1 ft (0.03 m), *tree age* (annual ring count on stump with 6 years arbitrarily added to reach stump height), and *height increments* (lengths of all externally visible internodes on the major living top, to the nearest 0.1 inch [0.3 cm]). *Radial increments* were sampled by sawing 1-inch-thick (2.5-cm) cross-sectional disks from each stem. Because radial growth reduction in grand firs defoliated by western spruce budworm was found to vary with height in the bole (Williams 1967), a disk was obtained from each of three bole levels defined as lower bole (at stump level), mid-bole (at the midpoint of the tree), and upper bole (approximately at the midpoint of the upper third of the bole). Three 1-inch-wide (2.5-cm) radial sections were sawn along equally separated radii from each disk. After cross-checking for traumatic, missing, or discontinuous annual rings, the widths, to the nearest 0.01 mm, of all annual increments present on the sections were measured. The three measurements of each annual ring were then averaged for analysis. *Disk diameter*, outside bark to the nearest 0.1 inch (0.3 cm), and *position*, distance from the tip of the tree to where the disk was cut to the nearest 0.1 ft (0.03 m), were also measured for volume calculations. Dead tops and stem deformities (crooks or forks) were dissected and these measurements taken: if present, the *dead top's basal diameter* at the lower limit of dieback, to the nearest 0.1 inch (0.3 cm), and whether it issued from the stem as a spike or stub, or was embedded in the stem; *stem diameter* (just below the deformity, to the nearest 0.1 inch [0.3 cm]); and *year when topkilling occurred*, determined by counting the number of annual rings formed around the dead top since topkilling (confirmed, in some of the recent topkills, by counting the number of internodes on the new top formed by an upturned branch). Any *beetle galleries* present were noted and the causal insects identified from their gallery patterns. The incidence and extent of all topkill-associated *decay* was determined by sectioning both within, and at 1-foot (0.3-m) intervals above and below the stem deformity until any decay present was no longer visible on the cut surfaces. The *total length of the decay column* to the nearest foot was then recorded. The *diameter of the decay column* was obtained as the average of diameters measured on the cut surfaces, to the nearest 0.1 inch (0.3 cm) and the presence or absence of "wetwood" was noted.[1] Decays that appeared to have originated as root or butt rots were noted but were not included in the results. *Causal fungi* were determined from field observations of decay characteristics. Decays of questionable origin were taken into the laboratory for further examination and identification.

Growth Analysis

Growth index analysis (Fritts 1966) was used to determine height and radial growth reductions attributable to the effects of topkilling caused by the outbreaks. The indexes eliminated growth patterns resulting from differences in tree size, age, and growing site, and isolated growth fluctuations caused by weather and outbreaks of defoliating insects. Growth index analysis previously had proven useful in isolating growth reductions caused by Modoc budworm (*C. retiniana* Walsingham = *viridis* Freeman) in northeastern California (Ferrell 1980), and a similar approach was used to analyze for tree growth reductions caused by western spruce budworm in Western Canada (Thomson and Van Sickle 1980).

The computer program INDXA (Fritts 1966) was used to calculate growth indexes for all annual increments measured. Either a straight line or a negative exponential curve was fit by least squares regression to each series of increment measurements representing annual growth in successive years (*fig. 1A*). Each year's index was obtained by dividing the increment measurement by the increment predicted by the regression function (*fig. 1B*). Separate regressions were calculated for the height increments, and for the radial increments at each bole level, in each tree. Index values of 1.0 (*fig. 1B*) represent the predicted annual growth for the tree in the absence of unusual factors, such as drought or outbreaks of defoliating insects. Indexes <1.0 indicate growth below that predicted from long-term patterns in the tree, and indexes >1.0 indicate annual growth above predicted levels.

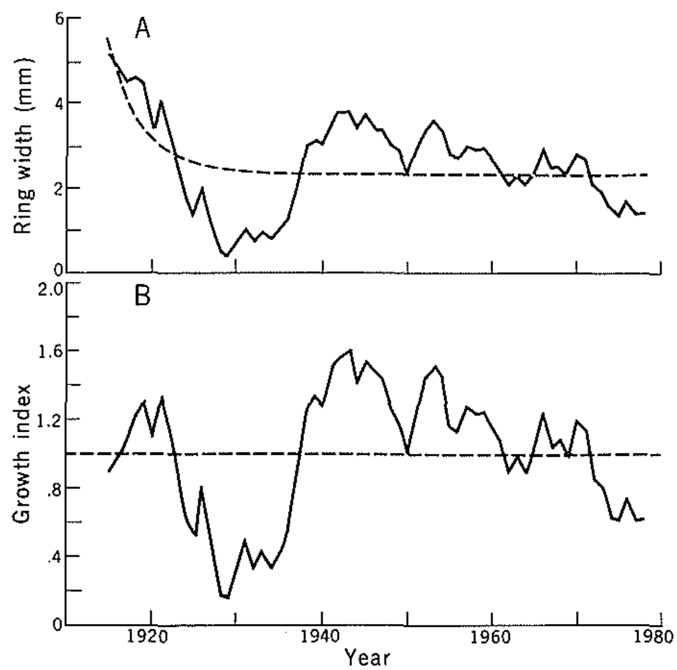

Figure 1—Annual growth indexes calculated for radial growth at the midbole level in a grand fir for the years 1915-78 by (*A*) fitting a negative exponential curve to the ring-width series to obtain predicted increments, and (*B*) dividing actual by predicted increments to obtain growth indexes. Horizontal line at an index value of 1.0 indicates predicted or expected growth.

