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THE EFFECTS OF SANITATION-SALVAGE CUTTING ON INSECT-CAUSED MORTALITY AT BLACKS MOUNTAIN EXPERIMENTAL FOREST 1938-1959

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THE EFFECTS OF SANITATION-SALVAGE CUTTING ON INSECT-CAUSED PINE MORTALITY AT BLACKS MOUNTAIN EXPERIMENTAL FOREST: 1938-1959

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Entomologists

Destructive insects have long been a problem to foresters concerned with protecting and managing ponderosa-Jeffrey pine forests in northeastern California. Bark beetle depredations in this timber type have been one of the most disruptive influences affecting the conversion of old-growth stands. Until 1937, foresters managing eastside pine (as the type is called locally) had but one recourse for dealing with these pests. They located and felled trees that became infested, and treated them by one of several methods designed to kill the beetles beneath the bark. The most common procedure was peeling and burning the bark of the felled tree, a technique first described by Hopkins (1909). Other direct-control methods subsequently developed included burning the tree, using solar heat, and applying chemical insecticides to destroy beetles (Miller and Keen, 1960).

In 1937, a method of selective cutting was developed as a means of reducing insect damage to pine forests. This cutting practice soon came to be called sanitation-salvage. Insect-susceptible or high-risk trees were to be selectively logged before beetles could attack them. The opportunity for a large-scale test of this control method also occurred that year. It arose at the Blacks Mountain Experimental Forest in northeastern California, where the Forest Service had recently begun an ambitious program to investigate the silviculture and management of ponderosa and Jeffrey pine (Hallin, 1959). Bark beetles had already been recognized as a major obstacle to the management experiments planned there.

Records of insect-caused mortality in the compartments that were cut and in comparable uncut compartments were, and still are being maintained annually. Several analyses made during the first 10 years of the study amply demonstrated the success of sanitation-salvage in reducing insect-caused damage. Most of these analyses have not been published, although the earlier ones formed the basis for the first article about this work (Salman and Bongberg, 1942). Johnson (1946) analyzed the records of the first 7 years, and Bongberg (1949) did the same for the first 10 years. Neither published their findings, although their results were later summarized by other authors (Hallin, 1959; Miller and Keen, 1960).

This study was originated by the Forest Insect Laboratory of the U.S. Bureau of Entomology and Plant Quarantine, which in 1954 became the Division of Forest Insect Research of the California (now Pacific Southwest) Forest and Range Experiment Station. It has been conducted in collaboration with the Station's Division of Forest Management Research since the beginning.

This report reviews the development of the sanitation-salvage concept and its application at Blacks Mountain. It presents results based on mortality records for 22 years through 1959. It contains an analysis of the data obtained and includes the findings and conclusions about the effectiveness of this approach for reducing insect-caused damage in the eastside pine type.

THE SANITATION-SALVAGE CONCEPT

For some years before 1937, forest entomologists had nurtured the idea that bark beetles in eastside pine could be controlled by methods other than direct suppression (Keen and Salman, 1942). One method they envisioned was selective cutting to harvest timber that these insects were likely to attack before the trees became infested. Beetle-killed trees deteriorate and decline rapidly in value. Thus it seemed reasonable to suppose that logging these susceptible trees before beetles attack them would, in one stroke, forestall large increases in insect abundance and retain the full mill value of the logged trees.

This indirect approach had a glaring weakness. Until 1937, forest entomologists had not decided what constituted a susceptible tree. Nor had they learned how to recognize such trees. However, they had uncovered some evidence on both scores. Person (1928), for example, found that bark beetles in old-growth ponderosa pine stands seemed to prefer trees growing less than 1 millimeter in diameter per year. Consequently, he advocated cutting the slowest growing trees to reduce the damage in these stands. Keen (1936), pursuing this lead, concluded that age and vigor indicated susceptibility in ponderosa pine. He proposed a system of tree classes based on bark and crown characters associated with age and vigor. These classes would differentiate the susceptible from the nonsusceptible trees. He also proposed marking ponderosa pine stands for a light selective cut designed to remove trees likely to foster infestations.

Both the growth rate and the tree classification theories had the same drawback as criteria for distinguishing susceptible trees. Neither was definitive enough to reveal the individuals in most immediate danger from bark beetles. The great outbreaks of the early 1930's highlighted this shortcoming, and they helped to spur the development of a somewhat different concept. The idea developed that the current health of a tree is symptomatic of its susceptibility or risk of beetle attack. Certain discernible crown characteristics, such as the length, color and abundance of the foliage, and the prevalence of crown weaknesses (dead or dying twigs or branches) were all taken to be indicators of risk.

Characteristics used to distinguish four degrees of risk, ranging from risk 1 for the healthiest trees to risk 4 for the weakest ones, were first described by Salman (1938)[1] and later published by Salman and Bongberg (1942). Preliminary studies of ponderosa pine on the Modoc National Forest showed that by far the highest rate of mortality did, in fact, occur among the more susceptible trees, that is, those rated as risk 3 and risk 4 (Salman, 1937).[2] They also showed that these high-risk trees usually comprised a relatively small part of the stand. This suggested that logging the high-risk trees might be effective in reducing insect-caused damage.

APPLICATION AT BLACKS MOUNTAIN EXPERIMENTAL FOREST

THE EXPERIMENTAL AREA

In selecting Blacks Mountain as the site for management studies in the eastside pine type, forest research workers made an ideal choice for tests of selective logging to control bark beetles (fig. 1). Hallin (1959) has described the experimental forest there and its purposes. The following information is condensed from his account.

Created in 1934 from lands in Lassen County administered by the Lassen National Forest, the experimental forest contains 10,252 acres, of which 9,585 acres were timbered at the time of establishment. The area ranges in elevation from 5,600 to 6,900 feet above sea level, and its climate, site, and vegetation are representative of conditions found over most of the eastside type. The average stand per acre was 18,400 board feet at the time of the first inventory. Ponderosa and Jeffrey pine made up 90 percent of this volume; white fir, 7 percent; and incense-cedar, 3 percent. Hallin (1959) found that "the site index at age 100 years varies from 60 to 80 feet and averages 72 feet."

The forest resources were first inventoried in 1933 and 1934. A network of utilization roads was constructed during the next 3 years so that any single compartment could be reached and logged without disturbing adjoining compartments. The data obtained provided the basis for planning silvicultural treatments to be applied to the 100 compartments into which the experimental forest later was subdivided (fig. 2).

1/ Salman, K. A. Susceptibility classification for ponderosa and Jeffrey pine, eastside forests of northeastern California. U. S. Bur. Ent. and Plant Quar., Forest Insect Lab. Memo of May 5, 1938, 4 pp.

2/ Salman, K. A. Preliminary results-test markings of tree susceptibility. U.S. Bur. Ent. and Plant Quar., Forest Insect Lab. Memo of Dec. 14, 1937, 5 pp. Also U.S. Bureau of Entomology and Plant Quarantine Project #7, selective logging study, Blacks Mountain Experimental Forest. Memo of April 5, 1937.

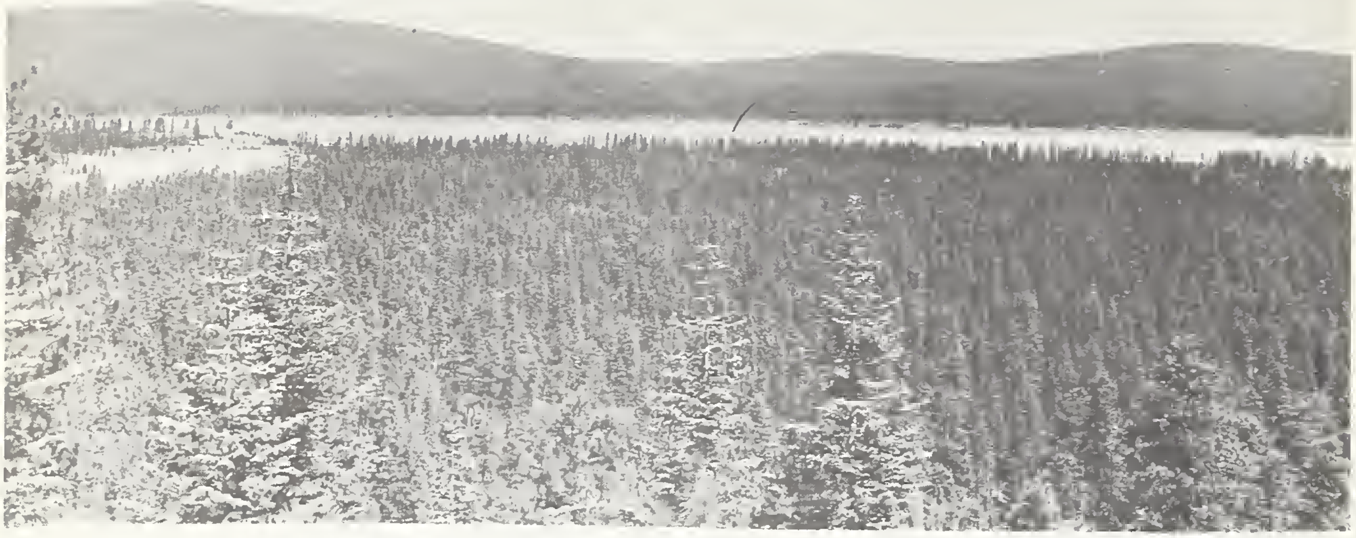

Figure 1.--The experimental forest lies in the background, extending from Blacks Mountain on the left to Patterson Mountain on the right.

INSECT PROBLEMS

The insect problems of Blacks Mountain are typical of eastside pine. The two most destructive insect species are the western pine beetle (Dendroctonus brevicomis Lec.) in ponderosa pine, and the Jeffrey pine beetle (D. jeffreyi Hopk.) in Jeffrey pine. In California, ponderosa pine is about five times as abundant as Jeffrey pine, so that the western pine beetle is a much greater pest of eastside pine stands than is the Jeffrey pine beetle.

Other injurious insects include the California flatheaded borer (Melanophila californica Van Dyke), various species of Ips, and the red turpentine beetle (Dendroctonus valens Lec.). All of these beetles alone, or more often in combination with each other, attack both hosts. They all occur on the experimental forest. The mountain pine beetle (D. monticolae Hopk.) occasionally kills ponderosa pine, but more often it destroys in combination with other bark beetles.

