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Risk-Rating Systems for Mature Red Fir and White Fir in Northern California

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IN BRIEF...

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1980. **Risk-rating systems for mature red fir and white fir in northern California.** Gen. Tech. Rep. PSW-39, 29 p., illus. Pacific Southw- Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkel- Calif.
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Risk-rating systems predicting the probability that a tree will die within 5 years have been developed for mature red fir and white fir in northern California. The systems are based on analysis of the crown and bole characteristics of trees. For field use, the systems are formulated into Award-Penalty Point Systems, in which a tree is awarded points on the basis of ratings of some characteristics and penalized points on the basis of ratings of others. The difference between the Award and Penalty Point Totals—termed the Risk Point Total—is related to the percentage of a hypothetical population of identical trees that are expected to die within 5 years.

The systems are applicable to firs at least 10 inches (25.4 cm) in d.b.h., growing in mature stands, with the original overstory at least partially intact, in northern California. Outside this range in central and southern California, the systems may be used only tentatively, pending the results of studies underway to test, and verify or modify, the systems in these areas.

The risk-rating systems were developed by characterizing living and recently dead firs during initial surveys of 47 plots, each 20 acres (8.1 ha) in area, in northern California during the years 1975-1977. Totals of 1012 red firs (851 live, 161 dead), and 2571 white firs (2430 live, 141 dead) more than 10 inches (25.4 cm) in d.b.h. were examined in virgin and cutover stands. Tree characteristics were screened by computer to select variables capable of predicting tree death. For red fir, the risk predictors selected were Crow Class, Live Crown Percent, Top Condition, and Percent Crown Raggedness (Ragged Percent). For white fir they were Percentage of Crown with branches oriented horizontally or upswept (Branch Angle Percent), Crown Density, Percent Crown Raggedness (Ragged Percent) and whether living inner bark was visible in bark crevices at breast height (Bark Fissures).

By using these predictor variables, regression equations in the form of logistics functions were developed to predict the probability of a tree's death within 1 year. These probabilities were extrapolated to probabilities of death within 5 years by using a variant of a standard compound interest formula. The risk equations adequately explained the mortality in the data base when the distributions of expected and observed mortalities were compared by chi-square goodness-of-fit tests.

The risk equations were directly translated into Award-Penalty Point Systems in which trees are awarded points on the basis of predictors with positive regression coefficients, and penalized points on the basis of predictors with negative coefficients.

Red fir (*Abies magnifica* A. Murr.) and white fir (*A. concolor* [Gord. and Glend.] Lindl.), are major components of conifer stands at elevations of 700 to 3000 m in California. Although they vary from repeatedly logged to virgin and show a range of structures, these stands frequently retain intact much of the original overstory of mature trees. To meet management objectives for these stands, it is often desirable to maintain some semblance of this original structure by selectively harvesting overstory trees. Among the many criteria for deciding which trees to remove, the probability of imminent tree death resulting from natural causes—disease, insects, weather—is frequently overriding, especially if death is anticipated some years before the next planned reentry of the stand for harvesting.

In addition to harvesting timber before it dies and deteriorates, thereby avoiding the hazard of standing dead trees, it is desirable to identify and remove weakened trees to prevent their being used as substrate by insects and diseases.

An outgrowth of tree vigor classifications designed primarily for silvicultural purposes (Dunning 1928), risk-rating systems have been developed for classifying mature ponderosa and Jeffrey pines according to risk of being killed by *Dendroctonus* bark beetles (Keen 1936, 1943; Keen and Salman 1942; Salman and Bongberg 1942; Struble 1965). Use of the Salman-Bongberg system, followed by sanitation-salvage logging, has been successful in reducing or preventing beetle-caused pine mortality in both northeastern (Wickman and Eaton 1962) and southern (Hall 1958) California. This system also applies, with little or no modification, to ponderosa pines in the Southwest (Pierce 1961) and in western Montana (Johnson 1972).

To be practical, risk-rating systems should be rapid and easy to use, species-specific, and provide reliable estimates of risk for trees managed for a variety of objectives. Such systems have not been available previously for red fir and white fir. On the basis of a single year's results (1941), the Ponderosa Pine Risk System of Salman and Bongberg appeared to apply to white fir in northeastern California, but the study was discontinued.[1] Although this system has been widely applied to true firs on an empirical basis, these species differ sufficiently from ponderosa pine in silvicultural charac-

[1]Hall, R.C. Preliminary results of risk-rating all coniferous tree species on the Hat Creek study plots. (Unpublished report on file at the Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.)

teristics and in the pest complexes attacking them to justify separate risk-rating systems. Local, unverified systems have also been used for these firs. White firs rated as ''high risk'' by such a system, and those recently killed by subcortical insects, were found to have high densities of old fir engraver (*Scolytus ventralis* Le Conte) attack scars embedded in their boles, indicating increased susceptibility to the beetles (Ferrell 1973). Although data were fragmentary, these results indicated that reliable risk-rating systems could be devised for these firs.

This paper describes studies designed to develop, test, and extend the risk-rating systems for mature red fir and white fir in northern California. Properly used, these systems should contribute to the sound, long-term management of California's true firs.

DATA COLLECTION

Mortality plots

Forty-seven mortality plots, each 20 acres (8.1 ha) in area, were established from 1975 to 1977 to characterize dead and living firs and to monitor changes in the latter during the life of the study. White fir and red fir occupy extensive, partially overlapping ranges in California, within which both species display considerable geographic variation (Griffin and Critchfield 1972). To sample only part of this range and yet include as much variation as possible, the Cascade and Siskiyou Mountains north of Lassen Peak were selected for initial study. Shasta red fir (var. *shastensis* Lemm.) is usually found in this region, and near the Oregon border in northwest California, white fir and red fir become increasingly intermediate in certain morphological and chemical characteristics, with *Abies grandis* (Dougl.) Lindl., and *A. procera* Rehd., respectively (Zavarin and others 1975, 1978).

Within the region selected the plots, by National Forest, were distributed as follows: Lassen National Forest—33 plots located on both west and east sides of the Cascade crest from the vicinity of Lassen Peak north to the Pit River; Shasta-Trinity National Forest—5 plots on the east side of the Cascade crest from the Pit River north to Mt. Shasta; Klamath National Forest—4 plots on the Siskiyou crest northwest of Mt. Shasta. In addition, five plots were located on the west side of the central Sierra Nevada crest in the Stanislaus National Forest to sample white fir infected by a leafy mistletoe (*Phoradendron bolleanum* spp. *pauciflorum* [Torr.] Wiens). This mistletoe is a risk factor (Felix and others 1971, Ferrell 1974) that was reported as not occurring north of the Mokelumne River drainage in the central Sierra Nevada (Wagener 1957).