[1] Wetwood is a condition in which the normally light-colored heartwood in firs turns darker, usually brownish, and is high in water content.

Outbreaks of conifer-feeding budworms usually have affected host trees for an unpredictable number of years after outbreaks have subsided (Johnson and Denton 1975, Kulman 1971). In this study, grand firs topkilled during or within the 3 years immediately after the outbreaks were attributed to the effects of the defoliation. Fir growth depressions that occurred during and persisted for several years after the outbreaks were attributed, at least partially, to defoliation, topkilling, or both.

Growth reduction was analyzed by comparing, in each stand, the mean annual growth indexes of firs that were topkilled by the outbreak with those of firs that were not. Mean growth indexes were plotted for years immediately before, during, and after each outbreak. Height growth and radial growth at each sampled bole level were compared separately. For periods when growth of topkilled firs was depressed below that of untopkilled firs, appreciable deficits—those that exceeded the pooled standard deviation for all trees and years compared—were attributed to the effects of topkilling caused by the outbreaks. This method was used because a tree's growth in any given year tends to be directly correlated with that in the next; therefore, the indexes did not represent the independent observations required by statistical tests. To facilitate interpretation, all growth indexes and their deficits were expressed as percentages of the predicted growth by multiplying them by 100. Growth deficits were then converted from percentages to feet of height, or inches of radius, by multiplying them by the periodic increment predicted by regression.

Volume Loss Calculations

Volume losses were calculated for topkills that affected the stems to a minimum 4-inch (10-cm) diameter top, the usual top diameter used in local cubic foot volume tables. As the diameters of the sample disks from the upper bole level averaged slightly more than 4 inches (10 cm), the merchantable stem was considered to consist of two logs bounded by upper, middle, and lower sample disks. Volume losses resulting from growth reductions were calculated as the difference between the existing stem volume, and the stem volume expected if no growth reductions had occurred, according to Smalian's formula. Volume losses because of topkill-caused stem deformities and associated decays were calculated according to local utilization standards. Because stem deformities were considered to result in the loss of 2 ft of log length, cylindrical volumes were calculated with the stem diameter measured 2 ft below the deformity. Cylindrical decay volumes were also calculated using the length and the average of the upper and lower diameters of the decay columns. The entire log was culled if the decay volume exceeded 67 percent of the volume of the log. Volume losses were expressed in cubic feet and as percent stem volume. No formal statistical tests were applied to log volumes and volume losses. The results are reported as averages and associated ranges or standard deviations.

RESULTS

Size and Age of Sample Firs

Grand firs sampled in the virgin stand were, on the average, both larger and older than those sampled in the cutover stand (*table 1*). This was probably the result of logging of the cutover stand in the late 1960's, which removed many of the larger and older firs. As this logging also removed the most defective trees, firs suffering the most severe topkilling from the budworm outbreaks in the 1920's and 1950's were probably also removed by the logging. Results from the cutover stand, therefore, represent only budworm-caused damage to the grand fir overstory that remained after the logging.

Incidence and Extent of Topkills

A total of 90 topkills was found, 45 in the 20 firs sampled in each stand. All but two of the 40 trees had been topkilled at least once, and the largest number of topkills found in any tree was eight. A topkill was visible as a dead top, or as crook or fork in the stem. Dead tops were either a spike or stub in 51 of the topkills (*fig. 2A, B*), but the dead top was completely embedded in the stem in 24 of the topkills. Dieback was extensive in most of the 75 topkills where a dead top was found. In more than half (37), basal diameter of the dead top exceeded 2 inches (5.1 cm) and five had basal diameters over 6 inches (15.2 cm). The length of some of the intact dead tops exceeded 12 ft (3.7 m). Small, usually embedded dead tops were found in an additional 15 topkills, indicating that top dieback was limited originally to only the terminal bud, or tip, of the tree.

On the basis of year of occurrence, 31 (69 percent) of the topkills in the cutover stand were attributed to the outbreaks. Only 20 (44 percent) of the topkills in the virgin stand, however, could be attributed to the outbreaks. In these old-growth firs, more topkills had occurred in years before there were any reliable records of budworm outbreaks. Topkilling increased in both stands in years near the end and immediately after the 1922-30 outbreak (*fig. 3*). For the period during and within 3 years after the 1922–30 outbreak, 29 topkills were found, 12 in the cutover stand, and 17 in the virgin stand (*table 2*). In the combined sample

Table 1—*Size and age of grand firs sampled in the cutover and virgin stands*

Size and age	Stand			
	Cutover		Virgin	
	Mean	Range	Mean	Range
Diameter-at-breast-height (d.b.h.) (inches)	18	(14 to 24)	25	(16 to 38)
Height (ft)	78	(40 to 101)	89	(35 to 129)
Age of stump (yrs)	123	(90 to 154)	192	(137 to 242)