Evidence of insect damage had become plentiful by 1933 when the resource inventory was started, and an epidemic of bark beetles was killing many ponderosa and Jeffrey pine trees throughout northern California. The magnitude of this damage is indicated by a survey in 1937 in which all of the trees killed on the experimental forest during the years 1933-1936 were measured (Anonymous, 1938). According to the results, insect-caused pine mortality during this period averaged 202 board feet per acre per year. These excessive losses occurred despite the fell-peel-burn control work done in 1934 (fig. 3), aimed at reducing the high bark beetle-caused losses. The mortality in 1937 averaged about 70 board feet per acre

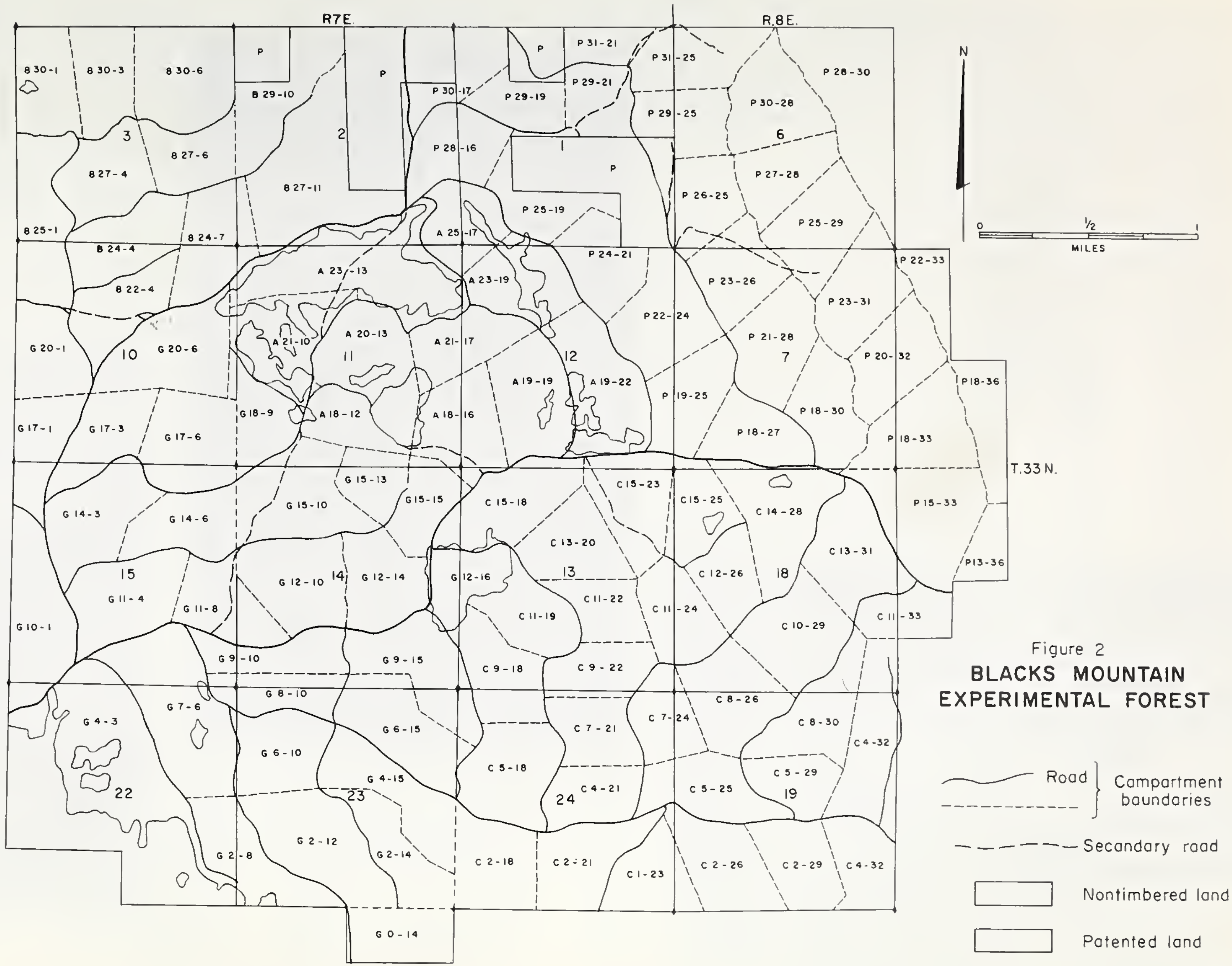

Figure 2
BLACKS MOUNTAIN EXPERIMENTAL FOREST

Figure 3.--The fell-peel-burn method was used in the western pine beetle control project at Blacks Mountain in 1934 to kill brood in the bark.

(Bongberg, 1949), a considerable reduction from the annual average of the previous four years. But even at this reduced level the mortality was still so great as to interfere seriously with the silvicultural studies planned.

CUTTING PROCEDURES

The crystallization of much of the thinking about risk rating ponderosa pine trees according to their susceptibility to bark beetles occurred at this time. It created the opportunity needed to test the practicability and value of logging the high-risk trees as a beetle-control measure. Proponents of this approach maintained that removing these trees would involve cuts light enough so that areas could be covered rapidly; that values would be realized from these cuttings which otherwise would be lost to the insects; and that taking out the preferred host material, as the high-risk trees were rated, would keep bark beetles from increasing. However, proof for these claims was lacking.

Research foresters and forest entomologists together devised the plan for testing the validity of these ideas. Their primary objective, according to Salman[3/] was "to determine the characteristics of susceptible trees, develop a practical classification of the relative susceptibility of pine trees on the area, and test that classification through application in methods of selective logging and management in which the more susceptible individuals are removed" (fig. 4).

The plan, as described by Johnson (1946), "provided for a series of sanitation-salvage cuttings to be applied as rapidly as possible to compartments showing the greatest insect hazard as a preliminary step to the silvicultural and management studies planned for the forest. The laboratory assumed responsibility for such technical details as (1) marking the trees to be removed by the cuttings, (2) suggesting the deployment of the cuttings according to the insect hazard of the compartments involved, (3) providing for means to check the insect control effectiveness of the cuttings, and (4) acting as consultant on entomological problems which arose during the cutting period."

This experiment station did all of the logging. Its Division of Forest Management Research had responsibility for the actual job of making sanitation-salvage and other types of cuttings. The division supervised logging activities, maintained cutting records, and handled other details (fig. 5). Civilian Conservation Corps enrollees logged the timber during the first few years. Thereafter, experienced lumberjacks were employed.

When a sanitation-salvage cut was made, all Risk 3 and Risk 4 trees were removed (fig. 6). In a few cases some of the less susceptible trees also were logged to bring the minimum average volume cut per acre to 2,500 board feet. When this study was started, logging lower volumes was not considered economically practicable.

3/ Memo of April 5, 1937; see footnote 2, page 3.

Figure 4.--High-risk ponderosa pine, left, is susceptible to western pine beetle attack. Low-risk ponderosa pine is on the right.

Figure 5.--White paint marked trees according to categories. One and two dots indicated low risk, three and four dots high risk. The latter types of trees were then removed by logging.

Figure 6.--Uncut, overmature ponderosa pine stand, Compartment G2-12 is shown at the top. A similar stand in G2-14, with high-risk trees removed by sanitation-salvage cut is shown below it.

From modest beginnings in 1937, sanitation-salvage was extended in the next 14 years until all parts of the experimental forest intended for treatment had been covered. It came to be regarded as the first step in converting old-growth stands to a managed condition. It was applied to compartments that had not previously been cut; then later, silvicultural cuttings were made on most of them. These cuttings were also made on many compartments where no previous cutting had been done, but the high-risk trees there were removed from the stand at the same time (Hallin, 1959).

SOURCE AND TREATMENT OF DATA

This analysis is based upon records from less than half of the area cut on the experimental forest. Sanitation-salvage was done on most of the remaining area, but in various combinations with silvicultural cuttings, which obscure the effects of either method alone. Consequently the records from such areas were eliminated from consideration here. Also excluded are the records from the 20-acre method-of-cutting plots (Eaton, 1959).

Originally the pine-sawtimber stand per acre averaged about 17,000 board feet for the compartments included in this study. This is slightly below the average for the experimental forest as a whole. About 2,650 board feet per acre, representing 15.6 percent of the original pine volume, were removed from the sanitation-salvage compartments, leaving a reserve stand of 14,354 board feet per acre (table 1; table 10, appendix).

DATA COLLECTION

Much of the data on the compartments, such as timbered area, volume cut, and time of cutting, were obtained from records of the Division of Forest Management Research. Timbered area was determined from data taken during the first inventory. The volume of green pine 12 inches in diameter and larger was determined when compartments were marked for cutting, usually just ahead of logging. The only exception is the uncut compartments where original inventory data were used.

Most of the cutting was done during the warmer months of a single calendar year. However, year of cutting does not always correspond in this report to the calendar year in which a particular compartment was actually logged. The period between July 1 of one calendar year and June 30 of the next was taken as the cutting year, largely because of the attack habits of the insects involved. Thus, compartments logged between July 1, 1939 and June 30, 1940, for example, were listed under the 1939 year of cutting.

Since 1937, records of timber killed have been collected annually by making a 100 percent cruise of the cut and uncut areas. In the earlier years this was a major undertaking, because until 1947 the entire experimental forest had to be surveyed each season to locate trees that were infested or had been killed. Beginning in 1948, the cruise was restricted to uncut compartments and those cut by the sanitation-salvage method only. The cruises usually have been made in early summer by a 3-man crew headed by an entomologist (fig. 7). Mortality cruises on the sanitation-salvage areas were discontinued when such areas were recut.

Table 1.--Area, number of trees, and volume of pine sawtimber stand per acre before and after cutting, by treatment and year of cutting[1/]

Year of cutting[2/]	Area acres	Original stand: Number trees	Original stand: Volume	Cut: Number trees	Cut: Volume	Reserve stand: Number trees	Reserve stand: Volume	Percent volume cut
			Board feet		Board feet			Board feet
			Sanitation-Salvage					
1937	302.0	22.5	19,320	2.5	2,976	20.0	16,344	15.4
1938	377.9	21.2	17,512	2.9	3,112	18.3	14,400	17.8
1939	596.7	16.4	15,852	2.1	3,048	14.3	12,804	19.2
1940	603.1	17.9	16,277	1.7	2,267	16.2	14,010	13.9
1941	800.1	17.7	17,169	1.7	2,614	16.0	14,555	15.2
1942	212.3	14.1	17,327	1.1	2,380	13.0	14,947	13.7
1944	66.6	21.5	16,109	1.5	2,085	20.0	14,024	12.9
1951	244.4	22.3	17,431	1.7	2,057	20.6	15,374	11.8
Subtotal	3,203.6							
Average		18.5	17,007	1.9	2,653	16.6	14,354	15.6
			Untreated					
--	470.9	19.8	16,198	0	0	19.8	16,198	0
Subtotal	470.9	19.8	16,198	0	0	19.8	16,198	0
Total	3,674.5							
Average		18.7	16,903					

1/ Condensed from table 10.

2/ All compartments logged between July 1 of the year listed and the following June 30 are grouped under the same year of cutting except as follows: Compartments included in the cutting year 1937 were logged between August 1, 1937 and June 30, 1938; the compartment included in the cutting year 1944 was logged between July 1, 1944 and November 1, 1945.

Figure 7.--Compassman marks the exact location of bark beetle-killed tree on a compartment map.

The mortality data collected for each dead tree found includes its location, species, diameter, and year and cause of death (Downing, 1956). Generally only trees in the 12-inch diameter class and larger were tallied; smaller trees that were occasionally recorded have been excluded from this analysis because they usually are killed by other causes than those affecting the merchantable size classes.