As the plots were concentrated in the Cascade and Siskiyou Mountains, the resulting risk systems should apply mainly in this region, and it was expected that further sampling, testing, and if necessary, modification of the systems would be required to make them applicable to other regions of California in which these firs occur.

Stands sampled by the plots had to meet certain criteria. They had to be "mature;" that is, with mature red or white fir, or both, comprising at least 30 percent of the overstory. The stand could be either virgin or cutover, but if cutover, the original overstory had to be at least partially intact. Also, the stand must not have been logged within the preceding 3 years, nor scheduled for logging for the next 5 years. Finally, the stand structure had to be as uniform as possible throughout the area of at least 20 acres.

Plots were selected by systematic examination of ¼-mile-wide roadside strips, and by sampling every stand that met the selection criteria. The plots did not constitute a random sample of all stands containing white and red firs in northern California, but they were considered to be a representative cross-section of most growing sites for these firs in the region studied. Twenty plots were established in 1975, 22 in 1976, and five in 1977. In the region sampled, the ranges of white fir and red fir broadly overlap at elevations of 1300 to 2300 m. Consequently, 29 of the plots contained both species, 12 had white fir only, and 6 had red fir only. Among the 47 plots, 26 had been logged—although many only lightly so—and 21 were virgin old-growth.

Each summer, after the crowns of firs dying since the previous summer had faded, each plot was completely surveyed and the characteristics of these faded firs recorded. Only firs 10 inches (25.4 cm) or more in d.b.h. were sampled. Also, during initial survey of each plot, an additional sample of obviously declining firs—"poor vigor" trees—was characterized to study rates of crown change. These trees were marked so that they could be reexamined annually. The number of firs selected for this purpose varied from plot-to-plot according to their availability, but an attempt was made to mark at least eight per plot.

Green Stand Subplots

Because of the scattered distribution of tree mortality when pest populations are endemic, dead trees were sampled in 20-acre plots. The high ratio of live-to-dead firs on these plots, however, made it infeasible to characterize all of the living firs on the entire 20 acres. Consequently, a subsample of the "green stand" was obtained by characterizing all living firs exceeding the minimum d.b.h. on a 1-acre (0.4-ha) green stand subplot. These firs were also marked so that they could be reexamined for changes in condition during the annual surveys. Although the sample stands were chosen to be as uniform as possible, considerable variation in forest cover within the mortality plots was inevitable because of their size. Each subplot was selected by noting variations in forest cover during the initial survey and by selecting a subplot that approximated the average stand structure, density, and species composition on the mortality plot. This method effectively avoided the selection of subplots with unrepresentative forest cover and, hopefully, any bias possibly introduced by the nonrandomness of the method did not seriously affect the ability of the subplots to represent living firs on the mortality plots for purposes of risk calculations.

Tree Characteristics

To be practical, a risk-rating system should use only a few tree characteristics, carefully chosen for their value as risk predictors. Predictors should be externally visible and capable of evaluation by rapid visual estimate or rating.

To ensure that this system could predict current and long-term risks, predictors of both were included in the study. Systems developed for ponderosa pine were valuable in suggesting characteristics to be studied in firs. Indicators of age (for example, bark color) and vigor (for example, live crown length) were used for long-term risk (Keen 1936); crown weakening and top condition were used as indicators of current risk (Salman and Bongberg 1942). Indicators selected from each pine system, living together with additional characteristics not previously used, were investigated for their value as fir risk predictors. Most characteristics could be estimated or

Table 1—*Tree characteristics evaluated as risk predictors*

Characteristic	Definition
D.b.h.	Bole diameter at breast height
Live crown percent	Percent of tree height in live crown
Cortex percent	Percent of tree height with smooth bark
Bole condition	Presence of scars caused by sapsuckers, beetle attack, lightning or logging; bole cankers
Bark fissures	Live inner bark visible (or not) in fissures
Bole scar percent	Percent of bole circumference scarred
Lightning scar percent	Percent of bole circumference scarred by lightning
Sapsucker scar percent	Percent of bole circumference scarred by sapsuckers
Bole cankers	Number of bole cankers
Mistletoe masses	Vertical extent of leafy mistletoe clumps
Crown width	Maximum width of crown
Branch angle percent	Percent of crown length with upswept to horizontal branches
Crown density	Density and raggedness of crown
Ragged percent	Percent of crown missing, dead, or dying
Top condition	Shape and condition (spike, topkill) of top
Topkill percent	Percent of crown length recently killed
Spike percent	Percent of crown length in old topkill
Crown class	Crown position in stand canopy
Tree height	Total height of tree
Tree age	Young or mature as less than, or greater than, 80 to 100 years old
Bark color	Color of dead bark at breast height
Foliage color	Normal, or abnormal (chlorotic, browned), color

rated by visual inspection. Some, however, required measurement to ensure sufficient accuracy of the data base, but were able to be estimated when used in practice to risk-rate trees. Although many characterisitcs were studied (*table 1*), only the most reliable predictors were included in the risk systems.

Mortality Agents

In addition to damage estimates for externally visible pests, such as mistletoes (crown raggedness, bole cankers), and woodpeckers (sapsucker scars), which were estimated in all sampled firs, dead and dying firs were also examined for subcortical pests possibly implicated in tree death. Boles were chopped into at breast height and at ground level, and the wood-bark interface was examined for evidence of subcortical beetles and root decay fungi. Beetles were identified by their borings or gallery patterns, or by any adults present (Keen 1952, Furniss and Carolin 1978). Root decay fungi were identified by their sporophores, rhizomorphs, mycelia, or the wood stains and decays produced (Hepting 1971, Smith 1978).

DATA ANALYSIS

Two complementary methods of analysis designed to provide for the early development of preliminary risk systems and, at the same time to lead to the development of final systems, were used. In both methods, the characteristics of dead and dying firs were compared with those of surviving firs.

Analysis of Initial Mortality

To develop the preliminary systems, the characteristics of firs judged to be recently dead during initial surveys of the mortality plots were compared with those of living firs within the green stand subplots. Because the plots were established in the years 1975 to 1977, the analysis, although considered adequate for preliminary systems, lacked the time-span required for development of final risk systems.

One drawback, inherent in the method of post-mortem examination of trees, was that characterization of the condition of the tree pertained only to the period just before it died. Also, certain pre-death characteristics were not obtainable. Color of the foliage before death, for example, was not obtainable from the dead tree. Other characteristics required interpretation; that is, topkilling occurring some years before tree death, denoted by branches bare of foliage, was judged to be recent or older, depending upon whether the fine twigs were still in place, or had been shed. Most of the characteristics used in the study, however, had not been altered by tree death and could be evaluated directly by post-mortem examination.