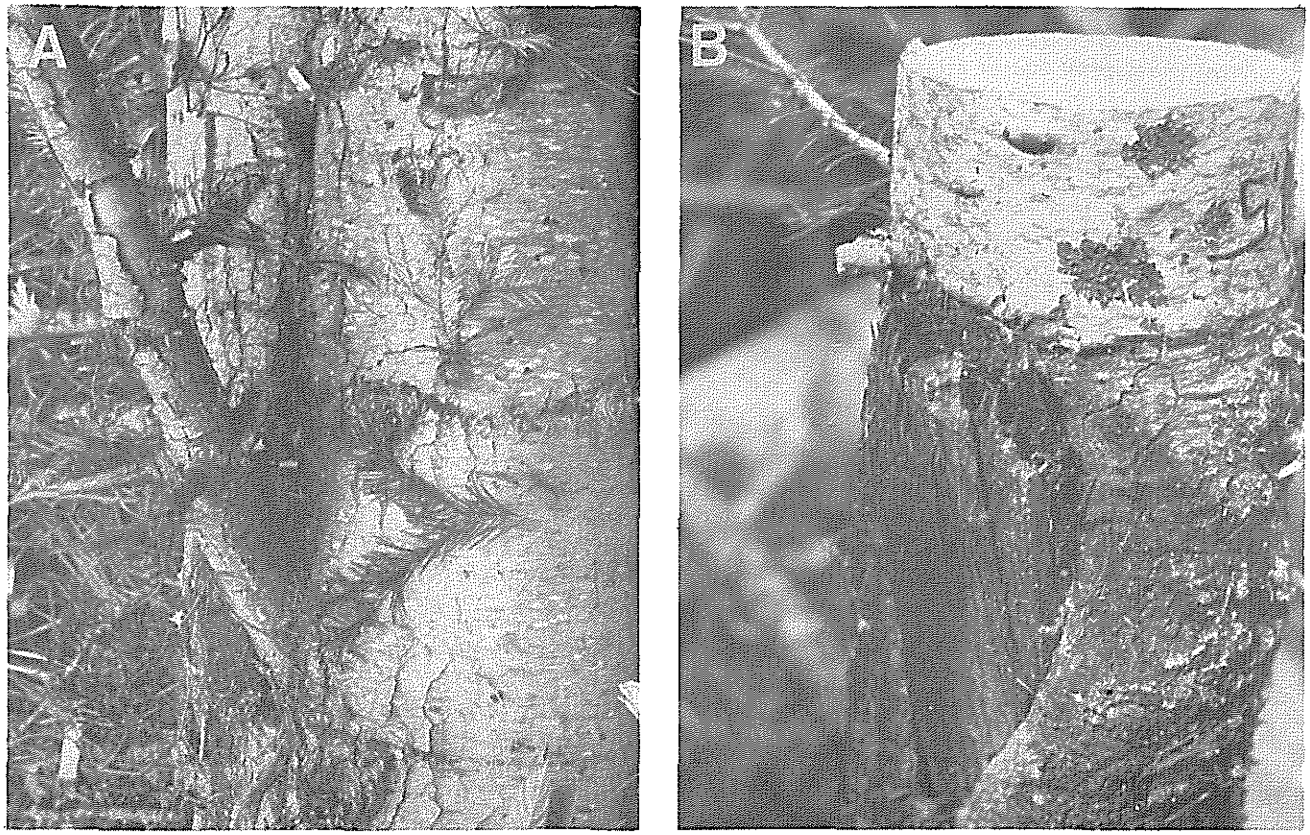

Figure 2—Old topkills in grand firs evidenced by (*A*) dead spike protruding from a bole fork, and (*B*) dead stub issuing from bole crook.

of firs from both plots, 60 percent were topkilled at least once during this 11-year period. No such increase was associated with the 1952-55 outbreak, however, when only about 18 percent of the combined sample of firs were topkilled, and topkilling continued at the same low rate observed for periods between the outbreaks. Topkilling again increased during the 1969-78 outbreak, but only in the cutover stand where 65 percent of the sample firs were topkilled. During this period no topkills were found in the virgin stand. The difference in the incidence of topkilling in the stands during this outbreak was related only partly to differences in defoliation, as rated in 1978 (*table 3*). All 20 of the firs sampled in the cutover stand were rated as having either medium or heavy defoliation, and a total of 15 topkills was found in these firs. In contrast, although 16 of the firs sampled in the virgin stand also were rated as having medium or heavy defoliation, none of these firs was topkilled during this outbreak.

Thirty-four topkills could not be attributed to the outbreaks. For the remaining four topkills, the year of occurrence could not be determined because of advanced stem decay.

The most extensive budworm-caused topkills were from the 1922-30 outbreak in firs sampled in the virgin stand. Basal diameters of some of these dead tops exceeded 5 inches (12.5 cm) (*table 2*). The size of tops killed in this stand by the 1950-55 outbreak was much smaller, with no basal diameter larger than 0.9 inch (2.3 cm). In firs sampled in the cutover stand, the size of tops killed by each of the two earlier outbreaks was about the same, with basal diameters averaging slightly more than 2 inches (5 cm), but only small tops averaging 0.2 inch (0.5 cm) had been killed during the 1969-78 outbreak.

Incidence and Extent of Decay

A major portion of the stem decay found in the firs sampled in both stands was associated with outbreak-caused topkilling. Excluding decay resulting from root, or butt rots, about one-half of the trees sampled in each stand

Table 2—*Incidence and extent of topkills and associated decays associated with western spruce budworm outbreaks in grand firs sampled on the cutover and virgin stands*

Topkills and decay	Outbreaks					
	1922-30		1952-55		1969-78	
	Average	Range	Average	Range	Average	Range
Topkills						
Number						
Cutover	12		4		15	
Virgin	17		3		0	
Basal diameter (inches)[1]						
Cutover	2.2	1.0 to 3.5	2.1	0.0 to 4.1	0.2	0.0 to 0.7
Virgin	4.1	0.8 to 6.8	0.3	0.0 to 0.9	—[2]	—
Associated decays						
Number						
Cutover	6		1		0	
Virgin	13		0		—	—
Length (ft)						
Cutover	15	2 to 45	2	0	0	0
Virgin	16	2 to 55	0	0	—	—
Volume (ft^3)						
Cutover	3.2	0.1 to 10.1	0.1	0	0	0
Virgin	5.4	0.1 to 22.9	0	0	—	—

[1]Dead top at lower limit of dieback recorded as 0 where only terminal bud or small shoot had been killed.

