THE CALIFORNIA PINE RISK-RATING SYSTEM: ITS DEVELOPMENT, USE, AND RELATIONSHIP TO OTHER SYSTEMS

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Abstract.--The California Pine Risk-Rating System provides a method for rating current probability of tree mortality caused largely by western and Jeffrey pine beetle. It was formulated in stands of old-growth, eastside ponderosa and Jeffrey pine in California. Individual trees are risk-rated on easily recognized and classified crown characteristics. When applied to selective logging, it is called sanitation/salvage. Removal of high-risk trees, generally about 15 percent of the stand, recovers the value of trees that would otherwise be lost to insects, and has significantly reduced beetle activity in the area by 80 percent for more than 20 years.

In the mid-1920's efforts were made to find host conditions that cause susceptibility to western pine beetle. No decisive or easily recognized condition was found until Salman turned to crown characteristics of eastside ponderosa pine in the mid-1930's. The California System resulted from this effort. It has become a silvicultural principle for eastside ponderosa and Jeffrey pine in California and Oregon and is applicable to other regions in the West.

Keen Tree Classes preceded and are related to the California System. A penalty system quantifying crown and stem characteristics is a refinement to assist field application of the System. Derivatives of California System include a stand hazard classification for ponderosa and Jeffrey pine in northeastern California and risk-rating systems for red and white fir in northern California.

INTRODUCTION

This paper traces the origins, development, testing, and application of the California Pine Risk-Rating System, called the California System throughout this paper. It is usually called sanitation/salvage when utilized as a logging practice. The System will be described, and examples will be given that first demonstrated its utility as a forest management procedure. A penalty scoring procedure that refines the System and a stand hazard classification that is derived from it will be reviewed along with efforts to extend its use to other forest regions. We conclude with a résumé of research which sought to explain the mode of operation of and causal relationships underlying the risk-rating system.

The California System is applicable primarily to eastside old-growth ponderosa pine *(Pinus ponderosa* Laws.) and Jeffrey pine *(P. jeffreyi* Grev. and Balf.) (fig. 1). Eastside is defined as east of the Sierra Nevada-Cascade crest. It is an individual tree classification system based on an array of easily recognized crown characteristics. Risk, as originally defined and as used in this paper, is basically an estimation of the current probability of a tree being attacked and killed by bark beetles, primarily the western pine beetle (WPB) *(Dendroctonus brevicomis* Lec.) and the Jeffrey pine beetle (JPB) *(D. jeffreyi* Hopk.), and to some extent by the flathead borer *(Melanophila californica* VD).

Figure 1.--Typical stands of eastside ponderosa pine suitable for risk rating.

From an evolutionary and developmental viewpoint it is worthwhile to discuss the Keen Tree Class System along with the California System, since there may be some confusion between the two. Both evolved from the same background experience and had nearly a parallel course of development. From all evidence it appears that the California System might have been par-

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tially derived from the Tree Class System; or at least those who developed the California System were able to benefit from the experience of the Tree Class System.

We chose to organize the review rather strongly around the processes which were involved because these are important aspects for subsequent research and development, and they are often overlooked. Much of the content of our review can be found in a small number of technical reports, particularly in several sections of Miller and Keen (1960). The task was to recheck old reports and publications and, hopefully, to highlight the processes used, to examine the successes and failures, and to record the ideas which were tried during the period of development.

BACKGROUND

Four related developments preceded the California System: (1) studies of tree selection, (2) development of tree classification systems, (3) conduct and analysis of large-scale direct control programs (i.e., directly killing the brood or removing it from the forest) in northeastern California and southern Oregon, and (4) establishment of a small experimental cutting based on tree classification.

Tree selection research was an early effort to determine the nature of trees attacked by WPB. This research was followed by Dunning's Classification, based on tree physiognomy (Dunning 1928), which in turn was modified to produce the Keen Tree Classification System (Keen 1943). All three developments in selection and classification partially reached their objectives, but none was successful in providing a reasonable explanation of selection or an easy and effective system of risk classification. These developments, however, formed a partial basis for the California System. Analysis of large-scale direct control programs, showing uncertainty of their results, established a climate that gave impetus to research on alternative methods of control. The small logging study, based on insect selection criteria, was a key development that led most directly to the California System.

Tree Selection

The origins of many new developments in biology are often lost in the past; and so it seems to be with the California System. Thirty years before it was formalized, there were suggestions, including reports by A. D. Hopkins shortly after 1900, of a preferential habit of attack by bark beetles. But until about 1925 these references were general, sketchy, and based on only casual field observations.

The story really begins in the 1920's, when there was a concerted thrust of research on the basic biology and ecology of the WPB. It was from this work that specific ideas of risk originated. Miller's report (1926b) is a good place to start. In that report of bark beetle losses on plots located on the western slope of the Sierra Nevada, he presented evidence of the preference of WPB for ponderosa pines with slower growth rates. He also found some degree of association between crown characteristics and the incidence of beetle attack, the starting point for thinking of the possible value of crown characteristics as indicators of risk. At about the same time Person (1926) reported on one of the key studies in the development of risk in which he concluded that trees with the smallest crowns were the most susceptible to attack. In fact, he suggested that there is an inverse relationship between crown size and susceptibility to attack. As for population phenomena in relationship to susceptible trees, Person (1928) thought that large numbers of susceptible trees in a stand permit a rapid increase in beetle population resulting in greater probability of epidemic infestations in trees that were not normally susceptible. Person (1931) then theorized that a secondary attraction for beetles is created in and by trees which are easily overcome.

Struble continued the work Person had started on growth rate. The final report (Struble 1942) showed 22 percent of the trees and 28 percent of the volume was killed over a 22-year period. In years of light beetle activity, a decided preference was shown for the slower-growing trees. This preference was less pronounced in years of heavy beetle activity.

From 1925 to 1929 research was expanded to discover the reasons for a tree's relative susceptibility or resistance to beetle attack. The early portion of this work was done near Northfork on the Sierra National Forest; the latter portion was near Buck Creek on the Modoc National Forest. Among the characteristics considered were phloem moisture, bark sugar, phloem electric potential, bark thickness, and resin toxicity. Neither these stem characteristics nor the crown characteristics studied by Miller and Person were found to be decisive. It is worth noting that much of this early research was done in west slope Sierra Nevada ponderosa pine type, an area in which no risk system yet developed has been found applicable. Although these early scientists had the right idea, they were working in the wrong place for demonstrating the risk phenomenon.

Nevertheless, they began a course of action which was to produce the California System. Their research also served as the training ground for many of those who did much of the subsequent studies on the more important bark beetles in the West.