Derived solely from post-mortem examination of firs dying within a 3-year period, the resulting risk systems, reported here, are considered preliminary to final systems being developed by the following method.

Analysis of Mortality Over Time

Living firs characterized within the green stand subplot, as well as "poor vigor" trees scattered over the entire mortality plot, were surveyed annually for changes in tree characteristics or mortality. This method is advantageous in that tree condition will be monitored over some years, in advance of death, allowing the development of rating systems capable of predicting long-term risk. The surveys will continue until adequate data upon which to base the final systems are obtained, as described later in this report.

Identifying Risk Predictors

To identify those traits of greatest value as risk predictors, tree characteristics were screened by the computer program SCREEN (Hamilton and Wendt 1975). Continuous variables (percentages or measurements) were subdivided into intervals or classes, as required by the Program. Comparing ratios in the numbers of dead-to-living trees, the Program screens the tree characteristics in step-wise fashion, selecting at each step the most significant predictor variable on the basis of user-specified levels of chi-square probability. The selective search principle upon which the choice of variables is made uses an algorithm based on assumptions that cannot, at present, be proven (Sterling and others 1969). Consequently, the method, although not guaranteeing results as valid as those from an exhaustive search of all variables, represents the best of the practical alternatives available.

Output from the Program, in the form of a "decision tree" diagram (*fig. 1*), arranged the variables from left to right along the tree's "branches," with each variable statistically explaining the largest amount of the mortality occurring in the interval or class to the immediate left. Intervals or classes with dissimilar mortality ratios were listed separately; those with similar ratios were combined. This method of screening identified variables that provided additional information about the mortality in groups of trees falling within particular intervals or classes of variables already selected.

In both tree species, more variables were significant at the 95 percent level than were usable in a practical risk system. Only those significant variables selected either early in the step-wise process, or in more than one branch of the decision tree, and convenient for field estimation, were included in the risk calculations. The variables included, therefore, were those that were the most significant indicators of risk for as many of the sample firs as possible with the expectation that as risk predictors, they would perform similarly for most trees risk-rated in practice. Further analysis of the larger data base accumulated by the end of the study, however, may result in the inclusion of other variables to supplant or augment those in the present system.

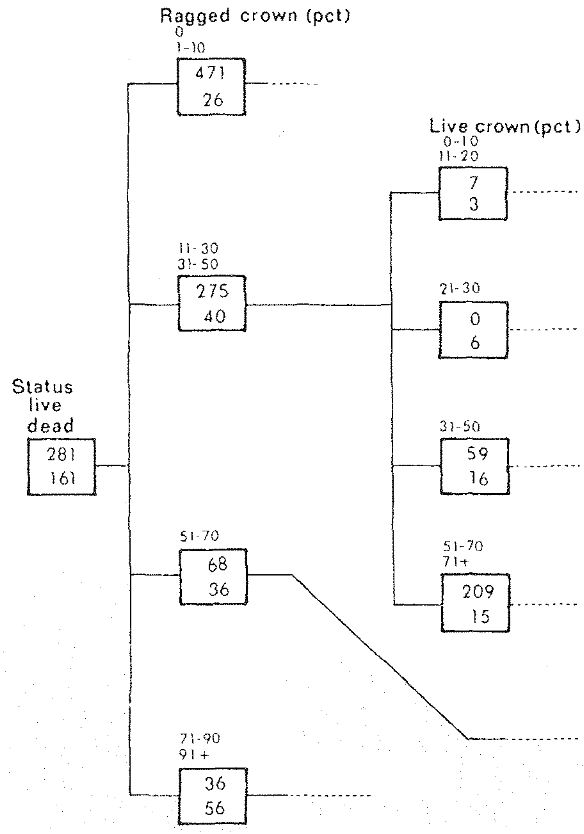


Figure 1—Portion of the "decision tree" produced by screening characteristics of mature red firs for value as risk predictors. Numbers above each box specify interval, or classes of the variables named above. Upper and lower numbers in boxes are the number of live and dead trees, respectively, in the intervals or classes. Intervals with similar mortality ratios are combined. The total numbers of live and dead firs sampled are shown under STATUS. Dashed lines extending to right from tree numbers indicate additional "branches" not shown.

Risk Calculations

Tree characteristics selected by the screening process were used as independent variables in the computer program RISK (Hamilton 1974). This Program calculates regression equations predicting risk of tree death. The equations predict the probability of individual tree death as a decimal between zero and 1, by using a logistics function of the form:

$$P = 1/(1+e^{X})$$

in which e is the base of natural logarithms, and X is a vector of the tree's characteristics. Graphically, the logistics equation is a sigmoid-shaped curve that Monserud (1976) found had greater power for predicting tree death than either discriminant, or probit, analysis.

The trees were sampled with unequal probability: living firs were sampled within 1-acre subplots and dead trees were sampled over 20-acre plots. To place the trees on an equal-area basis for calculation of risk probabilities, each live tree was weighted by an expansion factor of 20 in regression calculations. The assumption was that, on the average, each live fir on the subplot was represented by 20 similar living firs on the mortality plot.

Ability of the equations to explain statistically the observed distribution of fir mortality in the data base was judged by chi-square goodness-of-fit test (Hamilton 1974). Equations predicting the probability of death within 1 year were used to generate the distribution of estimated probabilities in the unweighted samples of firs. The distributions of observed and predicted mortality in the samples were then compared over the range of probabilities predicted by the equations.

Because the resulting risk equations were based mainly on firs that had died within 1 year before sampling ("initial mortality"), the resulting probabilities were considered to predict the risk of a tree's dying within 1 year. The stand manager, however, is primarily interested in predicting tree risk over somewhat longer time periods. Using the 1-year probabilities (P_1), the probability of death within 5 years (P_5) was calculated from the relationship:

$$P_n = 1 - (1 - P_1)^n$$

in which $n=5$ (Hamilton and Edwards 1976). The calculated probabilities were expressed either as decimals, or multiplied by 100 percent to obtain the percentage of a population of identical trees expected to die within a 5-year period.

RISK EQUATIONS

Red Fir

On the basis of screening the characteristics of the unweighted sample of 1012 mature red firs (851 live, 161 dead), Crown Class, Live Crown Percent, Top Condition, and Ragged Percent were selected as significant risk predictors.

From regression analysis of this sample of firs, the relationship for X in the equation $P_1 = 1/(1 + e^X)$, predicting probability of death within 1 year (P_1) was:

$$X = 3.096 + 0.159\ \mathrm{CCLS} + 0.049\ \mathrm{CPCT} - 0.010\ \mathrm{TCON} - 0.036\ \mathrm{RPCT}$$

in which

CCLS = Crown Class as one of following codes: (0) Suppressed, (1) Intermediate, (2) Codominant, (3) Dominant.