[2]No data, as no topkills were found.

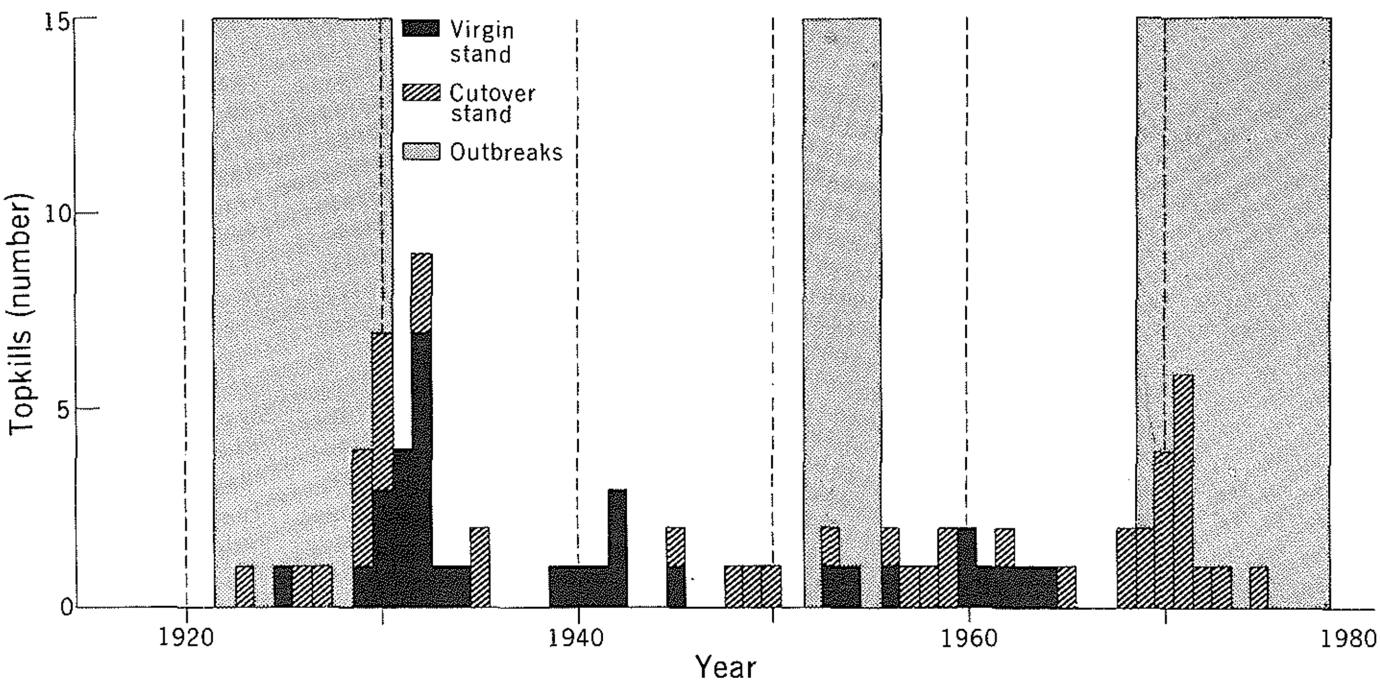

Figure 3—Incidence of topkills associated with outbreaks of western spruce budworm in sampled grand firs increased in the 1922-30 outbreak, showed no increase in the 1952-55 outbreak, and again increased in the 1969-78 outbreak, but only in the cutover stand.

Table 3—*Defoliation ratings and incidence of topkilling during the 1969-78 western spruce budworm outbreak in grand firs sampled in the cutover and virgin stands*

Defoliation rating[1]	Stand					
	Cutover			Virgin		
	Trees	Topkilled trees	Topkills	Trees	Topkilled trees	Topkills
Light	0	0	0	4	0	0
Medium	14	8	[2]9	14	0	0
Heavy	6	5	[2]6	2	0	0

[1]Percentage of crown defoliated, rated as light (<50), medium (50 to 70), or heavy (>70), August 1978.

[2]One was topkilled twice.

(10 in the cutover, 13 in the virgin) had at least some advanced stem decay, and in all but two of these trees, the decay appeared to have developed from topkills. Not all topkills, however, were associated with decay. Of the 45 topkills of whatever cause found in each stand, only 30 percent (12 in the cutover, 15 in the virgin) were associated with decay. Nearly all of the decays (19) developed in tops killed by the 1922-30 outbreak, and only one decay column was found in dead tops resulting from the more recent outbreaks (*table 2*).

Most of the decay associated with the 1922-30 topkills occurred in the old-growth firs in the virgin stand. Seventy-seven percent of these topkills in this stand had decay, compared with only 50 percent in the cutover stand (*table 2*). Decays were also more extensive in the virgin stand, and some of the decay columns exceeded 50 ft (15.3 m) in length and were 20 ft^3 (0.6 m^3) or more in volume. Consequently, the total volume of decay in the virgin stand (172 ft^3 or 4.8 m^3) greatly exceeded that in the cutover stand (37 ft^3 or 1.0 m^3).