Analysis of Direct Control Programs

Direct control is killing immature brood or beetles in, or as they emerge from, infested trees--before brood emergence. From 1910 to 1925 numerous direct control programs were conducted for WPB in California and southern Oregon, primarily using the feel-peel-burn procedure.

Craighead (1925) noted this about WPB:

> The theory that killing the broods in a large percentage of the trees will reduce the infestation to just such an extent sounds reasonable. It does not, however, take into consideration the fact that under favorable conditions these insects have extraordinary powers of multiplication and that under these same conditions possibly fewer beetles are required to overcome the resistance of the tree. Even with the most carefully executed work it is rarely possible to treat more than 80 percent of the infestation. The other 20 percent, under optimum conditions for attack and development, might readily offset such a reduction. For some time Mr. Miller has been doubtful of the effectiveness of this method of fighting the western pine beetle. He has stated his objections as follows: (1) This type of control work is expensive, (2) uniformly successful results have not been secured, and (3) the results are not permanent.

Miller (1926a) referred to the WPB/ponderosa pine relationship:

> In the early studies of this problem the insect itself was regarded as the primary active agent and the host tree was considered only as a passive medium which was attacked indiscriminately. It is now realized that the reactions of the tree must be considered as well as the activities of the beetles, and that the vigor of a tree has much to do with its susceptibility or its resistance to bark beetle attack.

After recounting the work on tree selection, Miller stated that

> these discoveries open up the possibility of reducing losses through logging practice and of taking out most of the susceptible trees in the marking practice on sale areas so as to leave only the more resistant trees for seeding purposes and future cuts.

Finally Craighead et al. (1931) noted that the benefits of direct control of bark beetles, including WPB, were sometimes uncertain and the effects were usually temporary. They asked for research and development on some kind of silvicultural practice to overcome these disadvantages.

It would appear that these three articles represented the attitude and philosophy that fostered research and development on tree classification and risk-rating.

Additional support for the position that the host played a critical role in the dynamics of bark beetle population came from the effects of a natural phenomenon, the cold temperatures of winter 1932-33. These temperatures caused a severe reduction in WPB broods throughout northern California (Miller 1933); yet 2 years later, the outbreak was as extreme and widespread as before the freeze.

Keen and Dunning Tree Classifications

In the late 1920's the research thrust shifted from the west slope of the Sierra Nevada to eastside ponderosa pine in northeast California and southern Oregon, where Keen was conducting annual surveys of areas with persistently heavy bark beetle losses. Early surveys were primarily loss surveys, although some attention was given to crown characteristics of attacked trees. Then, during an epidemic year, Keen added Dunning's (1928) new tree vigor classification to the requirements of the survey; that is, the survey crew placed each attacked tree into one of Dunning's seven classes. The relative abundance of Dunning's seven classes in the unattacked stand was tallied so that the ratio of attacked to unattacked trees could be obtained. This first effort to link attacked trees with Dunning's vigor classes was unsatisfactory, because often as much variation occurred within a Dunning class as between classes.

It was becoming clear, however, that what was described by the vague term "vigor" was a fruitful concept to explore. Keen expanded Dunning's 7 classes into 16 classes. First called bark-beetle susceptibility classes, these were later to become the Keen Tree Classes (fig. 2). Keen (1936) also saw quite clearly what was required for the solution of the bark beetle problem in southern Oregon and northern California:

> . . . one of the first requirements in the solution of the pine beetle problem is a knowledge of what type of tree presents the greatest risk of beetle attack. Once the type of tree most likely to be killed can be recognized with a fair degree of certainty, it is possible to make partial cuttings of beetle-susceptible trees, either for the purpose of salvaging valuable high-risk trees before they are damaged by beetle attack or

for the silvicultural objective of reducing mortality and increasing net growth.

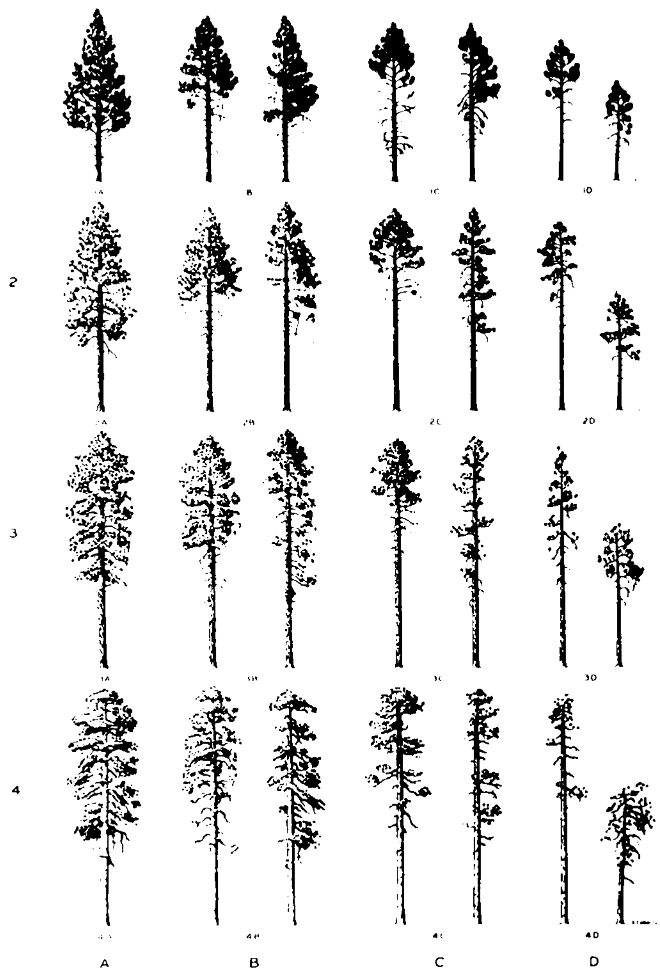


Figure 2.--The Keen ponderosa pine tree classification. Age increases from 1 to 4 and vigor decreases from A to D. (From Keen 1936.)

From 1928 to 1931 an impressive study was conducted in southern Oregon, near Ashland, in which 27,465 attacked trees were classified according to the Keen Tree Classes; and 22,428 unattacked trees were classified for comparison. The results showed a distinct improvement over the use of Dunning's vigor classes. Mortality ratios found ranged from 0.17 for trees with a high vigor classification to 2.50 for trees with a low vigor classification. The mortality ratio is the percentage of the loss in a given class divided by the percentage of that class in the original stand. Mortality ratios >1 denote susceptible classes. Therefore, the Keen Tree Classes provided, for the first time, a sharp and easily recognized difference among types of crown classes. However, there were too many trees in the susceptible classes, requiring the removal of too much of the stand. The development of the California System resolved this problem.