CPCT = Live Crown Percent as percentage of tree height in living crown estimated to nearest 10 percent (ignore isolated lower branches).

TCON = Top Condition as one of following codes: (0) Pointed, (1) Round, (2) Flat, (3) Broken with live regrown leader(s), (4) Spike with live regrown leader(s), (5) Broken without live regrown leader(s), (6) Spike without live regrown leader(s), and (7) Recent topkill.

RPCT = Ragged Percent as percentage of crown missing, dead, or faded estimated to nearest 10 percent (ignore isolated lower branches).

The chi-square goodness-of-fit test *(table 2)* indicated that the probability distributions of predicted and observed mortality did not differ significantly (χ^2 = 1.03, 6 df), indicating the equation adequately predicted the observed distribution of mortality in the sample.

Table 2—*Distribution of mature fir samples in intervals of predicted probability of death within 1 year, and goodness-of-fit of observed to predicted mortality, compared by chi-square for the range of prediction*

Interval	Number of trees in interval: Total[1]	Dead: Observed	Dead: Predicted	Chi-square
	Red fir (N = 1012)			
0.00 to 0.01	798.6	2.7	2.5	0.01
.01 to .05	178.8	3.1	3.8	.12
.05 to .10	23.2	2.0	1.6	.11
.10 to .15	8.2	1.1	0.9	.04
.15 to .20	3.9	0.4	0.7	.18
.20 to .25	0.2	0.2	0.0	.47
.25 to .30	0.1	0.1	0.0	.10
		Total chi-square =		1.03 (6 df)[2]
	White fir (N = 2571)			
0.00 to 0.01	2395.1	3.5	3.3	0.01
.01 to .05	161.1	1.8	3.2	.58
.05 to .10	14.1	1.4	0.9	.24
.10 to .15	0.7	0.7	0.1	4.78
		Total chi-square =		5.61 (3 df)

[1]Living plus dead firs.

[2]Probability distributions of predicted and observed mortality did not differ significantly, therefore the equations adequately predicted the occurrence of tree mortality in the firs sampled.

White Fir

On the basis of screening the characteristics of the unweighted sample of 2571 mature white firs (2430 live, 141 dead), Branch Angle Percent, Crown Density, Ragged Percent, and Bark Fissures were selected as significant risk predictors.

From regression analysis of this sample of firs, the relationship of X in the equation $P_1 = 1/(1 + e^X)$, predicting probability of death within 1 year (P_1) was:

$$X = 9.643 + 0.032\ \mathrm{BANG} - 0.078\ \mathrm{CDEN} - 0.047\ \mathrm{RPCT} - 1.419\ \mathrm{BFIS}$$

in which

BANG = Branch Angle Percent. Percentage of crown length with branches horizontal or unturned, estimated to nearest 10 percent.

CDEN = Crown Density as one of the following codes: (0) Dense (normal) foliage, (1) Ragged, one-sided, crown missing on one or more sides because of being raked by falling neighbor tree, or because of competition (shading) from neighbor tree, (2) Ragged, dead and flagged, crown ragged as a result of dead and/or dying branches scattered throughout crown, (3) Ragged because of combination of (1) and (2), (4) Thin, crown uniformly thinner than normal.

RPCT = Ragged Percent as the combined percentage of crown raggedness because of scattered missing, dead, and dying branches and one-sided crown.

BFIS = Bark Fissures as one of the following codes: (1) Live—Living bark visible between dead bark plates, (2) Dead—Living bark not visible between dead bark plates.

The chi-square goodness-of-fit test *(table 2)* suggests that the probability distributions of predicted and observed mortality did not differ significantly ($\chi^2 = 5.62$, 3 df), indicating the equation adequately predicted the observed distribution of mortality in the sample.

More complete definitions of the above predictors, together with instructions for using them to rate trees, can be found in the *Appendix*.

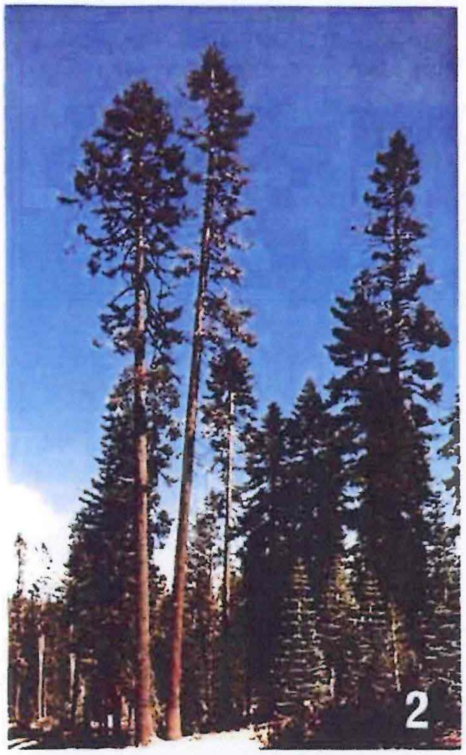
Using the Equations

Examples of rating risk by using the equations, and the effects of some of the predictors on the calculated risk are illustrated *(figs. 2,3,4)*.

Crown raggedness was the major risk predictor in both fir species. Crowns were frequently one-sided, with all or part of the crown missing or dead on one side because of shading from a neighboring tree or because of being raked when a neighboring tree fell. Also frequent were crowns ragged from scattered dead and dying branches, frequently resulting from infection of dwarf mistletoe (*Arceuthobium abietinum* Engelm. ex Munz) and a cankercausing fungus (*Cytospora abietis* Sacc.) (Scharpf 1969). In estimating Ragged Percent (RPCT), raggedness resulting from one-sidedness and scattered branch death were combined, as both were expected to contribute to crown weakening, and thus to increased risk of death. The estimates are combined by estimating the percentage of the crown missing or dead because of one-sidedness (R^1). Then the percentage of crown raggedness because of scattered branch death (R_{df}) is estimated, and multiplied by the proportion of crown remaining: $P = (100-R^1)/100$. The two estimates are summed to obtain the combined estimate as expressed in the formula: $RPCT = R^1 + (P \times R_{df})$.

The effect of crown raggedness is illustrated *(fig. 2)*. Because both red firs at center were dominant with 50 percent live crowns, 3 and 50 were entered in the red fir equation for CCLS and CPCT, respectively. The tree on the right, however, had a pointed top (TCON = 0), and the top on the tree at the left was rounded (TCON = 1). More importantly, however, the crown of the tree on the right was one-sided with nearly 50 percent missing ($R^1 = 50$), and about 60 percent of the remainder dead or dying ($R_{df} = 60$). Combining these, Ragged Percent (RPCT) = 50 + (0.5 × 60) = 80 percent. The calculated probability of this tree's dying within 1 year (P_1) was 0.04 and within 5 years (P_5), 0.19. In other words, about 19 percent of a population of identical trees was expected to die within 5 years. Only about 30 percent of the crown of the tree on the left was ragged, however, because of branch death, primarily in the lower crown (RPCT = 30). The calculated probabilities were: $P_1 = 0.007$, and $P_5 = 0.03$; that is, only 3 percent of such trees were expected to die within 5 years.