DATA ANALYSIS

Johnson (1946) has pointed out that "the control effect of a sanitation-salvage cutting is represented by the difference between the subsequent insect-caused pine mortality in the cutover stand and that in comparable uncut stands." In the early years of the study this was not difficult to determine by direct comparison of cut and uncut areas. The high-hazard compartments, believed to be most vulnerable to insect attack, were logged first; but it took several years to get over these areas, and for a time enough of them remained uncut so that such comparisons seemed valid. Eventually, however, all high-hazard compartments were cut. When this happened Johnson concluded that some change in the method used to evaluate the results was needed because he did not consider records from high- and low-hazard stands directly comparable.

Records of the mortality history of the experimental forest during the 1930's supported Johnson's ideas. They indicated that bark beetles did considerably more damage during this period in the high-hazard compartments than in the forest as a whole. In analyzing the first seven years of the sanitation-salvage experiment, Johnson assumed "that (1) the precutting mortality rate of the cut compartments could be projected over the post-cutting years in accordance with the natural mortality trend... on the virgin (uncut) compartments of the forest; (2) the 'predicted mortality' thus obtained...would be a valid expression of the mortality which would have occurred on the cut compartments had no cuttings been made; and (3) the difference between this 'predicted mortality' and the mortality actually cruised...could be considered a measure of the reduction in mortality, and hence the amount of insect control effected by the cuttings." Bongberg also used the concept of predicted mortality in his later analysis of the first 10 years' records (1949).

Whether we can safely assume that the precutting mortality rate can be projected over the post-cutting period for 22 or more years is open to question. Preliminary analyses showed that this assumption tends to place undue weight on the heavy losses of the mid-1930's. Thus, when predicted mortality was computed for compartments with a known loss history, it did not accurately reflect the actual mortality that occurred over the 22 years. Predicted mortality was consistently higher than the actual mortality, although it showed the same trends.

Salman (1935) found that in the pondersa pine type of California, losses from insects in cutover stands followed the same general pattern as in uncut stands, except for the lower volume. This study amply supports his conclusion. With this in mind, and knowing the deficiencies of the predicted mortality method, we have reverted to direct comparison of the losses on cut and uncut areas as the basis for evaluating the effectiveness of sanitation-salvage. This method seems a better choice than predicted mortality, despite its failure to account for differences in hazard in various areas.

The data have been handled in the same general way in this analysis as was done in analyzing similar records from methods-of-cutting plots (Eaton, 1959). Losses from insects were segregated from those due to other causes, such as lightning and wind. The records then were compiled to show average annual mortality in the cut and uncut compartments for the following periods: (a) entire post-cutting period, (b) calendar year after cutting, and (c) successive numbers of years after cutting. Both board feet and percent of stand per acre are used to express the results. Percent of stand is the better unit for many comparisons, since it compensates for differences in the amount of timber available for insects to attack.

We have not attempted to take into account ingrowth, either from trees that reached sawtimber size, or from the additional growth on trees in the reserve stand during the post-cutting period. Furthermore, the volume that died each year has not been deducted from the reserve stand volume, because preliminary analyses showed that this refinement had very little effect on the results. Ingrowth would be expected to offset mortality, at least in part, but to what extent it actually did so in this study is not known.

RESULTS

Only five compartments totaling 470.9 acres were left uncut for the entire period of study; but since compartments scheduled for sanitation-salvage could not all be logged at once they were treated as part of the uncut area until they were logged (table 10, appendix). Conversely, only one 81.3-acre compartment of the four cut by sanitation-salvage in 1937 has continuous records for the entire period; but as more compartments were logged in later years, they were added to the sanitation-salvage column. The net result is that for the early years of the study, the mortality records are based on relatively large uncut compared to cut areas; for the later years the reverse is true.

AVERAGE MORTALITY FOR PERIOD OF STUDY

The average annual pine mortality from all causes for the 22 years was far less in stands where sanitation-salvage logging had been done than in those left uncut (table 2). On the sanitation-salvage areas, mortality amounted to 26 board feet per acre per year, compared with 109 board feet for the uncut areas. In terms of percent of stand, three and one-half times as much timber was killed on the latter as on the former.

Table 2.--Average volume of pine sawtimber reserve per acre killed annually, by cause, 1938-1959

Cause	Treatment and weighted mean reserve stand volume (board feet)			
	Sanitation-salvage 13,682		Untreated 16,358	
	Board feet	Percent stand	Board feet	Percent stand
Insects	19.50	0.143	99.50	0.608
Wind	5.79	.042	6.25	.038
Lightning	.34	.002	.46	.003
Other	.34	.002	3.00	.018
Total	25.97	.189	109.21	.667

Insects accounted for most of the dead timber--much more than all other causes combined--in both cut and uncut areas. Of the reserve stand losses following sanitation-salvage, 75 percent were due to insects; in stands where no cutting was done, 91 percent of the losses were insect-caused. Wind was the next most destructive agent. It did considerably less damage than insects, although causing a much higher proportion of the total mortality on the cut compartments than on the uncut.

Average annual insect-caused mortality for individual compartments varied considerably, particularly among those with short records (table 11, appendix). For the sanitation-salvage compartments, it ranged from 0 to 40.8 board feet per acre, and the mean was 19.5 board feet. For compartments where no cutting was done, this mortality ranged from 9.4 to 249.2 board feet per acre and the mean was 99.5 board feet. Over the 22 years, insects did more than four times as much damage in the stands containing high-risk trees as in those that did not (fig. 8).

One source of variation in the records is the year of cutting, because insect-caused mortality in the treated compartments did not equal

Figure 8.--Five ponderosa pine trees killed by western pine beetle at Blacks Mountain. This type of loss was not uncommon on the uncut compartments.

a fourth of that in the untreated areas for all cutting years. This is evident from the data in table 3 where the records for the sanitation-salvage and corresponding untreated compartments have been grouped according to the year when the cutting was done. On this basis the greatest differences occurred in the logged compartments where, except for 1942, annual mortality ranged from a low of 0.10 percent of stand for 1938 to 0.29 percent of stand for 1944. By contrast the range in mortality for the untreated compartments was much narrower, the minimum being 0.58 percent of the stand for 1939, 1940, and 1951, and the maximum 0.71 for 1944.

Table 3.--Average annual insect-caused mortality of pine sawtimber reserve per acre on sanitation-salvage and untreated areas, by year of cutting, 1938-1959

Year of cutting	Treatment	Area	Mean reserve stand	Annual mortality		
				Mean	SE	Percent stand
		Acres	- - Board feet	- -		
1937	Sanitation-salvage	302.0	16,344	25.2±	3.3	0.15
	Untreated	2,415.6	16,339	96.8±	5.4	.59
1938	Sanitation-salvage	377.9	14,400	13.9±	2.5	.10
	Untreated	1,942.3	16,695	100.6±	5.8	.60
1939	Sanitation-salvage	596.7	12,804	14.7±	3.4	.12
	Untreated	1,447.1	16,929	97.9±	6.0	.58
1940	Sanitation-salvage	603.1	14,010	24.1±	4.4	.17
	Untreated	919.3	16,465	95.5±	6.3	.58
1941	Sanitation-salvage	800.1	14,555	19.8±	2.9	.14
	Untreated	707.0	16,206	99.7±	6.6	.62
1942	Sanitation-salvage	212.3	14,946	3.7±	3.7	.02
	Untreated	707.0	16,206	103.8±	6.9	.64
1944	Sanitation-salvage	66.6	14,024	40.8±	7.8	.29
	Untreated	640.4	16,216	115.3±	7.4	.71
1951	Sanitation-salvage	244.4	15,374	30.0±	6.6	.20
	Untreated	470.9	16,198	93.6±	10.4	.58

The length of record probably accounts for much of the difference in the mortality rate between areas cut in different years. The extremely low mortality for the area cut in 1942, for example, is based on only 4 years' records. For all other cutting years except this one, insects did between two and one-half and six times as much damage in untreated areas as on the sanitation-salvage areas.

MORTALITY BY CALENDAR-YEAR

Insect-caused mortality fluctuated considerably from one calendar year to the next. These changes are to be expected, and for the most part they undoubtedly are a manifestation of interactions between the insects and their environment, as Eaton (1959) pointed out. The greatest damage occurred in 1956 when the volume of timber killed exceeded 48 board feet per acre in the sanitation-salvage compartments and 207 board feet per acre in the uncut compartments (table 4). These losses are equivalent to 0.37 and 1.28 percent of stand, respectively. Insects did the least damage in 1943, killing only 2.3 board feet per acre (0.02 percent of stand) in the logged stands and 26 board feet per acre (0.16 percent of stand) in those that had not been logged.

Significantly, the mortality was consistently much lower in the sanitation-salvage compartments than in the uncut compartments (fig. 9). Fluctuations from year to year were somewhat more pronounced in the former than in the uncut areas, but the mortality trends for both were remarkably similar over the entire 22-year period. These results confirm Salman's (1935) findings that losses in cutover stands follow the same general pattern as those in uncut stands, except for being lower in volume.

MORTALITY BY SUCCESSIVE NUMBERS OF YEARS AFTER CUTTING

This favorable picture for sanitation-salvage by calendar years would be complete except that the cuttings had to be spread over several years. Thus these mortality records represent a mixture of recent and old treatments, and the results are bound to be colored to some extent by differences in the amount of damage that occurred from one year to the next.

A more meaningful measure of the effects of sanitation-salvage can be expected if we refer to records of elapsed time since the cutting was done, irrespective of calendar years. Grouped in this way, the data should show trends resulting from the treatment that otherwise might not be evident, and they should help to answer this important question: "How long do the effects of sanitation-salvage last?"

The mortality data for each calendar year were rearranged by successive numbers of years after cutting. We pooled the records for the first year after cutting, second year after cutting, third year after cutting, and so forth, without regard to the calendar year in which the losses took place. Thus, mortality during the first year after cutting under sanitation-salvage (table 8, appendix) was calculated by combining the 1938 data for compartments cut in 1937, the 1939 data for compartments cut in 1938, the 1940 data for compartments cut in 1939, and so forth. Mortality the second year after cutting was compiled in a like manner by combining the 1939 records for compartments cut in 1937, and the 1940 records for compartments cut in 1938. The same procedure was followed with the data in table 9, appendix, to obtain the mortality referred to in the same time periods for the uncut areas.