It is interesting to note that Dunning's classes were developed for ponderosa pine on the west slope of the Sierra Nevada, where the California System has been found unsuitable. Ecologically, east and west slope Sierra Nevada-Cascade have proved to be two quite different areas for ponderosa pine, and the insect complexes appear to be different and to operate differently in the two regions. This variation in site emphasizes the need to establish a sound ecological basis for risk studies.

An Insect Selection Cutting

Person shifted his base of operation from the west slope of the Sierra Nevada to northeastern California. And as Keen had done, Person started with Dunning's tree classes. In 1927 he established an experimental cutting on a 20-acre plot on the Modoc National Forest by using Dunning's classes and removing what were called "the most susceptible trees," although the classes were not identified. The purpose of the experiment was to determine for the first time if selection cutting could be used to remove susceptible trees and reduce subsequent loss. Shortly after Person established this experiment, K. A. Salman assumed responsibility for continuing the work. Salman seemed to benefit from Person's work on tree selection and was able to carry it forward to a risk system.

Increment cores were used to determine the year of tree death on both cut and uncut plots. From 1920 to 1927 ca. 28 percent of the stand had been killed at a fairly even annual rate. In the 4 years after the selection cutting, a 4 percent loss occurred in the untreated stand and a 1 percent loss in the treated stand. Salman (1932) concluded as Keen had that Dunning's classes did not discriminate risk clearly enough. Salient points of this study, particularly as they pertain to research and development processes are: it was the first experimental cutting in which a principle of insect selection was applied; the results were not strikingly successful; and scientists, particularly Salman, used the experience gained from this study to develop other and more profitable research.

CALIFORNIA PINE RISK-RATING SYSTEM

Development

Final formulation of the California System was made in 1936 by Salman, who was convinced by his analysis of the study Person had established that Dunning's classes were unsuitable for rating risk. Salman also noted two limitations in the 16-class system developed at this time by Keen for use in southern Oregon. First, the 16 classes made it cumbersome as a working tool, and second, it would require the removal of too large a volume of timber for quick treatment of stands. If the forest manager was to reduce the chances of bark beetle losses, the cutting should be light enough to cover stands quickly.

Salman took advantage of the observations of workers making annual loss surveys in northeastern California in the early 1930's. They had reported that most trees killed could be characterized by various kinds and degrees of crown deterioration before attack. These observations were crystalized into a study by Salman in 1936, in which 973 infested and 2,026 unattacked trees were cut and carefully examined for various types of crown deterioration.

A three-class structure was preliminarily established, but Salman's field crew found that four classes were better for field application. Eventually the elements of high risk were described as follows (Salman 1937 and Salman and Bongberg 1942) (fig. 3):

> --thin or sparse foliage complement, short needles, and the dying of twigs and branches were characters of the trees that become infested and die--active or recent top-killing infestations, the localization of branch or twig injuries, and the thinning and shortening of foliage in portions of the crown also occurred in many of the trees that died--green trees which exhibited those characters were likely to die and were considered as high-risk trees. High-risk characters were absent in healthy appearing trees considered (lower) risk from insect attack under normal conditions--gradations were segregated into four degrees of risk for application in field tests.

Figure 3.--Four stylized trees, illustrating the four risk classes of the California Pine Risk-Rating System.

The next step was to test the classification more extensively and 18,056 ponderosa and Jeffrey pines were classified according to risk on the Modoc and Lassen National Forests. About 11 percent of the trees fell into Risk Classes III and IV, the high-risk classes (table 1); and about 84 percent of the attacked volume fell into the same two classes (table 2) (Salman and Bongberg 1942). These data show that bark beetles attacked and killed 23 trees or 30 fbm in high-risk categories (Risk III and IV) for every one, tree or fbm, killed in the low-risk categories (Risk I and II).

It is important to note, as pointed out by Keen and Salman (1942), that neither the Keen tree susceptibility classes nor the California System risk classes are, in themselves, a timber management system. They are, instead, silvical principles. The Keen Tree Class system associates 16 age and crown vigor classes with average annual susceptibility to attack. It should be noted that the four classes of the California System are somewhat similar to certain of the Keen Tree Classes. The California System associates four generalized crown types with the current probability of attack, i.e., risk of being killed. To become a timber management procedure, or tree-marking system, the objectives of the timber manager must be considered also, i.e., the amount to be cut, the purpose of logging, the speed at which the stand is to be logged, the type of residual stand required, and the method and time of regeneration. When the California System became a logging procedure, the term sanitation/salvage was applied to the operation. This term has since been used to describe any process of removing low-vigor, more susceptible trees.

Thus, by 1936 the California System was fairly well fixed and a period of testing and modification began. The development period was characterized by large studies which associated certain crown characteristics with subsequent tree mortality. In a sense it appears that Keen modified the existing vigor classification system of Dunning, while Salman developed his definitions from the results of several years' observation of thousands of trees, though he was aware of the other classifications. Keen's classification seems to have been the more logical approach; Salman's, though oriented toward practical application, seems to have rested on some intuition.

Table 1.--Distribution of green trees by risk ratings, by trees and volume

Risk rating	Number of trees	Percent of total number of trees	Volume b.m.	Percent of total volume b.m.
I	12,184	67.5	8,725,015	54.9
II	3,865	21.4	4,692,573	29.6
III	1,099	6.1	1,418,457	8.9
IV	908	5.0	1,047,644	6.6
Total	18,056	100.0	15,883,689	100.0

Source: Salman and Bongberg (1942).

Table 2.--Distribution of insect-killed trees by risk ratings, by trees and volume

Risk rating	Number of trees	Volume b.m.	Percent of total loss volume b.m.	Percent of loss in total volume b.m.	Mortality ratio[1] volume b.m.
I	16	11,142	4.1	0.13	1
II	27	31,130	11.4	0.66	5
III	43	44,579	16.4	3.14	24
IV	178	185,395	68.1	17.70	136
Total	264	272,246	100.0		
Average				1.71	

[1] Percentage of loss in Risk I considered as 1, or the unit of comparison.

Source: Salman and Bongberg (1942).

Testing

Salman reasoned that the removal of the high-risk trees from a stand would result in significant benefits and he proposed a logging experiment to test his theory.

The basic experiment to test and verify the California System was started in 1937 on the Blacks Mountain Experimental Forest, located in the north-central portion of the Lassen National Forest. All of the high-risk trees, i.e., Classes III and IV, were removed on a 322-acre compartment; added to the high-risk trees was a sufficient volume of lower-risk trees to ensure a cut of 2,500 fbm/acre. In the following 6 years additional compartments were treated each year until about 3,200 acres had been treated. The average volume removed was 15.7 percent of the merchantable stand. An annual 100-percent cruise of cut and uncut compartments provided data on loss by classes of trees.