The effect of variations in crown vigor on risk calculated for white firs was similar *(fig 3.)*. The tree in *figure 3A* had a vigorous crown with about 30 percent of the crown length occupied by branches oriented at, or above, the horizontal, so Branch Angle Percent (BANG) = 30. A few lower crown branches were dead or dying (CDEN = 2), and Ragged Percent (RPCT) was set at 10. Although living inner bark was not visible in the bark fissures at breast height (BFIS = 2), the 5-year risk was only 0.004. Branch Angle Percent for the tree in *figure 3B* was also 30 percent (BANG = 30). About 60 percent of the crown, however, was ragged because of branch die-back (CDEN = 2, RPCT = 60) and, although living inner bark was also not visible in the bark fissures at breast height (BFIS = 2), the 5-year risk was higher ($P_5 = 0.04$). The living crown in the tree in *figure 3C* was limited to several clumps of foliage apparently produced adventitiously after death of the original crown. Because none of the latter was living, Branch Angle Percent (BANG), by definition, was zero. At least 90 percent of the crown was dead (CDEN = 2, RPCT = 90), however, and although the bark fissuring was the same as the other trees (BFIS=2), the 5-year risk (P_5) was 0.35. If RPCT, estimated to the nearest 10 percent, had instead been set at 100, the P_5 obtained would be 0.49. Because of the obvious difference in crown vigor, P_5 in the tree in *figure 3A* (left) varied about 100-fold from that in the tree in *figure 3C*.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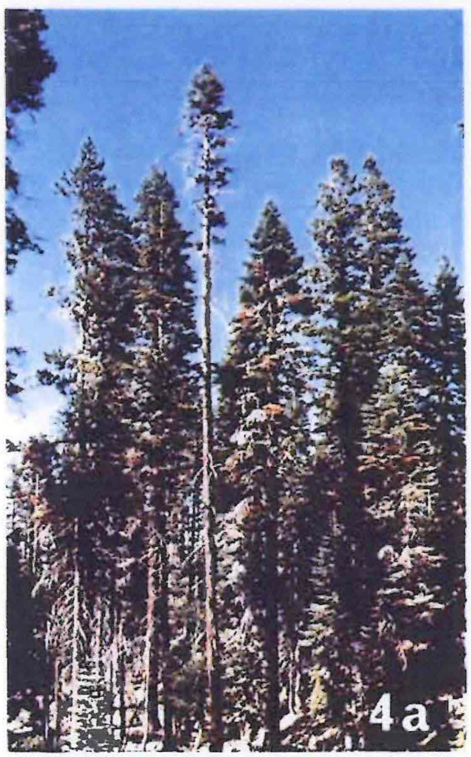
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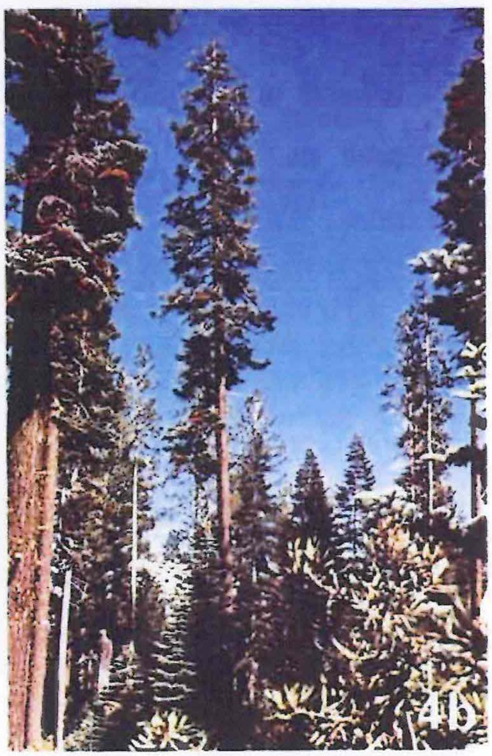
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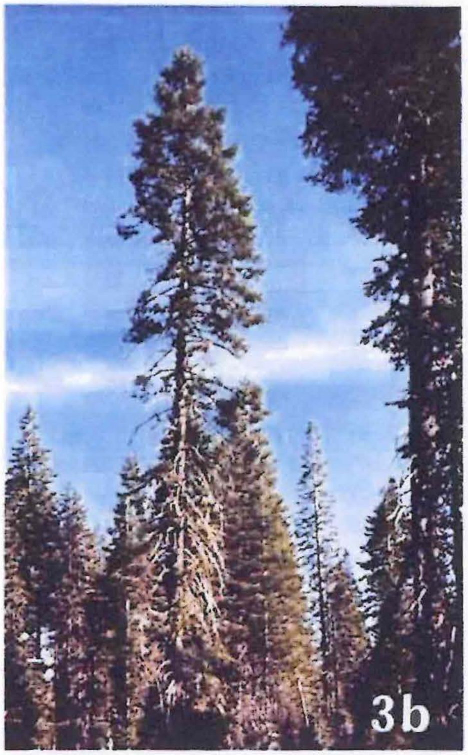

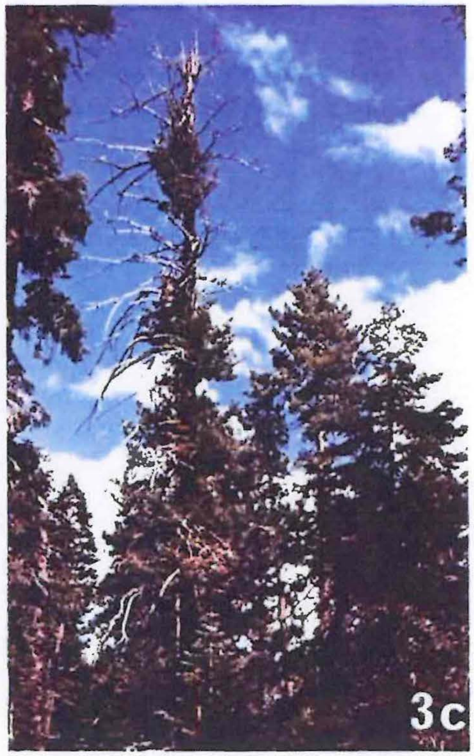

Figure 2 (upper left)—Effect of crown raggedness in mature red fir. Both trees had Live Crown Percent = 50, but tree on right had a more ragged crown (Ragged Percent = 80), and higher risk of death (19 percent within 5 years). Corresponding figures for tree on left were 30, and 5 percent, respectively.