Table 4.--Average annual insect-caused mortality of pine sawtimber reserve per acre by calendar years, 1938-1959

Year	Area	Reserve stand	Annual mortality	
	Acres	Board feet	Board feet	Percent stand
		Sanitation-salvage		
1938	302.0	16,345	16.8	0.10
1939	679.9	15,264	27.5	.18
1940	1,276.6	14,114	10.5	.07
1941	1,879.7	14,081	7.9	.06
1942	2,679.8	14,222	4.6	.03
1943	2,479.1	14,097	2.3	.02
1944	1,872.2	13,831	6.4	.05
1945	1,487.5	13,605	13.9	.10
1946	1,401.4	13,377	15.9	.12
1947	1,322.4	13,345	8.9	.07
1948	1,322.4	13,345	20.0	.15
1949	1,322.4	13,345	45.8	.34
1950	1,322.4	13,345	45.2	.34
1951	1,322.4	13,345	41.6	.31
1952	1,566.8	13,662	31.3	.23
1953	1,566.8	13,662	31.4	.23
1954	1,426.7	13,577	15.2	.11
1955	953.7	13,051	20.7	.16
1956	953.7	13,051	48.9	.37
1957	859.2	13,002	34.4	.26
1958	859.2	13,002	8.9	.07
1959	859.2	13,002	31.8	.24
		Untreated		
1938	2,415.6	16,339	75.2	0.46
1939	1,942.3	16,695	117.0	.70
1940	1,447.1	16,929	122.7	.72
1941	919.3	16,465	52.1	.32
1942	707.0	16,206	50.2	.31
1943	707.0	16,206	26.0	.16
1944	640.4	16,216	50.8	.31
1945	640.4	16,216	126.9	.78
1946	640.4	16,216	79.2	.49
1947	640.4	16,216	89.1	.55
1948	640.4	16,216	132.1	.81
1949	640.4	16,216	157.0	.97
1950	640.4	16,216	197.4	1.22
1951	470.9	16,198	181.7	1.08
1952	470.9	16,198	119.4	.74
1953	470.9	16,198	60.0	.37
1954	470.9	16,198	82.2	.51
1955	470.9	16,198	96.3	.59
1956	470.9	16,198	207.7	1.28
1957	470.9	16,198	68.0	.42
1958	470.9	16,198	93.8	.58
1959	470.9	16,198	66.0	.41

When we group data in this fashion (table 5), the acreage base, for obvious reasons, is broadest for the first year after cutting and becomes progressively smaller to the twenty-second year. Moreover, the base for the uncut area is much larger than that for the sanitation-salvage. Even the 22-year record is based on considerably more acreage of uncut than cut compartments, but these differences in area do not seem to have appreciably affected the outcome.

This comparison showed that removing the high-risk trees resulted in great reductions in damage on the cut versus the uncut compartments. And, as expected, the effect of the treatment on mortality in successive numbers of years after cutting was more consistent and more pronounced (fig. 10). In only one year did mortality on the treated area approach that on the untreated: in the twentieth year after cutting, the losses were 0.45 and 0.47 percent of the stand. Over the 22 years, mortality on the sanitation-salvage compartments ranged from a low of 0.03 percent of stand during the third year after cutting to a high of 0.45 percent of stand in the twentieth year. In the uncut compartments, the results ranged from 0.41 percent of stand in the twenty-second year after cutting to 0.91 percent in the twelfth year.

When the yearly losses shown on table 5 are cumulated, the contrast in amounts of timber killed on the sanitation-salvage compartments and on those from unlogged stands is even more striking than it is in the individual year comparison. To derive cumulative percent of stand mortality, mean annual mortalities in board feet were added together for different intervals after cutting, ranging from 1 up to 22 years. Then the cumulative board feet mortality for each time period was computed as a percent of the weighted mean reserve stand volume for the treatment (from table 11, appendix). The results (table 6) show that the total volume of timber killed in the sanitation-salvage compartments after logging was only 3.76 percent of stand. In the unlogged compartments during the same period, the mortality totaled 13.96 percent of stand. These values are equivalent to 515 and 2,281 board feet per acre, respectively. Figure 11 shows the upward trends in cumulative mortality on the treated and untreated areas throughout the study period.

MORTALITY REDUCTION

If sanitation-salvage had had no effect in reducing the volume of timber killed by insects, percent of stand mortality after cutting would have been about the same on the logged as on the unlogged compartments. The 22-year record shows clearly that this was not the case regardless of the time period used in making mortality comparisons. The difference between treated and untreated areas, that is, the percent of reduction in mortality between the two types of compartments best illustrates the effect of removing the high-risk trees. Percent reduction by calendar years annually, and by successive numbers of years after cutting annually and cumulatively, has been computed from the data obtained (table 7). The formula for computing percent reduction embodies the same principle used in calculating "percent control" from insecticide treatments, and as used here the two terms are quite comparable.

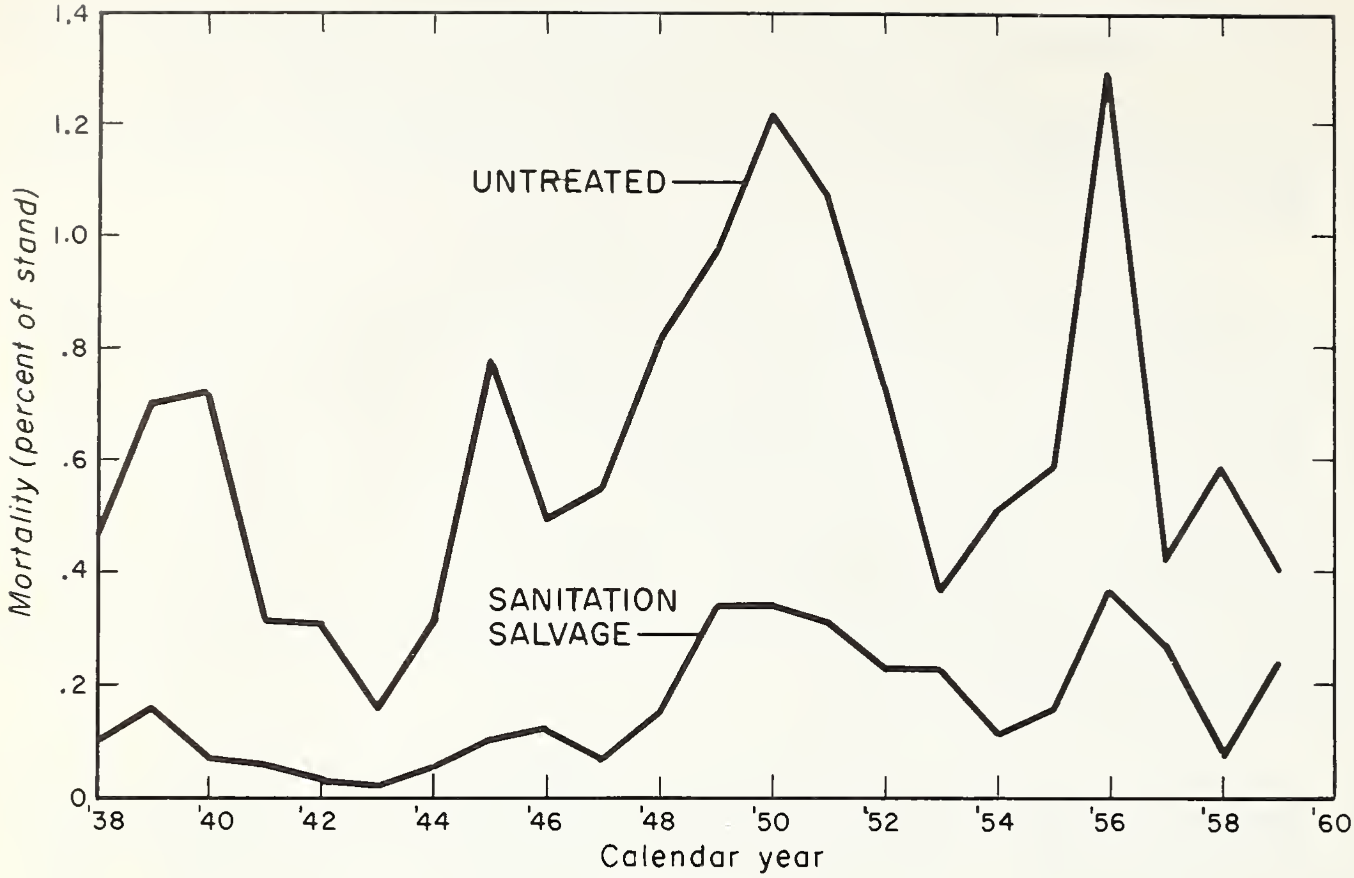

Figure 9.--Insect-caused pine sawtimber mortality on cut and uncut compartments for the calendar years 1938 to 1959.

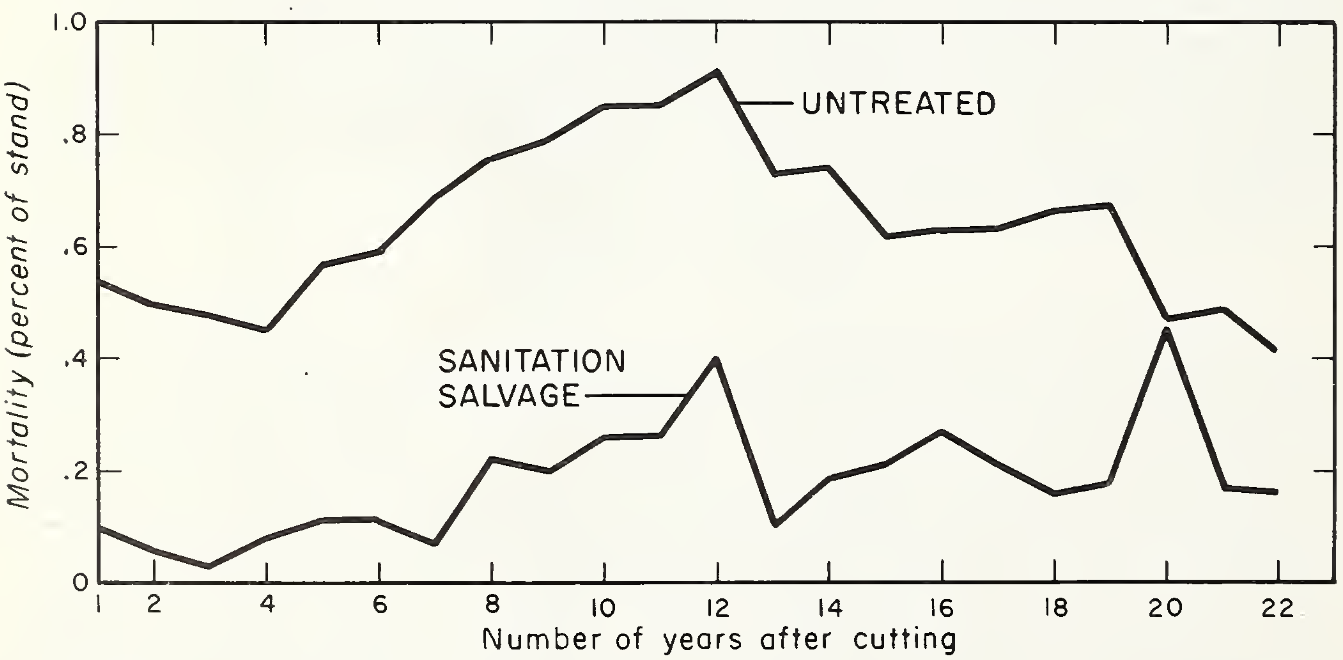

Figure 10.--Insect-caused pine sawtimber mortality on cut and uncut compartments in successive numbers of years after cutting.