Bongberg (1939) reported that the result of the first year's test was a very satisfactory 91 percent reduction in annual insect-caused timber loss. At the end of 10 years, Bongberg (1949) reported that the reduction in annual beetle-caused mortality ranged from 67 to 92 percent with an average of 82 percent for the 10-year period. The final results cover a 22-year period (table 3) (Wickman and Eaton 1962). If only insects are considered, this loss was reduced by 80 percent, i.e., 99.5 fbm/acre loss per year on the uncut blocks and 19.5 fbm/acre per year on the cut blocks. Annual mortality on treated and untreated plots varied considerably from plot to plot and from year to year. The mean annual loss ranged from 0 to 40.8 fbm/acre on the treated plots and from 9.4 to 249.0 fbm/ acre on the untreated plots. Part of this variation was attributed to year of cutting, since 6 years were required to establish the study; and part was undoubtedly attributable to the annual and spatial fluctuations in the beetle populations. The variation in the percent reduction from year to year ranged from a high of 97 percent in 1945 to a low of 38 percent in 1953 (fig. 4); neither year was an extreme of insect activity. Salman contended that risk rating was primarily a probability of current attack. If we consider that these probabilities lie in a confidence band, of say 90 percent, then we would expect by chance that twice in 20 years, deviations outside the confidence intervals would be observed. Al-

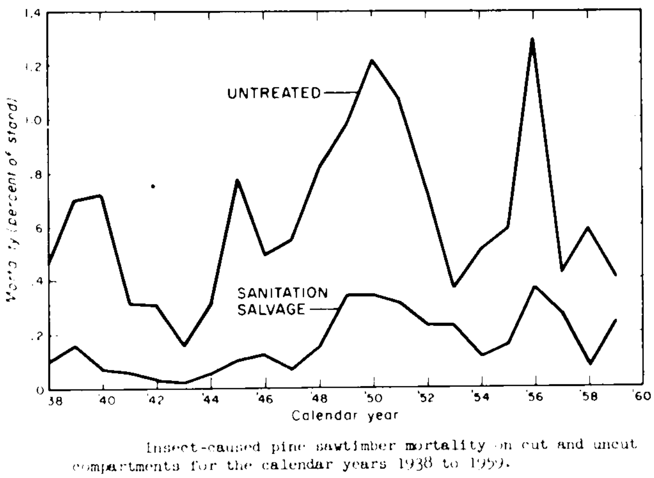


Figure 4.--Insect-caused pine sawtimber mortality on cut and uncut components for the calendar years 1938 to 1959. (From Wickman and Eaton 1962.)

though no estimates were made of confidence limits, we think this is the case. The cumulative insect-caused mortality (fig. 5) shows a steady and continued accrual of loss reduction.

A second study compared sanitation/salvage with several other types of Forest Service cutting methods (Eaton 1959). Results suggested that any system that removes a large volume of the total stand or much of the volume of trees with poor growth will reduce subsequent losses. In a sense it is a matter of getting to the tree before the beetle as well as improving growth conditions for the residual stand. Sanitation/salvage was the lightest of all cutting methods; therefore, it provided the quickest means of "sanitizing" an area as proposed by Salman.

The final step in establishing the sanitation/salvage procedures was a pilot test. In 1939, the McCloud River Lumber Company began logging under the guidance of Bongberg (1947). An area 10 miles north of Burney Falls, California, that had experienced continuing loss caused by WPB was marked using the California System. The cut of 563 fbm/acre was unusually light, but the cost of logging was only about 23 percent higher than a standard heavy cut. This additional cost was more than offset by the value of timber recovered that would have been lost to subsequent beetle attack. Insect-caused

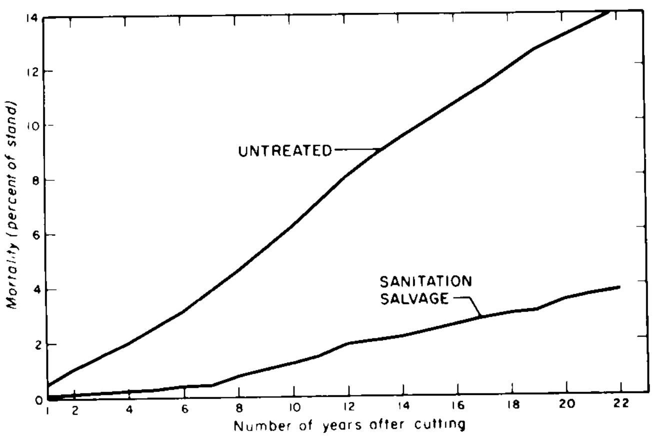
Table 3.--Cumulative insect-caused mortality of pine sawtimber reserve per acre in successive numbers of years after cuttings, by treatment, 1938-59[1]

Year after cutting	Treatment and weighted mean reserve stand volume (board feet)			
	Sanitation/salvage (13,682 trees)		Untreated (16,358 trees)	
	Board feet	Percent stand	Board feet	Percent stand
1	14.7	0.11	89.3	0.55
2	22.8	0.17	172.0	1.05
3	26.8	0.20	251.2	1.54
4	38.2	0.28	325.0	1.99
5	53.6	0.39	418.1	2.56
6	68.5	0.50	514.3	3.15
7	77.8	0.57	626.4	3.83
8	108.2	0.79	749.3	4.59
9	134.0	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] The first year after cutting is based on 3,200 treated acres and 9,250 untreated; the 22nd year is based on 81 treated acres and 407 untreated.

Source: Wickman and Eaton (1962).

loss in these stands was reduced by 85 percent over the next 6 years. Loss reduction was based on a projection of the loss experienced on the treated area for several years before logging. An unexpected and important benefit of sanitation/ salvage cutting materialized in 1944, when a rapid increase in WPB activity developed in the general geographic area. Losses in uncut stands were heavy and direct control operations were taken. Losses remained very low in the areas logged by sanitation/ salvage, however, and no direct control was necessary.



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

Figure 5.--Cumulative insect-caused mortality in pine sawtimber reserve on cut and uncut compartments. (From Wickman and Eaton 1962.)

Bongberg (1942) also applied sanitation/salvage to eastside Jeffrey pine and obtained results essentially the same as those obtained in ponderosa pine stands. This similarity showed the general suitability of the California System to stands of predominantly Jeffrey pine attacked by JPB.