	Rating	
Predictor	Left	Right
Crown Class (CCLS)	Dominant	Dominant
Live Crown Percent (CPCT)	50	50
Top Condition (TCON)	Round	Pointed
Ragged Percent (RPCT)	30	80

Figure 3 (above)—Effect of crown raggedness in mature white fir. Primarily on the basis of variation in crown raggedness in the firs at centers of A, B, and C (Ragged Percent = 4, 60, and 90, respectively), the 5-year risk of death varied as follows: (A) 0.4 percent, (B) 4.0 percent, and (C) 35.0 percent.

		Rating	
Predictor	A	B	C
Branch angle percent (BANG)	30	30	0
Crown density (CDEN)	Ragged (dead branches)	Ragged (dead branches)	Ragged (dead branches)
Ragged percent (RPCT)	5	60	90
Bark fissures (BFIS)	Dead	Dead	Dead

Figure 4 (lower left)—Effect of live crown length in mature red fir. Primarily because of its short crown (Live Crown Percent = 10), fir at center of A has a 5-year probability of death of 0.16, while longer-crowned tree at center of B (Live Crown Percent = 70) has a 5-year probability of death of only 0.006.

	Rating	
Predictor	A	B
Crown class (CCLS)	Dominant	Dominant
Live crown percent (CPCT)	10	70
Top condition (TCON)	Pointed	Round
Ragged percent (RPCT)	20	10

In red fir, the effect of another major risk predictor, Live Crown Percent (CPCT), is illustrated *(fig. 4)*. The fir in *figure 4A* (center) is dominant (CCLS = 3), but is short-crowned. If isolated lower branches are excluded, the living crown occupies only about 10 percent of the height of the tree, or Live Crown Percent (CPCT) = 10. The top is considerably rounded but a small pointed tip is present and so Top Condition is rated as pointed (TCON = 0). The short crown also includes a few dead and dying branches and Ragged Percent (RPCT) was set at 20. Primarily because of the short crown, however, this fir has a 16 percent chance of dying within 5 years. Fir in *figure 4B* is also dominant (CCLS = 3); however, it has a much longer crown: Live Crown Percent (CPCT) = 70. The top is round (TCON = 1), and a few dead and dying branches are present in the crown; Ragged Percent (RPCT) = 10. Primarily because of the longer crown, however, the risk of death is lower (P_5 = 0.006), and less than 1 percent of such trees are expected to die within 5 years.

AWARD-PENALTY POINT SYSTEMS

The risk equations were translated directly into point systems, thereby enabling calculation of risk by simple arithmetic *(tables 3,4)*. The relation-

Table 3—*Award-Penalty Risk System for mature red fir*

Crown Class			Award
Suppressed			0
Intermediate			2
Codominant			4
Dominant			6
Live Crown Percent (to nearest 10 percent of tree height)			
5 points for each 10 percent			____
Total Award			____
Top Condition			Penalty
Recent topkill			1
Ragged Percent (of crown missing, dead, and dying to nearest 10 percent)			
4 points for each 10 percent			____
Total Penalty			____
Risk Point Total			
a. Enter Total Award or Penalty (whichever larger)			____
b. Subtract smaller Total			____
c. Risk Point Total			____
Percent Mortality (within 5 years)			
a. Award equals or exceeds Penalty			0 to 20 percent
b. Penalty exceeds Award			
Points	Percent	Points	Percent
1 to 4	21 to 30	15 to 17	60 to 70
5 to 8	30 to 40	18 to 21	70 to 80
9 to 11	40 to 50	22 to 25	80 to 90
12 to 14	50 to 60	26+	90+

ships between risk and its predictors, as expressed in the equations, were maintained in the point systems so that little retraining would be required in shifting from one method of predicting risk to the other. In the point systems, the tree is awarded points on the basis of estimates of predictors with positive coefficients in the equations, and penalized points on the basis of the state of predictors with negative coefficients. For convenience of the user, it was desirable to have the points awarded or penalized in whole numbers as small as possible. This was done by rounding off each coefficient, multiplying it by the appropriate estimate of its predictor variable, and then multiplying the product by a factor of 10. The results from screening the tree characteristics for their association with tree death indicated that, for some of the predictors, certain ratings could be omitted or combined with others, with little loss in predictive power. Where possible, this was done to simplify the point systems.

By using the risk equations, the difference between Award and Penalty Point Totals—the Risk Point Total—was translated into the percentage of

Table 4—*Award-Penalty Risk System for mature white fir*

Branch Angle Percent	Award
(to nearest 10 percent of crown length)	
3 points for each 10 percent	
Total Award	
Crown Density	Penalty
Dense	0
Ragged, due to:	
a. One-sidedness	1
b. Dead and dying branches	2
c. Combination a and b	2
Thin	3
Ragged Percent (of crown missing, dead and dying to nearest 10 percent)	
5 points for each 10 percent	
Bark Fissures	
a. Living inner bark visible	0
b. No living inner bark visible	28
Total Penalty	
Risk Point Total	
a. Enter Total Award or Penalty (whichever larger)	
b. Subtract smaller Total	
c. Risk Point Total	

Percent Mortality (within 5 years)

a. Award equals or exceeds Penalty .... 0 to .03 percent

b. Penalty exceeds Award

Points	*Percent*	*Points*	*Percent*
1 to 50	.03 to 5	71 to 74	30 to 40
51 to 57	5 to 10	75 to 77	40 to 50
58 to 65	10 to 20	78 to 80	50 to 60
66 to 70	20 to 30	80+	60+

trees expected to die within 5 years. The range of possible Risk Point Totals was calculated from the minimum and maximum Award and Penalty Point Totals allowed by the system. All Risk Point Totals possible within this range were divided by 10 to convert them back into values appropriate for substitution in the equations in place of the vector of predictor variables, and probabilities of death were calculated for the entire range of prediction. During the calculations it was noted that, if the Award Point Total equaled or exceeded the Penalty Point Total, the predicted probabilities were all so low that they were placed in a single broad interval as no further breakdown was needed. When the Penalty Point Total exceeded the Award Point Total, the excess or Risk Point Total and the corresponding probability were also tabulated, for convenience, by intervals. These intervals were considered to be adequate for most risk predictions. For 85 percent of the red firs and 90 percent of the white firs, the probabilities obtained from the equations fell within the intervals predicted by the point systems when large samples of trees were rated by both methods. The probabilities were also plotted as a function of the Risk Point Total *(fig. 5)* so that more exact risk predictions could be obtained, if this was desired. As an aid to interpretation, both the tabulated and graphed probabilities were expressed as the percentage of a hypothetical population of identical trees expected to die within 5 years.