The incidence and extent of decay caused by the outbreaks was directly related not only to the period of time elapsed since the outbreak but also to the size of the killed tops. Much larger tops were killed by the 1922-30 outbreak in the virgin stand, and these dead tops had a greater incidence and extent of associated decay (*table 2*). Neither the incidence nor the average extent of the associated decays was usually great, unless the topkill occurred more than 30 years ago and the basal diameter of the dead top exceeded 3 inches (7.6 cm) (*tables 4, 5*). In only one topkill did age appear to be more significant than basal diameter. In this situation, the top was killed more than 45 years ago and the basal diameter of the dead top was less than 1 inch (2.5 cm), but the volume of the associated decay was 22.9 ft^3 (0.6 m^3).

Most of the decay in tops was caused by the Indian paint fungus (*Echinodontium tinctorium* Ell. and Ev.). The fungus was associated with budworm-caused topkills in six of the sample firs, and with topkills of unknown cause in four firs.

Intact (spikes), broken-off (stubs), or embedded dead tops all had associated decay. Dead tops associated with decay had basal diameters averaging 4 inches (10.2 cm), and ranged from 2.5 inches (6.4 cm) to 6.5 inches (16.5 cm). The number of years that had elapsed since the fungus had become established was not precisely determined, but it was not associated with topkills occurring less than about 30 years ago.

Our finding that the Indian paint fungus occurs in association with dead tops in grand fir is more or less in agreement with the results of others (Aho 1977, Aho and others 1979). We could not determine, however, whether the dead tops served as entrance courts for the fungus, or whether the top dieback activated semidormant infections of the fungus already present in the tree, as proposed by Etheridge and others (1976).

Advanced decay from Indian paint fungus in grand fir can be readily detected by the presence of fruiting bodies (Maloy 1967, Aho 1977). In our study, 10 of the 12 trees with the fungus had fruiting bodies and their presence indicated extensive decay and cull. Three trees had one, two, or three fruiting bodies each and one tree had six. The presence and number of fruiting bodies produced by the fungus has been used in the past by foresters to estimate the amount of cull or loss from decay (Maloy 1967).

No fruiting bodies were found for any of the other fungi involved in decay of grand firs in this study.

The only other fungi we identified as decay organisms in dead tops were *Pholiota adiposa* Fries and *Hericium abietis* (Weir ex Hubert) K. Harrison. *Pholiota* was found in one tree and *Hericium* in two. Nine trees had some decay caused by fungi that were not identified. In almost all instances, the decays caused by these unidentified fungi were restricted to the embedded portions of dead tops.

Table 4—*Incidence and extent of associated decay in relation to age of topkills in the combined sample of grand firs in the cutover and virgin stands*

Topkills and decay	Years since topkill[1]			
	0 to 15	16 to 30	31 to 45	Over 45
Topkills				
Total number	20	15	11	29
With decay	0	2	4	17
Percent with decay	0.0	13.3	36.4	58.6
Decay volume (ft^3)				
Average	0.0	0.1	6.2	2.3
Range	0.0 to 0.0	0.0 to 1.0	0.0 to 66.0	0.0 to 22.9

[1]Includes all topkills examined, regardless of cause of topkill.

Table 5—*Incidence and extent of associated decay in relation to the basal diameter of dead tops in the combined sample of grand firs in the cutover and virgin stands*

Topkills and decay	Basal diameter of dead top (inches)				
	0.0 to 1.0	1.1 to 3.0	3.1 to 5.0	5.1 to 7.0	>7.1
Topkills[1]					
Total number	32	30	12	3	2
With decay	2	12	8	3	2
Percent with decay	6.3	40.0	66.7	100.0	100.0
Decay volume (ft^3)					
Average	0.8	0.9	2.2	4.8	58.2
Range	0.0 to 22.9	0.0 to 8.8	0.0 to 10.1	1.0 to 8.3	50.4 to 66.0

[1]Includes all topkills examined regardless of cause of topkill.

Galleries of bark beetles (*Scolytus ventralis* Lec.) and roundheaded borers (unidentified Cerambycidae) were found in some of the dead tops examined, including both those caused by the western spruce budworm outbreaks and those of unknown cause. Attacks by these beetles might have been found in more of the topkills if the dead tops had not been largely missing or badly decayed. As a consequence, we did not try to determine either the incidence of beetle attacks, or whether they were associated with the presence of decay as was found in grand fir tops killed by the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) (Aho and others 1979).

Wetwood, often confused with incipient decay, was almost always associated with dead tops in grand fir regardless of whether decay was present. Wetwood, however, apparently forms in response to wounding or injury in general, and is not, by itself, a reliable indicator of the presence of decay.

Growth Reductions From Topkilling

The only discernible growth loss attributable to topkilling was in the reduction of height growth of firs topkilled by the 1952-55 outbreak (*figs. 4, 5*). Height growth of firs topkilled in the cutover stand by this outbreak averaged 11.7 ft (3.6 m) or 72.6 percent of predicted increment (16.1 ft or 4.9 m) over the period 1948-59 (*table 6*). Height growth of firs that were not topkilled in this stand, however, averaged 17.4 ft (5.3 m) or 108.3 percent of predicted increment, for this same period. Compared with trees not topkilled, the topkilled firs grew an average of 35.7 percent less, amounting to 5.7 ft (1.7 m) less in height during this period. In the virgin stand, height growth deficits in firs topkilled by the 1952-55 outbreak occurred somewhat later, and were not as large as those in the cutover stand. Height growth of firs topkilled in the virgin stand was less than that predicted during the years 1955-67, averaging 8.6 ft (2.6 m), or 80.4 percent of predicted (10.7 ft or 3.3 m), for this period. Height growth of firs with no topkills, however, averaged 11.4 ft (3.5 m), or were 106.5 percent of predicted increment, for this period. In the virgin stand, height growth of the topkilled trees averaged 26.1 percent less than that predicted.