These reports by Bongberg, Eaton, and Wickman and Eaton demonstrated conclusively the immediate, large, and lasting beneficial effects of applying cuttings to eastside ponderosa and Jeffrey pine based upon a risk-rating system. The next step was to determine the scope of its applicability as well as to establish it as a forest management tool.

Early Application

After the favorable results with sanitation/salvage on part of its holdings, the McCloud River Lumber Company adopted this method of management on the balance of its ponderosa pine stands.

In 1940, the U.S. Forest Service tested sanitation/salvage on 8,000 acres on the Dixie Valley Sale Area on the Plumas National Forest in a mixed ponderosa-Jeffrey pine type. The first year after treatment there was 100-percent reduction in loss of ponderosa and 82 percent of Jeffrey pine. In 1942, the Forest Service undertook another sanitation/salvage sale on the Lassen and Modoc National Forests and in subsequent years adopted sanitation/ salvage as standard management procedure on all eastside pine stands that it managed.

In 1940, Collins Pine Company at Chester, California, tested sanitation/salvage with excellent results and adopted this method of treatment on its 80,000-acre tract. The company continues to use this method today in appropriate stands.

After the successful application of sanitation/salvage, many private timber operators in northeastern California adopted it as standard management procedure.

Expanded Use

Keen (1940) extended the use of the California System to southern Oregon with the establishment of logging studies by the Weyerhaeuser Timber Company near Klamath Falls. The studies used hybrids of Keen Classes and California Risk Classes because the early results of using risk classes were so promising in northeastern California. The logging removed slightly more than 10 percent of the volume. Early results (Keen 1942) showed that a hybrid-based cutting worked as well as one based solely on the risk classification. Continued evaluation of the study showed the hybrid to have the desirable long-lasting effects shown by the California System (Keen 1955). In the early 1940's, Orr (1945) applied the hybrid system to extensive areas in southern Oregon. In all, 200,000,000 fbm, comprising ca. 25 percent of the volume of the stands, were logged. Subsequent losses were judged to be markedly reduced. Sowder (1951) extended the use of California System still further north in eastside Cascade to the area of Bend, Oregon. These studies and applications greatly expanded the area of applicability to nearly all of ponderosa-Jeffrey pine stands east of the Sierra-Cascade crest.

Sanitation/salvage was applied operationally to a limited area in the coastal mountains of southern California in 1953 and 1954. Losses over the preceding years had become progressively heavier and the direct control efforts applied had not been fully satisfactory. Primarily a recreational area, cutting of green trees was not viewed with favor. However, increasing salvage of dead trees was looked upon with even less favor. Thus a sanitation/salvage operation was carried out with favorable public support. Hall (1958) estimates that losses after sanitation/salvage logging was conducted were less than 10 percent of the losses experienced before the operation. With this experience as a basis, some 80,000 acres of similar forest were logged by sanitation/salvage operation between 1955 and 1957.

Although precise data were not recorded, Hall and Pierce (1965) estimated that losses on the recreational area were reduced by 60 percent for the first 6 years but then started to rise because of a rapid increase in the number of trees which became high risk. The area was logged again and the effect in subsequent years was favorable. In several other areas, a similar pattern developed and Hall applied direct control measures to suppress losses until sanitation/salvage could be applied. This procedure of combining sanitation/salvage with direct control is often called maintenance control.

A long-term study was established in 1948 to determine the applicability of risk-rating to ponderosa pine in western Montana (Johnson 1972). A second objective of the study was to determine the threat of WPB in that area. In all, 11,946 pines were tagged, measured for size and volume, and risk-rated according to the California System criteria. In Montana a much greater percent of the volume fell into the middle classes and a much smaller volume in the extreme classes (table 4) than was found in California (Salman and Bongberg 1942). The combined percent in risk III and IV--the trees usually cut in a sanitation/ salvage operation--is somewhat similar, with 11 percent in California and 20 percent in Montana.

Table 4.--A comparison of stand and loss volume, by percent, in the four risk classes in California[1] and Montana[2]

Risk	California Stand	California Loss	Montana Stand	Montana Loss
I	68	4	8	0
II	21	12	72	24
III	6	16	17	42
IV	5	68	3	34

[1] Data from Salman and Bongberg (1942).
[2] Data from Johnson (1972).

Bark beetle activity in ponderosa pine in Montana during the period of the study was lower than that experienced in northeastern California during the period of development of the California System. Nevertheless, the apportionment of loss in the various risk classes was quite similar. The results, therefore, suggest that the risk principles are applicable to low endemic conditions as well as to outbreak conditions. They further indicate that the percentage of high-risk trees in the study area is sufficient to support an outbreak of bark beetles when other factors become favorable for an increase in the beetle population. Even before the California System had been tested in Montana by Johnson's experiment, many land managers in the intermountain region, such as J. Neils, Anaconda Copper, Potlach, as well as the U.S. Forest Service and Montana State Forestry Division, were applying it to stands which were considered to be of the same type as the stands in California and Oregon (Johnson 1951).

Refinement: Penalty System

A refinement of the California System is the penalty system in which penalty points are assigned to crown and stem characteristics of a tree. The penalty system was devised primarily as a way to train inexperienced tree-markers in using the risk system. Usually after a day or two with a penalty card, the marker felt confident in continuing without the aid of a card.

The first penalty system, formulated in 1941 (Keen 1954), was based upon the association of crown or stem characteristic with risk classes and subsequent tree mortality. Values, called penalties, were assigned to these associated characteristics. Thus, the stronger the association of the characteristic with risk and tree mortality, the larger was the value and the greater the penalty. In practice, a penalty card was scored according to a quick visual assessment of the crown and trunk. Keen's original system has been modified several times, the last by Hall (1951) (table 5).