The differences between the two functions depicted in *figure 5* reflect differences in the observed mortality rates of the two species on the plots. Overall, mortality rates for white fir (0.3 percent of the estimated total number of mature white firs on the plots, or 0.14 trees/acre) were much lower than the corresponding rates for red firs (0.9 percent or 0.21 trees/acre). At least some of this difference was attributed to the greater amount of crown raggedness caused by heavier infections of dwarf mistletoe and *Cytospora* in the red firs as 53 percent of the trees had crowns with at least some scattered branch dieback attributed to these agents, and frequently more than one-half the foliage was dead or dying. In contrast, although 42.2 percent of the white firs sampled were similarly afflicted, only rarely was more than 20 percent of the foliage killed. Consequently, the highest 5-year probabilities obtained for white fir were just over 40 percent, while those calculated for red fir approach *100* percent.

Use of these point systems to risk-rate trees is described in the *Appendix*.

MORTALITY AGENTS

Subcortical examination of the dead trees on the plots indicated that virtually the same complex of insects and diseases was the proximal cause of death in both white and red firs. The incidence of insects and diseases found beneath the bark in the lower boles of the dead trees is summarized in *table 5*. No statistical comparisons were made because of the limited number of trees sampled. (The importance of crown-weakening agents such as dwarf mistletoe and *Cytospora* cankers in predisposing these firs to death has been

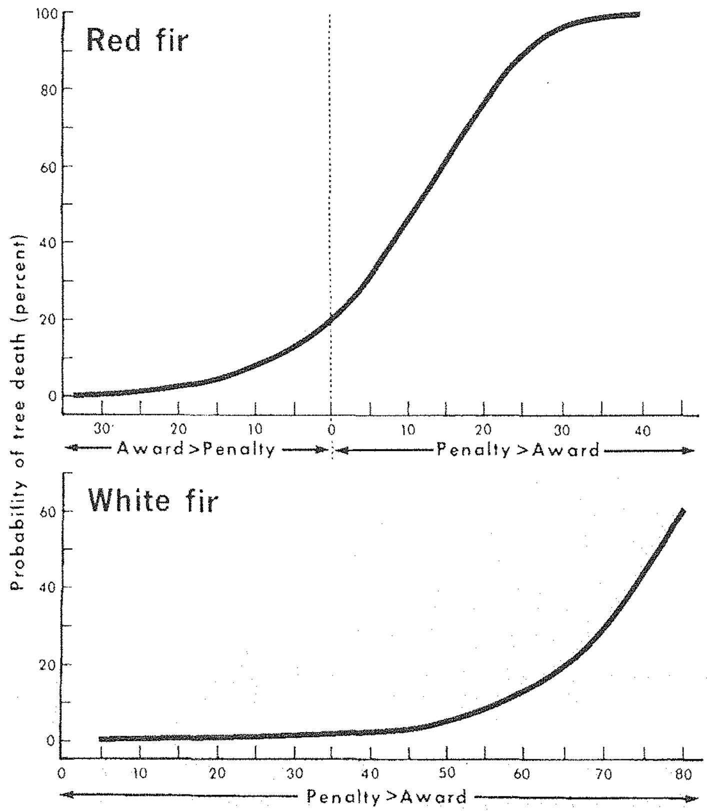

Figure 5—Percentage of mature firs expected to die within 5 years as a function of the Risk Point Total, obtained by comparison of the award, penalty point totals.

discussed above.) Overall, results from red fir and white fir were similar. More than two-thirds of the trees evidenced subcortical beetles, but no root decay fungi. The latter, without the former, were found in only 2 to 3 percent of the trees. Both agents were found in 10 percent of the firs, but neither agent was found in nearly 20 percent of the white firs, and 10 percent of the red firs. The relatively low incidence of observed root diseases, either by themselves or in combination with subcortical beetles, was probably because of the difficulty of diagnosing their presence on the basis of chopping into the trunk only at soil level. Surveys using partial excavation of root systems reported that more than 80 percent of dead white firs in the Central Sierra Nevada (Cobb and others 1974), and even higher percentages of dead white firs and Shasta red firs in southern Oregon (Lane and Goheen 1979), had root diseases.

Eighty percent of the red firs, and more than 50 percent of the white firs, had been infested by cambial-mining round- and flat-headed fir borers

Table 5—*Incidence in percentage of trees sampled, of subcortical mortality agents in lower boles of mature red firs and white firs occurring as initial mortality on risk plots, 1975-1977*

Agent(s)	Red fir (N = 161)	White fir (N = 141)
Beetles alone[1]	77.0	68.8
Root disease alone[2]	3.2	2.2
Beetles and root disease	9.9	10.6
Neither agent found	9.9	18.4
Round-head fir borers	57.1	45.4
Flat-head fir borers	13.7	2.1
Round-and flat-head fir borers	9.3	5.0
Borers, total	80.1	52.5
Silver fir bark beetles	1.9	0.0
Fir engraver bark beetles	0.0	0.0
Both bark beetle species	0.0	6.4
Bark beetles, total	1.9	6.4
Borers and bark beetles	5.0	14.9
Shoestring root decay	7.5	8.5
Annosus root decay	2.5	2.8
Both decays	0.0	0.0
Root decay, total	10.0	11.3

[1]Round- and flat-head fir borers (*Tetropium abietis*: Cerambycidae; *Melanophila drummondi*: Buprestidae), the silver fir (*Pseudohylesinus sericeus* [= *grandis*]), and fir engraver (*Scolytus ventralis*), bark beetles.

[2]Shoestring (Armillaria mellea), and annosus (*Fomes annosus*), root decay fungi.

(*Tetropium abietis* Fall, *Melanophila drummondi* Kirby; Cerambycidae, Buprestidae, respectively). Roundheads were more frequent than flatheads in both firs. Bark beetles (Scolytidae) were found in only 2 percent of the red firs, and 6 percent of the white firs. In white firs, silver fir beetles, *Pseudohylesinus sericeus* (Mannerheim) (=P. *grandis* Swaine), and fir engraver beetles, *Scolytus ventralis* LeConte, always were found together. Silver fir beetles, but not fir engravers, were observed in red firs, although this tree is a known fir engraver host (Struble 1957). Both borers and bark beetles were observed in 15 percent of the white firs and 5 percent of the red firs. The relatively low observed incidence of bark beetles, either by themselves or with the borers, could be a result of sampling only the lower boles of these mature trees. Full-stem dissections of similar white firs revealed that the bark beetles prefer the mid-to-upper regions, although the borers are found more frequently in the lower regions of the boles.[2]

Shoestring rot (*Armillaria mellea* Vahl. ex Fr.) and annosus rot (*Fomes annosus* [FR.] Cke.) were the only root decay fungi identified. Their incidence was similar in the two firs: the former was found in about 8 percent and the latter in 3 percent of the trees. The higher observed incidence of *A. mellea* may have resulted from its tendency to form rhizomorphs that were readily recognized. The presence of *A. mellea* may have obscured the presence of *Fomes annosus*, as mixed infections were not detected.