Table 6—*Height growth of grand firs topkilled, compared with those not topkilled, by the 1952-55 western spruce budworm outbreak in the cutover and virgin stands*

Stand	Trees	Height growth: Percent[1] Mean	Percent[1] (S.D.)	Feet Mean	Feet (S.D.)
Cutover stand					
Trees not topkilled	15	108.3	(3.9)	17.4	(1.5)
Topkilled trees	4	72.6	(5.7)	11.7	(2.3)
Growth reductions		35.7	(1.8)	5.7	(0.8)
Virgin stand					
Trees not topkilled	16	106.5	(5.1)	11.4	(1.7)
Topkilled trees	3	80.4	(5.8)	8.6	(1.9)
Growth reductions		26.1	(0.7)	2.8	(0.2)

[1]Percent of predicted height growth.

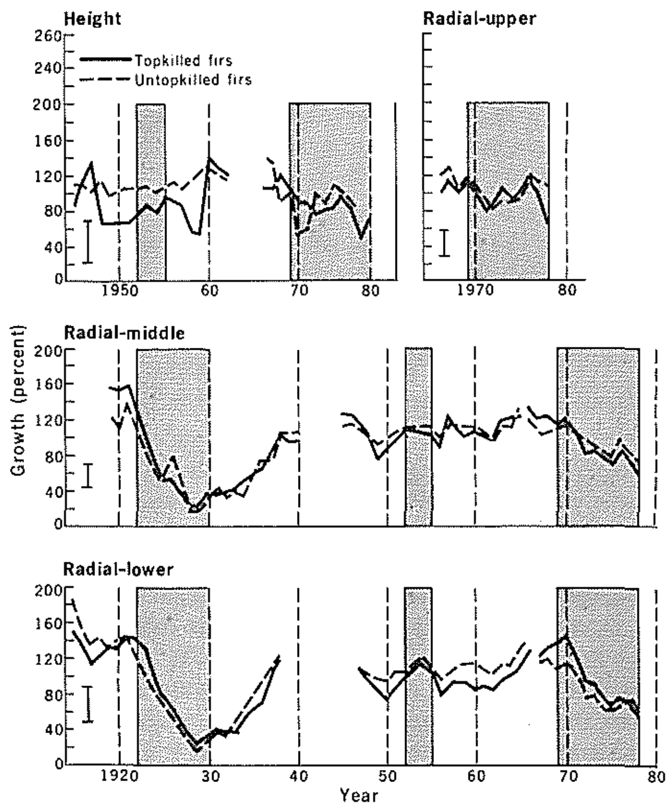

Figure 4—Except for reduced height growth in firs topkilled by the 1952-55 outbreak, height and radial growth of grand firs topkilled by western spruce budworm outbreaks in the cutover stand did not differ significantly from growth of untopkilled grand firs. Growth is expressed as percentages of increments predicted from long-term growth patterns in the trees.

Height growth reductions caused by topkilling by the 1922-30 outbreak were not studied because the internodes formed during this period were no longer visible on the exterior of the regrown tops at the time of sampling. During the 1969-78 outbreak, however, no appreciable difference was found between the height growth of topkilled and untopkilled firs in the cutover stand where a comparison could be made (*fig. 4*).

Height growth reductions found in topkilled firs resulted from the shorter internodes formed in the branches, which turned upward to replace the killed tops in all of the trees examined. For some of the tops killed by the 1952-55 outbreak in the cutover stand, the stem diebacks included internodes formed in the years 1948-51, before the outbreak began. The height growth reductions found for these years reflect the shorter internodes formed in the branches, which later became the new tops.

Radial growth of the firs was apparently not affected by outbreak-caused topkilling in either stand. When radial growth of firs during outbreak periods was expressed as percentages of predicted increments, trends were similar in both stands and at all bole levels sampled, and no appreciable differences between topkilled and untopkilled firs were found in any comparison made (*figs. 4, 5*).