Table 5.--Average annual insect-caused mortality of pine sawtimber reserve per acre in successive years after cutting, by treatment and number of years, 1938-1959

Year after cutting	Area	Reserve stand	Annual mortality	
	Acres	Board feet	Board feet	Percent stand
		Sanitation-salvage		
1	3,203.1	14,354	14.7	0.10
2	3,076.9	14,396	8.1	.06
3	2,905.2	14,316	4.0	.03
4	2,136.8	14,258	11.4	.08
5	1,845.6	14,134	15.4	.11
6	1,645.8	13,673	14.9	.11
7	1,645.8	13,673	9.3	.07
8	1,645.8	13,673	30.4	.22
9	1,401.4	13,377	26.6	.20
10	1,322.4	13,345	35.2	.26
11	1,322.4	13,345	34.5	.26
12	1,322.4	13,345	54.0	.40
13	1,322.4	13,345	14.2	.11
14	1,187.9	13,146	25.0	.19
15	939.9	12,662	26.2	.21
16	708.8	12,548	33.8	.27
17	595.1	12,616	27.1	.21
18	548.2	11,820	19.0	.16
19	372.4	10,958	18.2	.17
20	308.9	11,336	51.3	.45
21	177.0	12,755	21.4	.17
22	81.3	13,057	20.2	.16
		Untreated		
1	9,249.6	16,482	89.3	0.54
2	7,474.4	16,506	82.7	.50
3	6,172.5	16,417	79.2	.48
4	5,365.8	16,254	73.8	.45
5	5,086.9	16,212	93.1	.57
6	5,020.3	16,213	96.2	.59
7	4,784.2	16,212	112.1	.69
8	4,784.2	16,212	122.9	.76
9	4,143.8	16,212	128.7	.79
10	3,974.3	16,210	138.2	.85
11	3,804.8	16,207	138.5	.85
12	3,635.3	16,204	146.8	.91
13	3,465.8	16,201	119.0	.73
14	3,296.3	16,198	120.2	.74
15	3,296.3	16,198	99.9	.62
16	2,825.4	16,198	101.3	.63
17	2,825.4	16,198	102.3	.63
18	2,354.5	16,198	106.4	.66
19	1,883.6	16.198	108.9	.67
20	1,412.7	16,198	75.9	.47
21	941.8	16,198	79.9	.49
22	470.9	16,198	66.0	.41

Table 6.--Cumulative insect-caused mortality of pine sawtimber reserve per acre in successive numbers of years after cuttings, by treatment, 1938-1959[1/]

Year after cutting	Treatment and weighted mean reserve stand volume (board feet)			
	Sanitation-salvage 13,682		Untreated 16,358	
	Board feet	Percent stand	Board feet	Percent stand
1	14.7	0.11	89.3	0.55
2	22.8	.17	172.0	1.05
3	26.8	.20	251.2	1.54
4	38.2	.28	325.0	1.99
5	53.6	.39	418.1	2.56
6	68.5	.50	514.3	3.15
7	77.8	.57	626.4	3.83
8	108.2	.79	749.3	4.59
9	134.0	.99	878.0	5.37
10	170.0	1.24	1,016.2	6.22
11	204.5	1.49	1,154.7	7.07
12	258.5	1.89	1,301.5	7.97
13	272.7	1.99	1,420.5	8.69
14	297.7	2.18	1,540.7	9.43
15	323.9	2.37	1,640.6	10.04
16	357.7	2.61	1,741.9	10.66
17	384.8	2.81	1,844.2	11.29
18	403.8	2.95	1,950.6	11.94
19	422.0	3.08	2,059.5	12.60
20	473.3	3.46	2,135.4	13.07
21	494.7	3.62	2,215.3	13.56
22	514.9	3.76	2,281.3	13.96

1/ Calculated from data in table 5.

Table 7.--Reduction in insect-caused mortality of pine sawtimber reserve on sanitation-salvage compartments compared to untreated compartments, by years, 1938-1959[1/]

Calendar year		Successive years after cutting		
Year	Annual reduction	Number of years	Annual reduction	Cumulative reduction
	Percent		- - - - Percent - - - -	
1938	78.3	1	81.5	80.0
1939	74.3	2	88.0	83.8
1940	90.3	3	93.8	87.0
1941	81.3	4	82.2	85.9
1942	90.3	5	80.7	84.8
1943	87.5	6	81.4	84.1
1944	96.8	7	90.0	85.1
1945	87.2	8	71.1	82.8
1946	75.5	9	74.7	81.6
1947	87.3	10	69.4	80.1
1948	81.5	11	69.4	78.9
1949	64.9	12	56.0	76.3
1950	72.1	13	84.9	77.1
1951	71.3	14	74.3	76.9
1952	68.9	15	66.1	76.4
1953	37.8	16	57.1	75.5
1954	78.4	17	66.7	75.1
1955	72.9	18	75.8	75.3
1956	71.1	19	74.6	75.6
1957	38.1	20	4.3	73.5
1958	87.9	21	65.3	73.3
1959	41.5	22	61.0	73.1

1/ Computed from data in tables 4, 5, and 6 by subtracting sanitation-salvage mortality (percent of stand) from control mortality, and dividing result by control mortality.

Sanitation-salvage measured by this standard produced the greatest benefits during the years immediately after cutting. Starting at 81.5 percent the first year after cutting the reduction reached a high of 93.8 percent during the third year (fig. 12). Thereafter it tended to decrease as the length of time after cutting increased, so that by the twenty-second year the volume of timber killed on the cut compartments was only 61 percent below that on the uncut compartments. Cumulated, the mortality was 73.1 percent less for the study period as a whole in stands where the high-risk trees had been removed than in uncut stands. Eaton (1959) reported a similar pattern of loss reduction for this method of cutting. In his study, as in this one, the greatest reduction occurred a few years after cutting rather than immediately thereafter. The evidence from these and other studies (Keen, 1955) supports the belief that stand disturbances from logging probably account for this delayed effect.

The data on mortality reduction over a number of years after cutting show a linear relationship that can be expressed by the regression equation $E = 90.9 - 1.71X$. Mortality reduction is negatively correlated with time after cutting, and the correlation coefficient -0.61 is statistically highly significant. Actual values of the percent reduction year by year were somewhat closer to the calculated values during the first part of the study period than during the last. This may be due in part to the broader base for the data for the early years after cutting as compared to the later ones, and in part due to decrease in the effects of sanitation-salvage with the passage of time.

These effects can be expected to persist for some time, because while the regression of loss reduction on time after cutting slopes downward (fig. 12), the rate of decline is quite gradual. Even this trend may be lessened somewhat as additional records swell the sample base for what are now the longer intervals since cutting. However, if we assume that the downward trend will continue at no change in rate, it will be 53 years from the time cutting was done before percent of stand mortality on the cut and uncut compartments reaches the same level. Eaton (1959) reported about the same result from his earlier analysis. This is a much longer time span for sanitation-salvage to influence the loss pattern than was anticipated by the originators of this method.

Some degree of decline in the beneficial effects of sanitation-salvage with the passage of time is inevitable in the normal course of events. The reason is that while logging leaves a residual stand that initially is composed entirely of low-risk trees, at least some of these trees can be expected to decline in health as they become older and eventually become high risk. Furniss and Hallin (1955) found that the volume of high-risk trees occurring on four sanitation-salvage compartments at Blacks Mountain between 16 and 17 years after the compartments were cut, averaged 1,110 board feet per acre. This was 37 percent of the volume in high risk originally present on these compartments. At this rate it would take from 43 to 46 years for enough trees in the reserve stand to become high risk to equal the precutting level. This is 7 to 10 years short of the period indicated from the regression analysis described above.

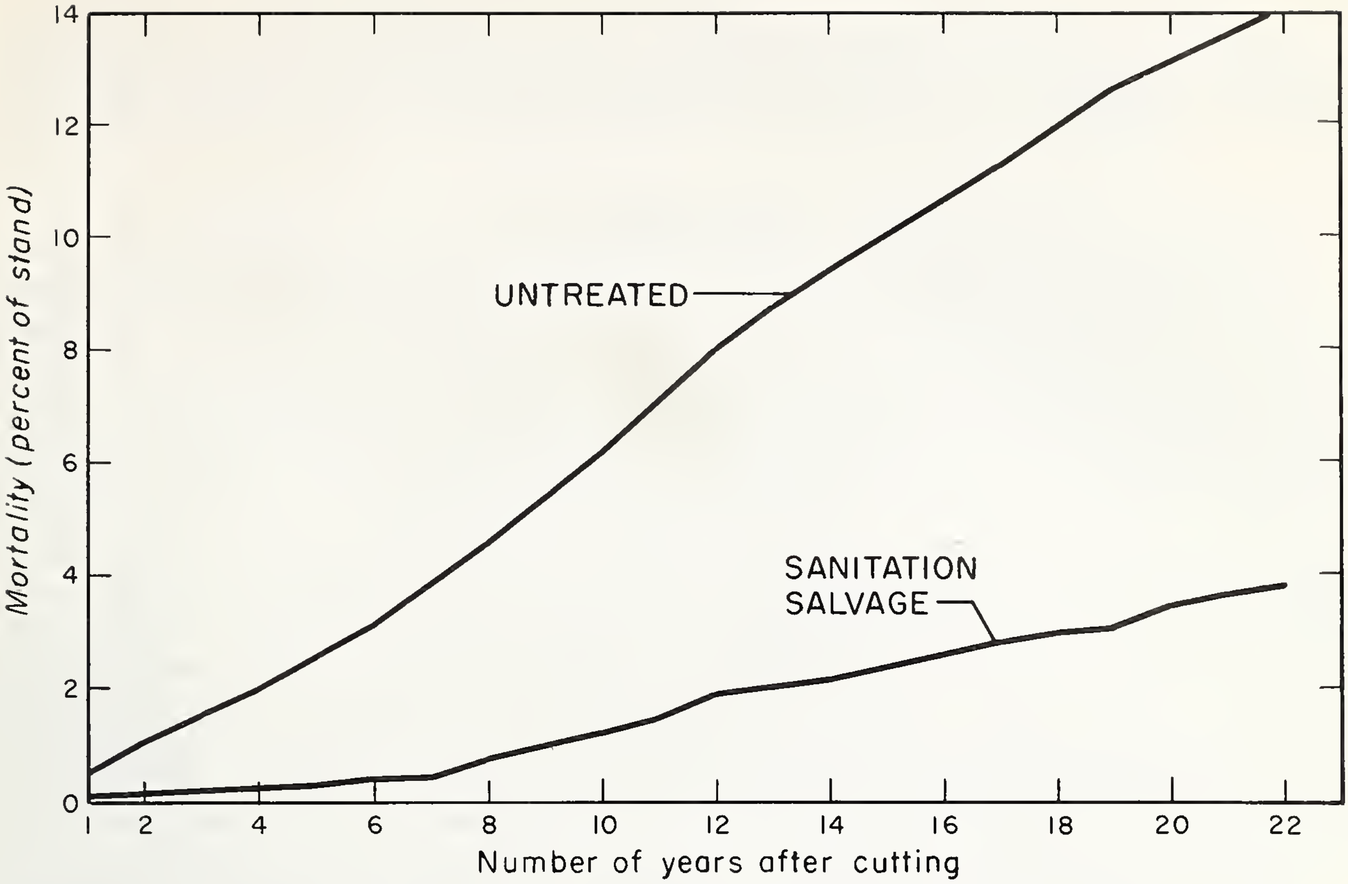

Figure 11.--Cumulative insect-caused mortality in pine sawtimber reserve on cut and uncut compartments.