Derivative: Stand Hazard

No sooner had the California System been preliminarily formulated than entomologists turned their attention in 1937 to developing a system for rating stand hazard. The 1936 field season was spent in developing indices for classifying some 2 million acres of ponderosa-Jeffrey pine type in northeastern California (Salman 1938). As a result of this study two separate but related stand characteristics were used for hazard classification (Miller et. al. 1941) (Johnson 1949): (1) the past 10 years' cumulative volume of beetle-caused mortality, (2) the current volume of high-risk trees in the stand. The current green volume of the stand was determined and two percentages were calculated by dividing each of the above volumes by the green stand volume. The two

Table 5.--A penalty card with values for crown characteristics and four risk classes

PENALTY SYSTEM FOR RATING HIGH-RISK TREES
Eastside Ponderosa and Jeffrey Pine

	Penalty
A. NEEDLE CONDITION	
1. <u>Needle complement</u>	
a. Needle complement normal	0
b. Less than normal needle complement through crown. No contrast between upper and lower crown	2
c. Thin complement in upper crown, normal in lower crown. Contrast evident in upper and lower crown	5
2. <u>Needle length</u>	
a. Needle length normal	0
b. Needles shorter than normal throughout crown. No contrast between upper and lower crown	2
c. Needles short in top, normal below. Marked contrast	5
3. Needle color	
a. Normal	0
b. Off color	2
c. Fading	8
B. TWIG AND BRANCH CONDITIONS	
1. No twigs or branches dead	0
2. A few scattered dead or dying twigs or branches in crown	1
3. Many scattered dead or dying twigs or branches in crown	2
4. Dead or dying twigs or branches in crown forming a definite weak spot in crown, notably in top 1/3 of crown	3
5. Dead or dying twigs on branches in crown forming more than one weak spot or hole, notably in top 1/3 of crown	5
C. TOP CROWN CONDITIONS	
1. No top killing	0
2. Old top kill with no progressive weakness or killing in green crown below	5
3. Current top killing	8
4. Broken top--recent, less than 1/3	5
5. Broken top--recent, more than 1/3	8
6. Broken top--old, no progressive weakness	2
D. OTHER FACTORS	
1. Lightning strikes--recently struck, no healing evident	8
--healed strike	2
3. *Dendroctonus valens* attacks in base--current, successful	6
--old, pitched out	2

The following factors have local significance and will differ by area. We have little information on their importance, and the marker should weight these in terms of local observation and experience.

3. Mistletoe
4. Needle scale (various spp.)
5. Needle blight (*Elytroderma deformans*)
6. Rust (*Cronartium* spp.)

Risk class	Penalty score
I	0
II	1 to 4 inc.
III	5 to 7 inc.
IV	8 and higher

Source: Hall (1951)

percentages were added and five stand (or beetle) hazard classes were established; values less than 4 were considered very low hazard and 27 or more considered very high hazard. A map showed areas with various degrees of hazard (fig. 6). With this information the land manager could then direct his logging to the most hazardous stands first in order to reduce losses until a normal high volume logging operation could be installed.

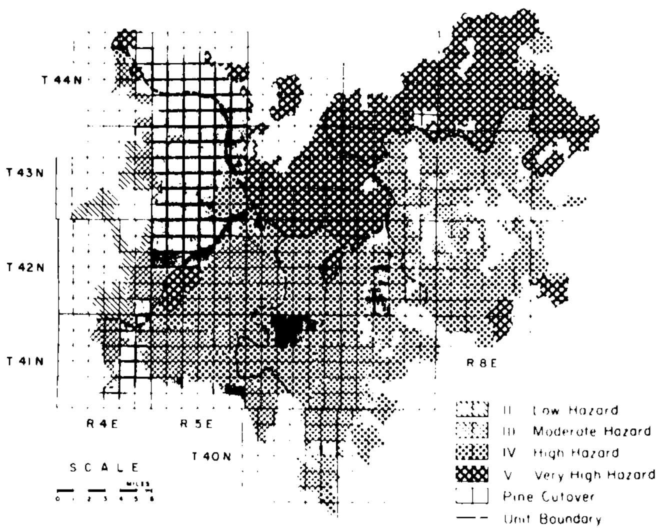


Figure 6.--Relative hazard is illustrated in this map of eastern Lassen County, California. (From Miller et al. 1941.)

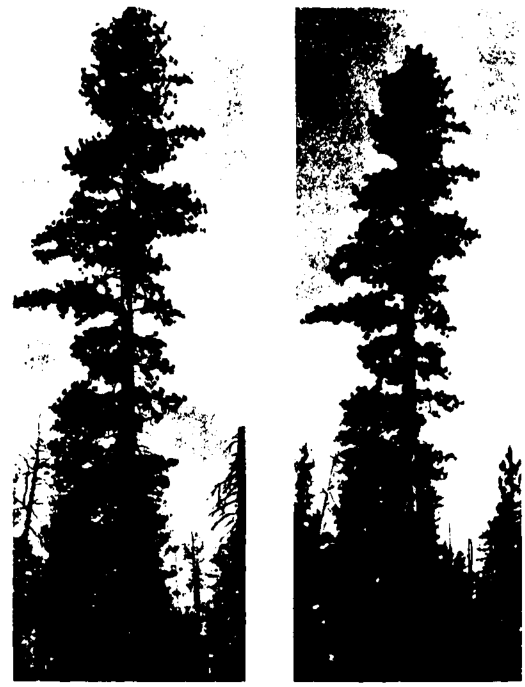


Figure 7A.--Tree shows no change in risk from 1942 (left) to 1953 (right). (From Furniss 1954.)

Figure 7B.--Tree shows decrease in risk from 1942 (left) to 1953 (right). (From Furniss 1954.)

Contingent Research

After the California System was established, several studies analyzed, explained, qualified, or elaborated the principles behind risk; six of these are worthy of brief review.

Changes in Risk

The question was logically asked about the permanence in the risk class of a tree, i.e. does the risk of a tree tend to increase gradually (or quickly), does it remain fairly constant, or does it even decrease?

Eaton (1941) initiated a photographic study to answer these questions. Forty-eight trees representing the four risk classes were selected for periodic photography. Furniss (1954) reports the following results after 13 years:

Accidentally cut	5
Killed and showed increase in risk	11
Still alive	32

The 32 trees still alive showed as follows:

An increase in risk	2
No change in risk (fig. 7A)	3
A decrease in risk (fig. 7B)	27

Others found much the same phenomenon after reclassifying large numbers of trees. Records were not kept on specific trees, but the average risk structure of the stand improved over a period of several years.

These studies were conducted over the same climatic cycle in which there was a general improvement in precipitation, which is usually assumed to be a factor regulating risk. Thus, risk can be a reversible process; but because many trees did not show improvement, the factors and processes expressed by risk may not be simple.

In another locality, however, Furniss and Hallin (1955) found a slow change to high-risk trees. They recorded one high-risk tree per acre in an area 16 years after all such trees had been removed.

California Flathead Borer

Incipient attacks by the borer (*Melanophila californica* VD.) were suspected as one of the more important agents which determined the condition making a tree high risk. Substantial effort was made to confirm these suspicions. Salman (1940) concluded from a 4-year study that incipient infestations of the borer tended to occur more frequently in trees that were killed, and that the incidence of incipients was much greater in the higher-risk classes. However, incipient attacks could be found in low-risk trees. The borer appeared to be part of the whole risk phenomenon, but other factors were involved as well.