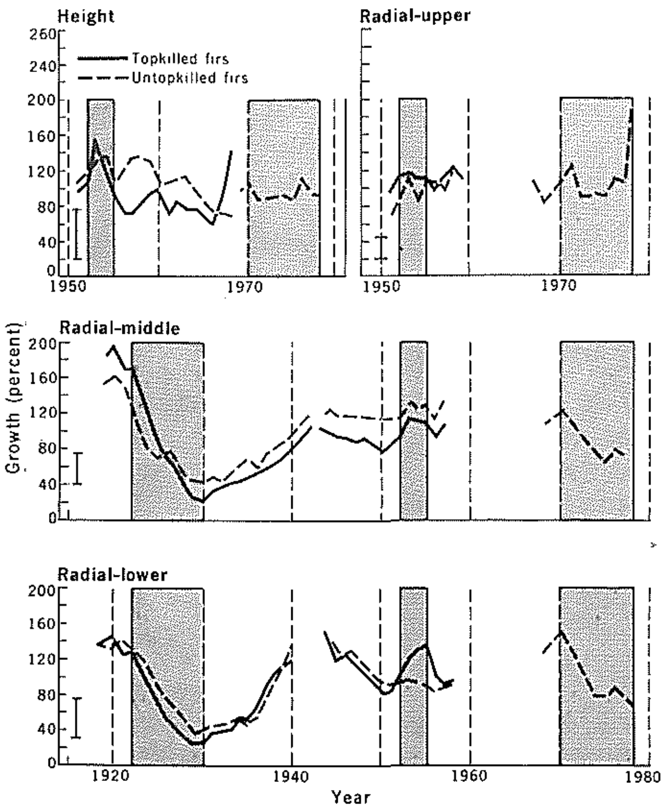

Figure 5—Height growth was reduced in firs topkilled by the 1952-55 outbreak in the virgin stand, but in other comparisons, height and radial growth of grand firs topkilled by western spruce budworm outbreaks was not significantly different from growth of untopkilled grand firs (no firs were topkilled in this stand by the 1969-78 outbreak).

Radial growth depressions did occur, however, during both the 1922-30 and 1969-78 outbreaks. Growth of firs in both stands fell below predicted levels within 2 to 3 years after the outbreaks began. During the earlier outbreak, fir radial growth fell to 20 to 40 percent of predicted increments and did not return to predicted levels until 7 to 12 years after the outbreak subsided. By 1978, during the most recent outbreak, radial growth declined to 60 to 80 percent of predicted increments at the mid- and lower-bole levels. Evidently, these radial growth depressions resulted from defoliation and subnormal precipitation, and not from topkilling. No pronounced depressions in radial growth were associated with the 1952-55 outbreak, in either stand at any bole level sampled.

Volume Losses From Topkilling

Most of the volume losses associated with budworm-caused topkilling occurred in firs topkilled by the 1922-30 outbreak. When volume losses due to height growth reduction, stem deformity, and decay were combined, firs topkilled by this outbreak in the cutover stand had volume losses averaging 9.5 ft^3 (0.3 m^3) or 11.1 percent of stem volume, with one tree losing 83.1 ft^3 (2.4 m^3) or 85.0 percent of stem volume (*table 7*). Virgin stand losses were greater, averaging 26.3 ft^3 (0.7 m^3) or 20.5 percent, and ranging up to 145.1 ft^3 (4.1 m^3) or 93.3 percent. In both stands, more than 90 percent of these volume losses resulted from decays, some so extensive that logs and entire trees were considered cull. Volume losses varied greatly among sample firs topkilled by this outbreak, mainly because of variations in the extent of the associated decays. Volume losses associated with topkilling by this outbreak would probably

Table 7—*Volume losses in merchantable stems of grand firs topkilled by western spruce budworm in the 1922-30 and 1952-55 outbreaks in the cutover and virgin stands*

Stand	Outbreaks	
	1922-30	1952-55
Cutover stand		
Topkilled trees	11	4
Volume loss[1]		
Cubic feet		
Average	9.5	3.3
Range	0.0 to 83.1	0.4 to 6.6
Percent		
Average	11.1	5.4
Range	0.0 to 85.0	0.6 to 11.5
Virgin stand		
Topkilled trees	12	3
Volume loss[1]		
Cubic feet		
Average	26.3	0.5
Range	1.5 to 145.1	0.0 to 0.9
Percent		
Average	20.5	0.3
Range	0.6 to 93.3	0.0 to 0.6

[1]Combined volume loss due to height growth reduction, stem deformity, and decay, in cubic feet and as a percentage of the volume of the stem, to a minimum 4-inch diameter top.

have been even greater had we been able to measure height growth losses.

The few topkills caused by the 1952-55 outbreak resulted in smaller volume losses not exceeding 6.6 ft^3 (0.2 m^3) or 11.5 percent per tree, due primarily to height growth reductions and not decay. Volume losses from stem deformities caused by the topkills were minor, never exceeding 5 percent of stem volume for the 1922-30 outbreak, or 1 percent for the 1952-55 outbreak. No volume losses resulted from tops killed by the 1969-78 outbreak. These occurred in the upper region of the stem less than 4 inches in diameter and did not result in stem defects below this region.

DISCUSSION AND CONCLUSIONS

A high incidence of topkilling, attributed to three western spruce budworm outbreaks during the last six decades, was found in the mature grand firs sampled. More than 75 percent of these firs were topkilled at least once, and some several times as a result of one or more of the outbreaks. Some of the dead tops were large, resulting in serious stem deformities, some height growth loss and, eventually, substantial volumes of associated decay. Incidence and size of the tops killed, as well as the effect of topkilling on fir stems, varied among the outbreaks and between the stands studied.

Most tree damage and volume losses resulted from the 1922-30 outbreak—60 to 70 percent of the firs sampled had topkills. Some of the tops killed were large with basal diameters exceeding 6 inches (15 cm). Because these large tops were killed 50 to 60 years ago, the stem deformities and decays associated with them affected merchantable portions of the stem, resulting in combined volume losses that were highly variable, but exceeded 80 percent of stem volume in some trees. Volume losses recorded for this outbreak might have been even larger if we had measured height growth reduction.

Topkills resulting from the 1952-55 outbreak were found in less than 20 percent of the sampled firs. Because the basal diameter of the dead tops never exceeded about 4 inches (10 cm) and the tops were killed only about 25 years ago, combined volume losses (due mainly to height growth reductions) never exceeded about 12 percent of the volume of the stem.