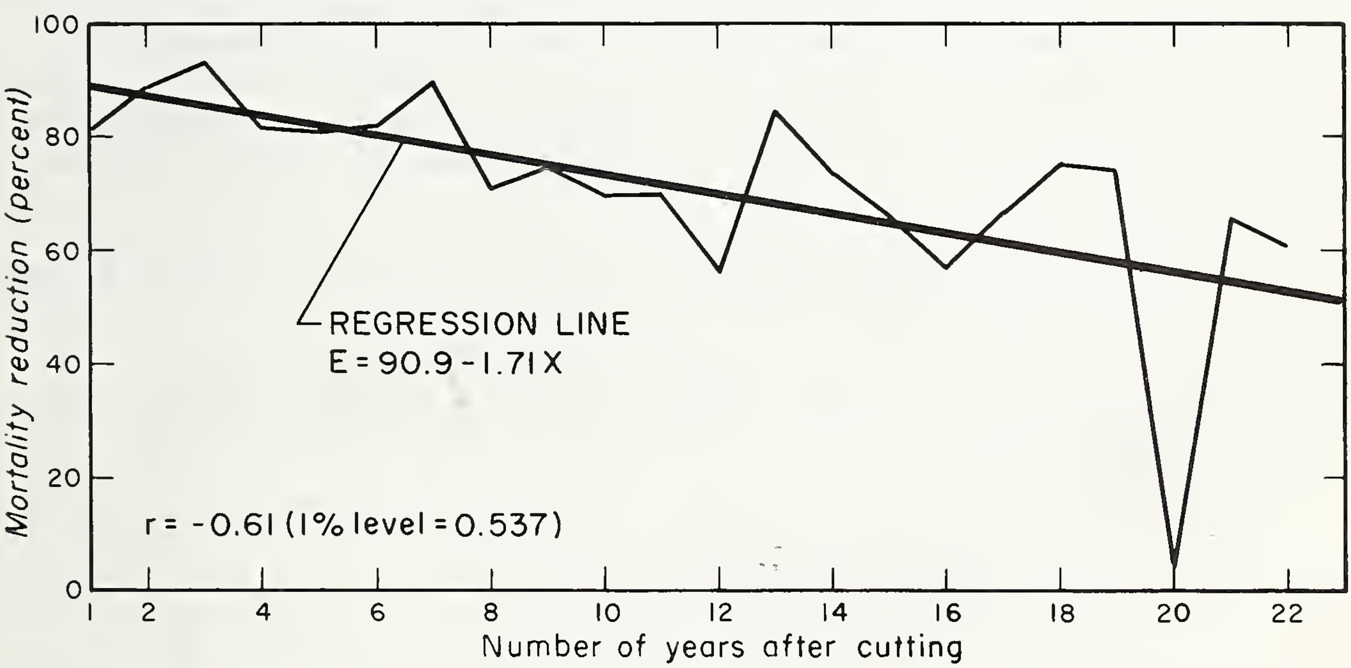

Figure 12.--Reduction in insect-caused pine sawtimber mortality on sanitation-salvage compartments compared to untreated. Based on percent of stand.

The discrepancy may be attributed in part to the difficulty of applying risk ratings with absolute consistency. These ratings are visual estimates, and to some degree their application is affected by experience and judgment; consequently, findings concerning changes in risk need to be judged accordingly.

CONCLUSIONS

Just how the removal of high-risk trees affects bark beetle infestations is still largely a conjectural matter. In speculating on this point, Bongberg (1949) noted that the effect seems to be ecological. He surmised that during endemic periods, at least, high-risk trees fulfill food requirements for the successful development of broods in a way that low-risk trees do not. He also pointed out that fewer beetles seem to be required to kill high-risk trees, and that the progeny of beetles attacking such trees are far more numerous than for low-risk trees. His conclusion about the mechanism through which sanitation-salvage affects bark beetle populations is that "when beetles are deprived of their preferred host material by removing the high-risk trees from the stand, populations remaining in the area, or those which have access to the treated area from surrounding untreated stands, are absorbed by the resistant reserve stand." Although this explanation seems plausible, to date it remains largely a hypothesis without a great deal of factual information to support it.

On the question of whether removing the high-risk trees prevents bark beetle epidemics, the evidence from this study is a little more tangible. On the experimental forest, the pattern of insect-caused mortality after sanitation-salvage almost invariably has paralleled that in uncut stands, but at a much lower level. This parallel pattern prevailed even in the early years when relatively small proportions of the total area had been logged. Thus far, the influence of bark beetle populations in untreated compartments has not been enough to nullify the effects of sanitation-salvage, even though the treated and untreated areas are intermingled. Timber mortality of the type characteristic of bark beetle outbreaks has not occurred on the compartments to which sanitation-salvage has been applied.

How successful is this method in providing a high degree of protection during years of epidemic infestations? Miller and Keen (1960) noted that the level of infestations has been low during the period that sanitation-salvage has been under test, and mentioned the lack of proof that the effects of the treatment would stand up under the onslaught of high bark beetle populations.

Between 1937 and 1949, bark beetle infestations on the experimental forest, as well as elsewhere in the eastside pine type, did not reach the destructive level that they had attained during the preceding decade. However, in 1950 and 1951, heavy damage of the type associated with outbreaks did occur in the untreated stands. In 1956, annual mortality in these stands exceeded the average for 1933-1936, the years of severe bark beetle infestations. If the premise were true that the benefits of sanitation-salvage were lost during epidemics, then tree mortality in the treated and untreated stands should have been about equal. This was not the case; rather mortality on the sanitation-salvage compartments remained much lower than it was on the uncut compartments in all years.

We previously noted that sanitation-salvage was one of several methods of cutting tested on 20-acre plots in a separate study at Blacks Mountain (Eaton, 1959). The effects of this method on post-cutting mortality were about the same in both studies, although the mortality on the plots was substantially below that on the compartments in the present analysis, irrespective of the treatment. Because of inherent weaknesses in small plots for studies of insect-caused mortality in old-growth stands, Eaton concluded that the data from the compartments are probably the more reliable since they have a much larger base.

In the 22 years covered by this study, insects have not yet killed the amount of timber in uncut stands equivalent to the 2,650 board feet per acre removed by sanitation-salvage. They have killed 2,281 board feet per acre. Theoretically, only about three-fourths of this volume can be considered susceptible, because in stands from which the high-risk trees had been cut, insects killed some 515 board feet per acre in the same period. Presumably a comparable amount makes up the remaining quarter of the total mortality on the uncut. The results thus support previous findings that the practical effect of removing the high-risk trees through sanitation-salvage cutting is one of getting to these trees ahead of the beetles.

Sanitation-salvage cutting has proved economically as well as technically feasible in forests managed for timber production. It has shown promise as a protective measure in forests managed primarily for recreation (Hall, 1958). High-risk trees yield timber grades comparable to the stand as a whole (Garland, 1940), and the cost of logging these trees is only slightly higher than for harvest cuttings (Hasel, 1946). At 1961 prices, sanitation-salvage at Blacks Mountain would have resulted in savings in stumpage values aggregating $62 per acre that otherwise would have been lost to insects over the 22 years studied. The actual savings have not been this large because of lower stumpage prices in the years of cutting.

The effectiveness of this method of reducing insect-caused damage in old-growth stands of eastside pine has been recognized almost from the start of the trials at Blacks Mountain. Bongberg (1949), commenting upon the results achieved in the first decade, observed: "The sustained benefits of control over the period of 10 years have far exceeded original expectations." To this we can add that after more than two decades, the effects of the treatment are still quite remarkable.

SUMMARY

Insects, notably bark beetles, are a major cause of tree mortality in ponderosa pine forests. They are especially destructive to unmanaged old-growth stands. In the early attempts to convert such stands to a managed condition, the insect control measures available could be applied only to infested trees. About 25 years ago, sanitation-salvage cutting was conceived as a means of reducing the damage by logging the insect-susceptible or high-risk trees before the beetles attack them.

The first trial of sanitation-salvage occurred on the Blacks Mountain Experimental Forest in northeastern California, where logging high-risk trees was started in 1937. Early results were so promising that the cutting was extended over most of the 10,252-acre forest in the next 14 years, except for certain areas reserved in a natural condition or for other reasons. Tree mortality in cut and uncut stands has been measured annually since the start of this test. The records for the 22-year period, 1938 to 1959, have been analyzed to determine the effectiveness of this method of control.

The original volume of pine sawtimber per acre averaged about 17,000 board feet on the compartments studied. Logging reduced this volume on the sanitation-salvage compartments by 2,653 board feet (1.9 trees) per acre, or 15.6 percent, leaving a reserve stand averaging 14,354 board feet per acre.

Bark beetles accounted for 75 percent of the total pine sawtimber that died following sanitation-salvage, and 91 percent of the mortality in the unlogged stands during this period. The average volume killed annually in the treated compartments was 0.143 percent of stand; in the untreated compartments the mortality was 0.608 percent of stand, or more than four times greater.

The volume of timber killed by insects fluctuated from one calendar year to the next, but was consistently much lower in stands where the high-risk trees had been cut than in uncut stands. In both types of stand, however, the loss trends between 1938 and 1959 were remarkably similar.

The mortality in successive numbers of years after cutting showed the same consistent and striking differences between treated and untreated stands as calendar-year mortality. The total volume of timber killed where the high-risk trees had been logged was only 3.76 percent of stand, or 515 board feet per acre for the 22 years. In the same period, the losses in uncut stands totaled 13.96 percent of stand, or 2,281 board feet per acre.

Sanitation-salvage reduced the toll taken by insects the most during the years immediately after cutting. The reduction was largest during the third year when the mortality in the treated stands dropped 93.8 percent below that in untreated ones. Thereafter, the effects of the cutting declined, so that by the twenty-second year, insects killed about two-fifths as much timber in the logged stands as in unlogged ones.

The results indicate that reductions in losses, achievable by logging high-risk trees in old-growth ponderosa-Jeffrey pine stands, are negatively correlated with time after cutting. They substantiate previous findings about this method of insect control. Projections of the data suggest that it will take about 50 years from the time of cutting for percent of stand mortality in cut and uncut stands to reach the same level.