Crown Analysis

Since risk is based almost entirely on crown characteristics, Wygant (1942) studied in detail these crown and stem components: (1) needle fascicles per twig, (2) needle length, (3) needle diameter, (4) annual twig growth in length and (5) in diameter, (6) annual radial growth in different parts of the stem. For all components he found that the values for low-risk trees were much greater, usually significantly so, than for high-risk trees (table 6). The one measure that did not change was needle retention. Trees in both risk I and IV retained needles for 5 to 6 years. Other studies have shown that the period of needle retention is largely controlled by local environmental conditions.

Accuracy of Risk-Rating

Though much effort was made to make risk-rating objective and to define classes as distinctly as possible, the four classes overlap and there is still considerable subjectivity in assigning trees to classes. Thus the accuracy of comparing risk-rating among observers or two evaluations by the same observer come into question. Among the many studies of this problem, the one by Eaton (1942) illustrates the general results. He found the agreement among expert risk-raters was about 80 percent, i.e. experts disagree on the risk class of about 20 percent of the trees (fig. 8). He concluded that the percent of agreement improves with experience, and that there was close agreement among experienced classifiers using all three tree classification systems. But, inexperienced raters used the risk system more accurately than the Keen or Dunning classifications.

In commenting on Eaton's results, Keen[2] reports that trained survey crews were about as accurate as trained forest entomologists in using Keen Tree Classes, and both groups were considerably better than untrained rangers.

[2] Personal communication to J. M. Miller, April 9, 1942, on file at Pacific Southwest Forest and Range Experiment Station, P. O. Box 245, Berkeley, California, 94701.

Table 6.--Average growth characteristics of 16 Risk I and of 17 Risk IV ponderosa pines

	Top crown		Mid crown[1]		Lower crown[2]	
	Risk I	Risk IV	Risk I	Risk IV	Risk I	Risk IV
Number of needle fascicles per twig	197.4	119.1	188.1	108.8	173.9	
Needle length in inches	6.22	4.91	6.47	4.96	6.56	
Needle diameter in mm	1.87	1.80	1.86	1.76	1.80	
Annual twig growth in inches, 1917-1940	.80	.58	.72	.57	.70	
Twig diameter in cm	1.52	1.23	1.38	1.10	1.32	
Annual radial stem growth inches, 1912-1941	.0128	.0105	.0211	.0112	.0144	.0126

[1] For radial stem growth this column should be headed "mid bole."
[2] For radial stem growth this column should be headed "stump."

Source: Wygant (1942).

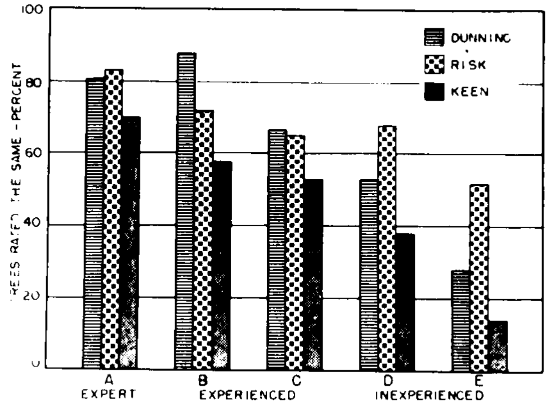


Figure 8.--Frequency of agreement in two sets of tree class ratings made by men of different experience levels, based on observations on 100 trees. (From Eaton 1942.)

These two studies, along with many others of the same type, illustrate the very important point that there is still some imprecision in the risk system for an individual tree. However, for a stand, the effects average out, and cutting the high-risk trees reduces subsequent losses.

It is important to keep this imprecision in mind when studies of individual trees do not produce clear results. There is an inaccuracy in rating the tree, a further uncertainty in risk itself, a compounding phenomenon of changing risk, and changing environmental conditions which might override all these factors.

Brood Production

Just how the risk class of a tree functions in the dynamics of the beetle population is a basic question. Curiously enough, it has had surprisingly little attention, probably because the system works so well that scientists felt it was more profitable to expand and refine the use of risk rather than attempt to explain its mode of operation. It is generally hypothesized that high-risk trees are most easily overcome by the beetles. But how does this influence the beetle population?

Hall (1942) recorded brood production from trees of the four risk classes. The results, even though based on only four to seven trees per risk class, are striking (table 7). Emergence per square foot of bark surface was 18, 24, 44, and 115 beetles for Risk Classes I, II, III, and IV, respectively. The ratio of attacking to emerging beetles was not measured, but the results suggest that high risk trees can provide a source of population maintenance and may provide a real impetus to population increase.

Table 7.--Emergence of adult western pine beetle from bark of infested trees of the four risk classes

Risk class	Trees sampled	Ft^2 of bark	Total beetles emerging	Emergence per ft^2
I (low)	4	29	510	18
II (medium)	4	33	795	24
III (high)	7	56	2488	44
IV (very high)	7	57	6543	115

Source: Hall (1942).

If we assume an average of 12 attacking pairs per square foot and inflight mortality of 75 percent, only the high-risk trees would produce sufficient brood to support an increasing population. Such a situation might exist under endemic conditions but might not prevail under epidemic conditions, where the enormous beetle population and some overall change in host condition could override much of the influence of risk.

Resin Flow

For as long as forest entomologists have been observing bark beetles in conifers, they have associated attack failure with copious resin flow. Little experimentation was attempted, however, until Callaham (1955) investigated resin flow from trees rated for risk and for Keen tree classes by using permanent plot trees on the Blacks Mountain compartments. Additionally, he had both Keen and Bongberg rate the permanent plot trees again. Not surprisingly, their agreement exceeded 80 percent for the risk I and III trees but dropped to less than 60 percent for the risk II and IV trees. Their lack of agreement was particularly pronounced in the very high-risk class, i.e. IV, with one rating 25 trees and the other only 5 in that class. Callaham's hypothesis was that low-risk trees would have greater flow of resin and, therefore, would be less likely attacked and killed. To test this hypothesis, resin flow from a standard wound was measured. Although there was less flow of resin from high-risk trees, mean values for the total flow of resin were not significantly different among risk classes. There were significant differences in the duration of flow however. Resin flow from the low-risk trees, i.e. I and II, continued much longer than from high risk trees, i.e. III and IV. There was appreciable flow of resin from low-risk trees even after the fourth day after wounding, while resin flow from very high-risk trees had nearly stopped by then.

Callaham (1955) hypothesized that the shorter duration of resin flow from high-risk trees permitted successful attack by the beetles while the continued flow from low-risk trees prevented successful attack. Because the study was conducted toward the end of the period in which Eaton (1941) and Furniss (1954) studied change in risk, the lack of sharp differences might have been caused by some basic improvement of tree condition prior to external evidence of change of risk.