In the cutover stand, volume losses found for topkilling resulting from the 1922-30 and 1952-55 outbreaks might have been greater if this stand had not been subjected to a sanitation cut in the late 1960's.

During the 1969-78 outbreak, incidence of topkilling was highly variable between the two stands. Sixty-five percent of the firs sampled in the cutover stand were topkilled, but none of the firs sampled in the virgin stand were topkilled. This difference in the incidence of topkilling was only partially attributable to differences in defoliation observed on the two plots in 1978, but may have resulted from differences in defoliation in earlier years of the outbreak, for which records were not available. As the basal diameters of the killed tops never exceeded 0.7 inch (1.4 cm) and the tops were killed within the last 9 years, these topkills had not resulted in volume loss in the merchantable stems.

The frequency and size of tops killed appeared to be related to the duration of the outbreaks and the duration and intensity of any associated droughts. The earliest outbreak, 1922-30, was accompained by severe and protracted drought. Weather records from nearby McCall, Idaho (obtained from annual summaries of Idaho weather published by the U.S. Weather Bureau) indicated that precipitation was 12 percent below normal for the years 1917 to 1922, and 27 percent below normal for the years 1928 to 1937. The relatively short 1952-55 outbreak, however, was not accompanied by drought, and precipitation was considerably below normal (21 percent) only in 1952. Also, this outbreak was terminated by insecticide spray projects in 1955 and 1956. Severe drought did not occur during the 1969-78 outbreak although precipitation was somewhat below normal for 1969 (13 percent), 1971-72 (6 percent), and 1976-78 (9 percent).

Radial growth was evidently not affected by the topkilling during any of the outbreaks, perhaps because not enough of the crowns were killed. But the radial growth depressions found in all sampled firs, topkilled or not, during the 1922-30 and 1969-78 outbreaks were doubtless caused by the interaction of the defoliation and subnormal precipitation during these periods.

The largest source of volume loss associated with the budworm-caused topkilling was stem decay, caused mostly by the Indian paint fungus. Almost all of this decay was associated with tops killed by the earliest (1922-30) outbreak, which was undoubtedly related to the large size of some of the tops killed by this outbreak and also to the years elapsed since the topkilling during which decay could develop. Among all topkills examined, associated decays were neither frequent nor extensive, unless the topkill occurred more than 30 years ago and the basal diameter of the dead top exceeded 3 inches (7.6 cm). Somewhat different results were found in grand firs topkilled by Douglas-fir tussock moth in eastern Oregon where the incidence and extent of decay was associated with the size, but not the age, of the topkill; the oldest topkills studied, however, occurred only 28 years ago (Aho and others 1979). In contrast, it was concluded that nearly all balsam fir (*Abies balsamea* [L.] Mill.) tops killed by spruce budworm *C. fumiferana* (Clemens) in New Brunswick, with basal diameters over 0.5 inch (1.3 cm), would eventually develop decay (Stillwell 1956).

Our results indicate that grand firs suffering severe topkill by western spruce budworm can, after 30 to 60 years, suffer substantial volume losses from decay. In managing stands for the future, grand firs with large tops killed by western spruce budworm outbreaks should be harvested within 30 years to avoid losses from extensive decay. Trees with tops killed that are less than 3 inches (7.6 cm) in basal diameter will suffer some height growth reduction but likely will not experience volume loss from decay. For some time, however, forest managers can expect substantial volumes of decay in some mature grand firs topkilled by the 1922-30 western spruce budworm outbreak in west-central Idaho.

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Ferrell, George T.; Scharpf, Robert F. **Stem volume losses in grand firs topkilled by western spruce budworm in Idaho.** Res. Paper PSW-164. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 10 p.

Mature grand firs (*Abies grandis* [Dougl. ex D. Don] Lindl.) were sampled in two stands, one cutover and one virgin, in the Little Salmon River drainage in west-central Idaho, to estimate stem volume losses associated with topkilling. Damage to the stands resulted from three outbreaks of western spruce budworm (*Choristoneura occidentalis* Freeman) in 1922-30, 1952-55, and 1969-78. Stems of the firs were dissected and examined for reductions in height and radial growth, stem deformities, and decay associated with topkills. Merchantable volume losses (to a minimum 4-inch diameter top) were calculated for each outbreak. Greatest volume loss was associated with tops killed by the 1922-30 outbreak. Loss varied widely among the trees and stands sampled. In the cutover stand, which received a sanitation cutting in the late 1960's, firs topkilled by the 1922-30 outbreak averaged losses of 9.5 ft^3 (0.3 m^3), amounting to 11.1 percent of merchantable stem volume. In the virgin stand, losses averaged 26.3 ft^3 (0.7 m^3) or 20.5 percent of stem volume. Topkill-associated decays, caused mainly by Indian paint fungus (*Echinodontium tinctorium* Ell. and Ev.), were responsible for most of this loss. Smaller volume losses were recorded in firs topkilled by the 1952-55 outbreak. Losses per tree averaged 3.3 ft^3 (0.1 m^3) or 5.4 percent in the cutover stand, and 0.5 ft^3 (0.02 m^3) or 0.3 percent in the virgin stand. These losses resulted mainly from height growth reductions rather than decay. No merchantable volume losses were recorded for the 1969-78 outbreak.

Retrieval Terms: Abies grandis, Choristoneura occidentalis, Echinodontium tinctorium, topkilling, growth loss, decay, volume loss