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APPENDIX

Table 8.--Average annual insect-caused mortality of pine sawtimber per acre in the reserve stand, following sanitation-salvage cutting, by compartment and calendar year

Year of cutting	Compartment	Timbered area	Reserve green stand: volume per acre	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947
		Acres	Board feet										
1937	G 0-14	79.0	13,906	3.9	32.9	0	61.8	0	0	0	30.9	39.6	Recut
	G 2-14	81.3	13,057	22.9	13.5	12.4	5.3	0	0	0	79.8	54.8	21.9
	G 6-10	94.8	18,434	13.4	68.9	27.5	3.3	20.2	- - - -Recut - - - -				--
	G 8-10	46.9	21,927	34.8	33.6	0	0	0	0	0	59.6	5.0	17.3
1938	B 25-1	113.7	12,190	--	28.0	15.0	0	3.7	0	8.2	12.0	0	11.6
	B 27-4	95.7	12,498	--	15.0	19.2	13.2	4.5	0	0	0	0	0
	G 4-15	105.0	17,469	--	9.8	4.2	1.1	0	24.2	- - - Recut - - -			
	G 15-15	63.5	16,147	--	19.2	0	27.1	0	- - - -Recut - - - -				--
1939	G 12-10	111.6	14,033	--	--	43.3	0	0	- - - -Recut - - - -				--
	G 12-14	91.1	14,666	--	--	8.9	0	6.7	- - - -Recut - - - -				--
	G 14-3	53.4	21,573	--	--	0	0	0	0	0	0	8.0	3.5
	G 14-6	86.7	10,176	--	--	0	16.3	0	0	0	0	0	0
	G 15-10	131.9	9,431	--	--	0	7.4	0	0	0	0	15.2	11.1
	G 15-13	52.0	12,741	--	--	2.3	0	0	- - - - - Recut - - - -				--
	G 17-3	21.9	15,917	--	--	0	0	0	0	0	0	91.4	0
	G 17-6	48.1	9,332	--	--	0	0	0	0	0	0	0	0
1940	G 9-10	32.9	23,880	--	--	--	82.4	0	0	0	3.6	31.2	31.2
	G 11-4	115.2	10,246	--	--	--	0	0	0	- - - Recut - -			--
	G 11-8	88.8	18,603	--	--	--	0	0	0	- - - Recut - - - -			
	G 18-9	63.5	9,119	--	--	--	0	0	0	0	6.6	70.1	0
	P 15-33	139.1	15,111	--	--	--	0	0	0	1.1	- - - Recut - - -		
	P 18-30	88.6	14,162	--	--	--	8.7	27.9	0	0	- - - Recut - - -		
	P 18-33	31.1	10,403	--	--	--	7.5	0	64.4	0	0	0	0
	P 20-32	43.9	13,039	--	--	--	0	8.7	0	0	7.0	0	0
1941	C 8-30	94.5	13,494	--	--	--	--	0	0	0	0	0	21.8
	C 11-33	53.4	13,860	--	--	--	--	44.2	0	0	- - - Recut - - -		
	C 13-31	85.9	12,025	--	--	--	--	0	0	0	- - - Recut - - -		
	C 14-28	123.9	14,121	--	--	--	--	0	0	0	0	0	0
	C 15-23	100.3	15,826	--	--	--	--	0	0	- - - Recut - - - -			
	C 15-25	71.4	15,670	--	--	--	--	0	0	- - - Recut - - - -			
	P 18-27	84.3	17,325	--	--	--	--	19.9	0	1.4	- - - Recut - - -		
	P 19-25	36.6	16,178	--	--	--	--	0	0	0	73.3	0	47.0
	P 22-24	47.1	15,909	--	--	--	--	0	0	0	48.6	38.9	20.4
	P 23-31	50.8	13,577	--	--	--	--	40.4	0	0	11.6	0	0
	P 24-21	51.9	12,512	--	--	--	--	0	0	0	0	35.4	0
1942	G 7-6	86.1	17,319	--	--	--	--	--	14.7	0	0	- - Recut - -	
	G 10-1	126.2	13,327	--	--	--	--	--	0	- - - - Recut - - - -			
1944	C 7-24	66.6	14,024	--	--	--	--	--	--	--	18.6	14.1	6.4
1951	B 24-7	74.9	18,000	--	--	--	--	--	--	--	--	--	--
	B 27-6	73.2	14,032	--	--	--	--	--	--	--	--	--	--
	B 29-10	96.3	14,351	--	--	--	--	--	--	--	--	--	--

Table 8.--Continued

Year of cutting	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
	-Board feet-											
1937	- - Recut - -		--	--	--	--	--	--	--	--	--	--
	60.4	19.0	65.7	13.9	36.0	67.3	27.3	12.1	76.3	46.5	32.2	20.2
	--	--	--	--	--	--	--	--	--	--	--	--
	2.5	36.9	37.7	59.3	0	8.1	48.8	Cruise terminated		--	--	--
1938	1.6	31.0	65.5	24.4	31.4	36.3	20.0	- - - - - - -Recut- - - - - -				--
	21.7	54.2	69.0	1.9	0	11.7	8.1	0	28.2	6.1	0	12.3
	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
1939	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
	33.2	69.1	68.0	141.7	0	5.5	Cruise terminated		--	--	--	--
	6.5	131.2	0	0	0	22.5	Cruise terminated		--	--	--	--
	0	39.3	0.9	93.4	0	69.0	24.0	30.8	52.7	28.6	0	91.4
	--	--	--	--	--	--	--	--	--	--	--	--
	0	0	0	136.4	0	0	0	Cruise terminated		--	--	--
	8.9	0	0	16.0	0	0	0	Cruise terminated		--	--	--
1940	8.0	82.4	46.0	119.1	12.8	46.0	38.5	Cruise terminated		--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
	57.7	60.3	67.8	26.5	57.0	2.9	0	0	44.6	30.7	0	0
	Recut	--	--	--	--	--	--	--	--	--	--	--
	Recut	--	--	--	--	--	--	--	--	--	--	--
	0	0	47.1	6.1	121.9	31.6	170.3	Cruise terminated		--	--	--
	103.6	16.8	121.6	127.8	0	12.0	0	Cruise terminated		--	--	--
1941	0	46.4	46.4	50.5	24.2	41.4	10.4	28.7	25.0	- - - - Recut - - - -		
	Recut	--	--	--	--	--	--	--	--	--	--	--
	Recut	--	--	--	--	--	--	--	--	--	--	--
	1.2	0	35.4	0	50.8	10.2	1.2	10.2	52.5	65.8	21.9	14.3
	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
	Recut	--	--	--	--	--	--	--	--	--	--	--
	16.1	97.9	81.5	81.1	37.2	5.1	42.9	Cruise terminated		--	--	--
	32.8	110.8	33.3	4.0	20.8	149.5	0	Cruise terminated		--	--	--
	0	23.1	71.7	0	28.8	86.5	0	Cruise terminated		--	--	--
	0	27.3	8.1	18.1	0	60.2	0	0	43.4	0	0	22.5
1942	- - Recut - -		--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
1944	85.3	78.4	73.2	64.1	76.6	10.8	0	64.3	39.3	42.6	4.6	33.1
1951	--	--	--	--	66.9	0	0	0	37.7	22.0	3.1	38.7
	--	--	--	--	31.7	2.0	19.8	43.9	5.2	71.2	7.5	60.4
	--	--	--	--	102.8	28.0	2.4	33.4	114.1	16.7	12.5	0

Table 9.--Average annual insect-caused mortality of pine sawtimber per acre in uncut stands, by compartment and calendar year

Compartment	Timbered area	Reserve green stand volume per acre	1938	1939	1940	1941	1942	1943	1944	1945	1946
	Acres	- - - - - - - - - - - - - - - - - Board feet	- - - - - - - - - - - - - - - - -								
G12-10	111.6	16,598	211.8	Cut	--	--	--	--	--	--	--
G12-14	91.1	17,426	28.5	Cut	--	--	--	--	--	--	--
G14-6	86.7	13,428	135.2	Cut	--	--	--	--	--	--	--
G15-10	131.9	12,045	64.8	Cut	--	--	--	--	--	--	--
G15-13	52.0	16,384	183.6	Cut	--	--	--	--	--	--	--
G11-4	115.2	12,389	49.8	114.7	Cut	--	--	--	--	--	--
G11-8	88.8	21,151	4.7	179.9	Cut	--	--	--	--	--	--
G18-9	63.5	10,340	0	30.7	Cut	--	--	--	--	--	--
P15-33	139.1	17,609	55.3	56.5	Cut	--	--	--	--	--	--
P18-30	88.6	17,114	198.8	299.6	Cut	--	--	--	--	--	--
C8-30	94.5	16,370	38.4	169.1	106.6	Cut	--	--	--	--	--
C11-33	53.4	16,687	0	0	28.3	Cut	--	--	--	--	--
C14-28	123.9	17,362	49.2	80.8	33.3	Cut	--	--	--	--	--
C15-23	100.3	18,619	34.7	47.5	51.5	Cut	--	--	--	--	--
C15-25	71.4	17,299	33.1	115.6	65.4	Cut	--	--	--	--	--
P18-27	84.3	19,811	98.5	149.6	227.6	Cut	--	--	--	--	--
G7-6	86.1	19,784	20.0	57.4	84.0	0	--	--	--	--	--
G10-1	126.2	15,650	80.6	50.3	46.7	22.0	Cut	--	--	--	--
C7-24	66.6	16,109	29.8	42.3	164.5	15.6	99.3	0	Cut	--	--
B27-6	73.2	16,096	55.3	314.7	178.6	94.2	69.5	28.0	41.9	120.6	166.4
B29-10	96.3	16,398	232.3	118.6	156.5	90.9	3.2	17.9	95.2	123.0	83.2
A21-10	64.7	13,103	0	45.9	6.6	11.9	0	35.7	35.7	97.9	46.2
B24-4	91.2	14,943	92.8	168.7	128.1	75.8	9.8	63.8	48.1	101.4	20.9
C4-21	72.0	17,055	75.9	149.9	80.8	16.7	45.7	30.8	21.2	84.0	95.6
G2-12	143.1	16,918	66.5	74.0	283.8	90.3	86.6	0	63.5	185.8	88.5
P21-28	99.9	17,698	64.7	217.6	220.1	66.4	68.8	42.7	29.7	123.9	60.8

Table 9.--Continued

Compartment	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
	Board feet												
G12-10	--	--	--	--	--	--	--	--	--	--	--	--	--
G12-14	--	--	--	--	--	--	--	--	--	--	--	--	--
G14-6	--	--	--	--	--	--	--	--	--	--	--	--	--
G15-10	--	--	--	--	--	--	--	--	--	--	--	--	--
G15-13	--	--	--	--	--	--	--	--	--	--	--	--	--
G11-4	--	--	--	--	--	--	--	--	--	--	--	--	--
G11-8	--	--	--	--	--	--	--	--	--	--	--	--	--
G18-9	--	--	--	--	--	--	--	--	--	--	--	--	--
P15-33	--	--	--	--	--	--	--	--	--	--	--	--	--
P18-30	--	--	--	--	--	--	--	--	--	--	--	--	--
C8-30	--	--	--	--	--	--	--	--	--	--	--	--	--
C11-33	--	--	--	--	--	--	--	--	--	--	--	--	--
C14-28	--	--	--	--	--	--	--	--	--	--	--	--	--
C15-23	--	--	--	--	--	--	--	--	--	--	--	--	--
C15-25	--	--	--	--	--	--	--	--	--	--	--	--	--
P18-27	--	--	--	--	--	--	--	--	--	--	--	--	--
G7-6	--	--	--	--	--	--	--	--	--	--	--	--	--
G10-1	--	--	--	--	--	--	--	--	--	--	--	--	--
C7-24	--	--	--	--	--	--	--	--	--	--	--	--	--
B27-6	16.0	331.1	193.9	163.3	Cut	--	--	--	--	--	--	--	--
B29-10	149.6	185.4	194.6	297.8	Cut	--	--	--	--	--	--	--	--
A21-10	35.7	107.7	130.4	238.3	90.8	128.2	118.2	67.3	134.6	169.9	29.2	11.9	59.2
B24-4	86.0	106.1	135.2	179.5	233.0	18.0	30.1	84.5	50.8	264.0	48.8	32.7	67.5
C4-21	164.1	49.0	92.7	154.2	141.5	53.5	59.2	22.9	24.3	108.9	46.5	164.1	8.2
G2-12	77.4	55.9	141.9	189.1	201.5	233.4	42.0	102.3	94.0	261.2	42.9	126.6	101.6
P21-28	84.7	143.3	198.7	158.4	164.1	90.4	75.8	103.4	168.1	175.1	161.9	104.8	59.9