SYSTEMS FOR TRUE FIRS

Risk-rating systems derived from the California System have been developed for individual, mature red firs (*Abies magnifica* A. Murr.) and white firs (*A. concolor* Gord. and Glend.) (Ferrell 1980). These systems, as yet untested, predict the probability of tree death within 5 years based mainly on the same crown characteristics used by the California System. The fir systems were developed by using computer-based analytical techniques for extensive cutover and virgin, old-growth stands of these firs in northern California. For routine field use, the systems have been formulated on an award/penalty basis in which trees are awarded points based on some characteristics, and penalized points based on others.

To expedite development of preliminary systems, characteristics of recently dead and live firs, obtained during initial survey of 47 20-acre plots, were computer-screened and major predictors of risk were selected from the resulting "decision tree" output. Risk equations, predicting 1-year probabilities of tree death, were developed by regressions based on the logistics model, then tested for goodness-of-fit to the observed distribution of mortality in the data base. One-year probabilities were extrapolated to 5-year probabilities by using a variant of the standard compound interest formula. For field use, the equations were translated into Award-Penalty Point Systems based on the signs of the predictors' regression coefficients. Annual surveys of tree mortality and decline are continuing in order to refine the present systems, producing final systems capable of predicting risk over longer time periods.

SUMMARY AND CONCLUSIONS

The California Pine Risk Rating System is basically a silvical principle which rates the current probability of attack by insects, primarily western and Jeffrey pine beetles for eastside ponderosa and Jeffrey pine. The System is based on the classification of individual trees by easily and quickly recognized crown characteristics. When the system is utilized as a forest management practice, it is called sanitation/salvage logging. It has been found to be highly effective in reducing losses by bark beetles on applicable forest sites. The removal of as little as 10 to 15 percent of the stand volume, as high-risk trees, reduces subsequent losses by as much as 80 percent for more than 20 years.

The California System evolved during the period 1925 to 1940 in California and southern Oregon. It was the first risk-rating system of its kind to be developed and applied. The experiences of research on tree selection and classification, and the analysis of large-scale bark beetle surveys and direct control programs formed the background of information and attitudes for the research and development of the California System. This endeavor commanded the whole or partial attention of some of the most competent forest entomologists in the West. Contributions were made by many whose names do not appear on the cited reports and publications, through their participation in meetings, consultations, and correspondence. Those early scientists accomplished an amazing amount of high-caliber work without many of the tools and amenities of today's research. They also seemed to apply a fortunate balance of logic and intuition along with careful and extensive field observations. This was also the developmental period for the forest entomologists who did many of the basic studies on forest insect pests in the West.

The critical study which resulted in the formulation of the System was designed and conducted by K. A. Salman, who was guided by results of careful research, collaboration, and testing of many scientists and forest managers. His study in 1936 resulted in the definition of four risk classes, based primarily on kinds and degrees of crown deterioration. This formative research was followed by large-scale logging studies starting in 1937 on the Blacks Mountain Experimental Forest on the Lassen National Forest. These studies were highly successful in proving the immediate, large, and lasting favorable benefits of sanitation/salvage logging. The first use of the System by private forestry was designed by J. W. Bongberg in 1939 for the McCloud River Lumber Company in Shasta County, California. This operation demonstrated both its effectiveness and ease of application. The California System meets most of the requirements of a good forest practice; it is easy to apply, is economical, and has large and lasting favorable benefits with a minimum of adverse environmental effects. It was adopted as a standard management practice by the U.S. Forest Service in Region 5 and by many timberland owners in California and Oregon.

Three important modifications or derivatives of the System are a stand hazard classification system, a penalty scoring procedure, and an award/penalty system for risk rating true firs. The stand hazard classification uses risk-rating values of a stand and the recent past experience of insect-caused losses to rate the relative need of areas for pest management attention, either survey or control. That is, hazard rating is a guide to the resource manager to target or intensify surveillance or to direct his sanitation/salvage operation. The penalty scoring procedure was designed to train timber markers and to increase the objectivity of risk rating by assigning numerical penalties to easily recognized tree characteristics. The sum of the penalties determines the risk class of a tree. The award/penalty system for risk rating individual true firs uses the principles and procedures developed by the California System and can be considered a derivative of it.

In 1962, efforts were made to define more clearly the risk classes through the use of several types of recently developed statistical procedures. The results of the analysis did not improve the definition or identity of the risk classes. However, recently developed analytical procedures using computers were effectively used in the work on true fir.

Subsequent research has attempted to explain the System and its mode of operation in the dynamics of the tree and the beetle. One study showed the expression of crown deterioration was largely a function of size, growth, and position of needles and twigs. Another study showed that the duration of xylem resin flow was shorter for high-risk trees than for low-risk trees. Also, high-risk trees produced the largest number of beetles. The risk classification of a tree can change over long periods; some trees showed improvement, others showed decline. Another study showed the accuracy and repeatability in rating the risk class of trees is increased by experience.

Although risk rating is based on individual trees, it appears to function most effectively on an area basis. This is probably caused by the compensating action of such factors as imprecision of definition, inaccuracy in rating, changes in risk, overall shifts in environmental conditions, and the spatial and temporal fluctuations in beetle populations.

The System has been widely applied via sanitation/salvage logging on private and public forests of the eastside pine type of northeastern California and southern and eastern Oregon. In many areas the System has been effectively hybridized with the Keen Tree Classes. The extent of its use is difficult to determine, but there may be 3 to 5 million acres of applicable forests which have been processed to some degree by sanitation/salvage logging. Also, it has been found to be generally applicable to ponderosa and Jeffrey pine stands that are under long-term stress; such stands occur in southern California and intermountain regions of Montana and Idaho. The System may be more widely used than direct evidence can show because the terms risk and sanitation/salvage or derivatives of them are now standard terminology in forest practice; thus, the principles of the California System may be applied without the conscious effort to identify the System.

The California Risk Rating System is one of the more notable developments in forest insect control because of its intrinsic value. It has also been of inestimable extrinsic value in demonstrating the possibilities of utilizing insect/host relationships in pest control for a wide variety of insects.

It would seem advisable to close with an air of optimism and hope for future risk-rating systems. But we have chosen to close with a precautionary note as expressed by Craighead et al., (1931) as they concluded about bark beetle control in general.

> However, at least one outstanding conclusion applies to the entire matter, (of bark beetle control) and may be stated as follows: Each species of bark beetle presents its own special problem and must be dealt with differently from other species as to control methods and strategy, and even the same species may present problems which differ in different regions. The management of control operations must therefore vary according to local conditions within the area being protected.

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