Table 10.--Area, number of trees, and volume of pine sawtimber stand per acre before and after cutting by treatment, year cut, and compartment

Year of cutting	Compartment	Area	Original stand: Number trees	Original stand: Volume	Cut: Number trees	Cut: Volume	Reserve stand: Number trees	Reserve stand: Volume	Percent stand cut[1/]
		Acres		Board feet		Board feet		Board feet	
				Sanitation-salvage					
1937	G 0-14	79.0	21.4	16,565	2.7	2,659	18.7	13,906	16.0
	G 2-14	81.3	21.9	15,921	2.5	2,864	19.4	13,057	18.0
	G 6-10	94.8	21.3	21,322	2.0	2,888	19.3	18,434	13.5
	G 8-10	46.9	28.1	25,810	3.0	3,883	25.1	21,927	15.0
1938	B 25-1	113.7	20.2	14,815	2.5	2,625	17.7	12,190	17.7
	B 27-4	95.7	20.4	16,338	3.7	3,840	16.7	12,498	23.5
	G 4-15	105.0	23.6	20.166	2.6	2,697	21.0	17,469	13.4
	G 15-5	63.5	20.4	19,721	2.7	3,574	17.7	16,147	18.1
1939	B 12-10	111.6	16.5	16,589	1.7	2,556	14.8	14,033	15.4
	G 12-14	91.1	19.8	17,426	1.8	2,760	18.0	14,666	15.8
	G 14-3	53.4	28.0	24,796	2.6	3,223	25.4	21,573	13.0
	G 14-6	86.7	13.1	13,428	2.4	3,252	10.7	10,176	24.2
	G 15-10	131.9	11.3	12,045	1.5	2,614	9.8	9,431	21.7
	G 15-13	52.0	20.6	16,384	3.2	3,642	17.4	12,742	22.2
	G 17-3	21.9	17.0	19,031	2.1	3,114	14.9	15,917	16.4
	G 17-6	48.1	11.8	14,019	2.8	4,687	9.0	9,332	33.4
1940	G 9-10	32.9	21.8	26,595	1.2	2,715	20.6	23,880	10.2
	G 11-4	115.2	11.7	12,389	1.2	2,143	10.5	10,246	17.3
	G 11-8	88.8	20.9	21,151	2.2	2,548	18.7	18,603	12.0
	G 18-9	63.5	10.0	10,340	.5	1,221	9.5	9,119	11.8
	P 15-33	139.1	21.2	17,609	2.1	2,498	19.1	15,111	14.2
	P 18-30	88.6	21.8	17,114	2.7	2,952	19.1	14,162	17.2
	P 18-33	31.1	15.0	11,604	1.3	1,201	13.7	10,403	10.4
	P 20-32	43.9	19.9	14,878	1.7	1,839	18.2	13,039	12.4

Table 10.--Continued

Year of cutting	Compartment	Area	Original stand: Number trees	Original stand: Volume	Cut: Number trees	Cut: Volume	Reserve stand: Number trees	Reserve stand: Volume	Percent stand cut 1/
		Acres		Board feet		Board feet		Board feet	
				Sanitation-salvage					
1941	C 8-30	94.5	12.5	16,370	1.1	2,875	11.4	13,495	17.6
	C 11-33	53.4	14.1	16,687	1.5	2,827	12.6	13,860	16.9
	C 13-31	85.9	13.0	14,165	1.8	2,140	11.2	12,025	15.1
	C 14-28	123.9	16.6	17,362	1.9	3,241	14.7	14,121	18.7
	C 15-23	100.3	20.3	18,619	1.0	2,793	19.3	15,826	15.0
	C 15-25	71.4	21.4	17,299	1.4	1,629	20.0	15,670	9.4
	P 18-27	84.3	22.6	19,811	2.4	2,486	20.2	17,325	12.5
	P 19-25	36.6	20.7	18,708	1.8	2,530	18.9	16,178	13.5
	P 22-24	47.1	21.2	18,596	2.4	2,687	18.8	15,909	14.4
	P 23-31	50.8	15.6	14,891	.8	1,314	14.8	13,577	8.8
	P 24-21	51.9	19.3	16,194	2.9	3,682	16.4	12,512	22.7
1942	G 7-6	86.1	15.3	19,784	1.0	2,465	14.3	17,319	12.5
	G 10-1	126.2	13.3	15,650	1.2	2,323	12.1	13,327	14.8
1944	C 7-24	66.6	21.5	16,109	1.5	2,084	20.0	14,025	12.9
1951	B 24-7	74.9	26.1	20,064	1.7	2,064	24.4	18,000	10.3
	B 27-6	73.2	21.1	16,096	1.7	2,064	19.4	14,032	12.8
	B 29-10	96.3	20.2	16,398	1.6	2,047	18.6	14,351	12.5
				Untreated					
	A 21-10	64.7	10.7	13,103	0	0	10.7	13,103	0
	B 24-4	91.2	22.6	14,943	0	0	22.6	14,943	0
	C 4-21	72.0	22.2	17,055	0	0	22.2	17,055	0
	G 2-12	143.1	19.9	16,918	0	0	19.9	16,918	0
	P 21-28	99.9	21.4	17,698	0	0	21.4	17,698	0

1/ Computed by dividing the volume cut, by the volume in the original stand, and converting result to percent. All data for pine only.

Table 11.--Average annual insect-caused mortality of pine sawtimber reserve per acre during period after cutting, by compartments, 1938-1959

Compartment	Area	Reserve stand	Period	Annual mortality	
	Acres	Board feet	Years	Board feet	Percent stand
		Sanitation-salvage			
G 0-14	79.0	13,906	9	18.8	0.14
G 2-14	81.3	13,057	22	31.3	.24
G 6-10	94.8	18,434	5	26.7	.14
G 8-10	46.9	21,927	17	20.2	.09
B 25-1	113.7	12,190	16	18.0	.15
B 27-4	95.7	12,498	21	12.6	.10
G 4-15	105.0	17,469	5	7.9	.05
G 15-15	63.5	16,147	4	11.6	.07
G 12-10	111.6	14,033	3	14.4	.10
G 12-14	91.1	14,666	3	5.2	.04
G 14-3	53.4	21,573	14	23.5	.11
G 14-6	86.7	10,176	14	12.6	.12
G 15-10	131.9	9,431	20	23.2	.25
G 15-13	52.0	12,742	3	0.8	.01
G 17-3	21.9	15,917	15	15.2	.10
G 17-6	48.1	9,332	15	1.7	.02
G 9-10	32.9	23,880	14	35.8	.15
G 11-4	115.2	10,246	3	0	0
G 11-8	88.8	18,603	3	0	0
G 18-9	63.5	9,119	19	22.3	.24
P 15-33	139.1	15,111	4	0.3	0
P 18-30	88.6	14,162	4	9.2	.06
P 18-33	31.1	10,403	14	32.1	.31
P 20-32	43.9	13,039	14	28.4	.22
C 8-30	94.5	13,495	15	19.7	.15
C 11-33	53.4	13,860	3	14.7	.11
C 13-31	85.9	12,025	3	0	0
C 14-28	123.9	14,121	18	14.6	.10
C 15-23	100.3	15,826	2	0	0
C 15-25	71.4	15,670	2	0	0
P 18-27	84.3	17,325	3	7.1	.04
P 19-25	36.6	16,178	13	37.1	.23
P 22-24	47.1	15,909	13	35.3	.22
P 23-31	50.8	13,577	13	20.2	.15
P 24-21	51.9	12,512	18	11.9	.10
G 7-6	86.1	17,319	3	4.9	.03
G 10-1	126.2	13,327	1	0	0
C 7-24	66.6	14,024	15	40.8	.29
B 24-7	74.9	18,000	8	21.1	.12
B 27-6	73.2	14,032	8	30.2	.22
B 29-10	96.3	14,351	8	38.7	.27
Weighted mean[1/]		13,682		19.5	0.14
Mean		14,354		20.8	.14
S. E.		±52.5		±1.5	

Table 11.--Continued

Compartment	Area	Reserve stand	Period	Annual mortality	
	Acres	Board feet	Years	Board feet	Percent stand
		Untreated			
G 12-10	111.6	16,589	1	211.8	1.28
G 12-14	91.1	17,426	1	28.5	0.16
G 14-6	86.7	13,428	1	135.2	1.01
G 15-10	131.9	12,045	1	64.8	.54
G 15-13	52.0	16,384	1	183.6	1.12
G 11-4	115.2	12,389	2	82.3	.66
G 11-8	88.8	21,151	2	92.3	.44
G 18-9	63.5	10,340	2	15.4	.15
P 15-33	139.1	17,609	2	55.9	.32
P 18-30	88.6	17,114	2	249.2	1.46
C 8-30	94.5	16,370	3	104.7	.64
C 11-33	53.4	16,687	3	9.4	.06
C 14-28	123.9	17,362	3	54.4	.31
C 15-23	100.3	18,619	3	44.6	.24
C 15-25	71.4	17,299	3	71.4	.41
P 18-27	84.3	19,811	3	158.6	.80
G 7-6	86.1	19,784	4	40.4	.20
G 10-1	126.2	15,650	4	49.9	.32
C 7-24	66.6	16,109	6	58.6	.36
B 27-6	73.2	16,096	13	136.4	.85
B 29-10	96.3	16,398	13	134.5	.82
A 21-10	64.7	13,103	22	72.8	.56
B 24-4	91.2	14,943	22	93.0	.62
C 4-21	72.0	17,055	22	76.8	.45
G 2-12	143.1	16,918	22	118.6	.70
P 21-28	99.9	17,698	22	117.4	.66
Weighted mean[1/]		16,358		99.5	0.61
Mean		16,339		96.8	.59
S. E.		±48.4		±5.4	

1/ Weighted by area and years. To compute weighted mean reserve stand volume, for example, multiply number of acres times number of years' records times board feet per acre for each compartment; then add products and divide result by the sum of acres times years for all compartments.

GPO 965098

Wickman, Boyd E., and Eaton, Charles B.
1962. The effects of sanitation-salvage cutting on insect-caused pine mortality at Blacks Mountain Experimental Forest: 1938-1959. U.S. Forest Service Pacific Southwest Forest and Range Expt. Sta. Tech. Paper 66, 39 pp., illus.

The volume of timber killed by bark beetles in old-growth pine fluctuated from one calendar year to the next, but was consistently much lower than on uncut compartments. The results indicate that reductions in losses on sanitation-salvage treated compartments are negatively correlated with time after cutting. Projections of the data suggest that it will take about 50 years from the time of cutting for percent of stand mortality in cut and uncut stands to reach the same level. The results substantiate previous findings about this method of insect control.

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