On the basis of sampling only lower boles of a limited number of dead trees, drawing firm conclusions regarding the relative incidence of these agents must await full-stem dissection and statistical analysis of the larger sample of trees expected by the completion of the study.

EXTENDING THE RISK SYSTEMS

Several studies, intended to extend the preliminary systems and lead to final systems, are either underway or planned.

Annual surveys of established mortality plots will continue. In the second year of the study (1976), California entered a severe drought that ended in 1977. Previous studies in the region sampled by the mortality plots (Ferrell and Hall 1975), indicated that increased fir mortality is associated with such drought periods. During the years 1975 to 1977, mortality rates on the plots were low for both red fir and white fir and drought-related, increased mortality was not yet apparent. Increased mortality rates were expected in 1978 and possibly in 1979 as an aftermath of the drought, and annual survey of the mortality plots will continue until mortality rates again return to approximate the levels found in the initial surveys. Risk will then be calculated for both periods of normal and subnormal precipitation, so that the resulting systems should be capable of predicting variations in risk resulting from drought. Of even greater value to the forest manager, however, is the expectation that continued monitoring of fir mortality should provide a firm basis for reliably predicting risk over somewhat longer time periods than the 5-year capability of the present system.

Parallel studies to develop risk systems for younger firs released by over-story removal are continuing to enlarge the data base.

The risk systems must be tested, refined, and verified throughout the geographic ranges of red fir and white fir in California. Large samples of firs must be risk-rated and monitored, to determine if observed mortality rates agree with those predicted by the systems.

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[2]Struble, George R. 1931. The fir engraver beetle and associated insects in white fir, season of 1930. (Unpublished report on file, Pacific Southwest Forest and Range Experiment Station, Berkeley, California).

Finally, cutting experiments must be made, in which fir stands are marked and cut using the risk systems, and subsequent mortality rates are compared with those in similar, uncut stands. If lower fir mortality results from logging stands on this basis, the risk systems can be considered to be verified, and should contribute to the long-term management of California's true firs.

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APPENDIX — USERS GUIDE: AWARD-PENALTY POINT SYSTEMS

The Risk-Rating Systems . . .

- Predict the probability of individual tree death within 5 years as a result of natural causes—insects, diseases, weather, or other.
- Apply only to mature firs at least 10 inches (25.4 cm) d.b.h., growing in mature stands with the original overstory at least partially intact.
- Are most applicable to the region sampled in developing them; outside the region sampled they should be used only tentatively, pending results of studies intended to verify or modify them for use in these other areas. These risk-rating systems are applicable to the southern Cascade Mountains from the vicinity of Lassen Peak, north to Mt. Shasta, and the eastern Siskiyou Mountains near the Oregon border. The red fir system is also applicable to Shasta red fir (var. *shastensis* Lemm.) growing within this region. These systems should apply also to firs in the Warner Mountains and nearby ranges in northeastern California, in the Salmon-Trinity and Marble Mountains in northwest California, and in the Sierra Nevada north of Lake Tahoe.

Award-Penalty Point Systems

A tree is awarded points on the basis of estimates of predictors that are negatively correlated with risk; a tree is penalized points on the basis of estimates of predictors that are positively correlated with risk.

Risk predictors selected for red fir are: *Crown Class*, *Live Crown Percent*, *Top Condition*, and *Ragged Percent*.

Risk predictors selected for white fir are: *Branch Angle Percent*, *Crown Density*, *Ragged Percent*, and *Bark Fissures*.

Estimating Predictors

Several of the predictors are used in both the red fir and white fir systems and, because estimation procedures are identical, definitions of these predictors are common to both systems:

Crown Class—the estimate of the tree's crown relative to those of adjacent trees. Crown classes are those ordinarily used by foresters:

Dominant—considerably taller than adjacent trees or isolated from competitors for light.

Codominant—about the same height as adjacent trees, with sides of crown receiving only limited light.

Intermediate—crown well beneath taller trees but receiving limited direct light, often only at midday.

Suppressed—completely overtopped by nearby trees, receiving only diffuse light.

Live Crown Percent—percentage of a tree's total height occupied by live crown, estimated to nearest 10 percent. The live crown is defined as extending from the tree's top, regardless of whether live or dead (topkill, spiketop), to the lower limit of the living crown. If top is broken off, live crown extends downward from point of breakage. Live crown includes all internal dead branches above lower limit of live crown (see Ragged Percent definition).

Setting lower limit of live crown:
- Exclude single, isolated lower branches
- For one-sided crowns, use longer side.
- If branches droop, use horizontal projection of branch tips onto bole.
- Exclude epicormic foliage unless judged to "contribute significantly to sustenance of tree." Note: This is subjective and needs more research.

Crown Density—categorize crown as to shape and condition of foliage and branches.

Dense—foliage with needles normal in length, number, and color. Dead, dying, off-color or thin foliage absent or, if present, amounting to less than 5 percent of total crown.

Ragged—localized reduction in foliage density because of: One-sidedness—one side of crown or portion thereof missing because of shading or crown injury resulting from falling neighbor tree (crown-raking); dead and/or dying branches or twigs, either scattered throughout crown, or concentrated in top (topkill, spiketop) or other section of crown (ignore broken, missing tops); or, combination of one-sidedness and dead-dying branches or twigs.

Thin—crown uniformly sparser than normal from reduced number and length of needles.

Ragged Percent (RPCT)—combined percentage of crown missing, and/or dead or dying, estimated to nearest 10 percent of crown. Include missing portions of crown above lower limit of live crown, whether contributing to one-sidedness or not. Include portions of crown that are dead or missing because of topkilling, regardless of whether topkill is recent (dead foliage retained) or older (dead foliage missing as in spiketop).

In the red fir risk system, variation in estimates of Live Crown Percent and Ragged Percent tend to compensate for one another in the calculation of risk for any individual tree. Including isolated, lower living branches in the live crown, while leading to higher estimates to Live Crown Percent will be compensated for by resultant increases in estimates of Ragged Percent. Trials indicate that the same, or closely similar risks will be obtained regardless of such differences in the height at which the observer sets the lower limit of the live crown. Branch Angle Percent and Ragged Percent similarly compensate for one another in the white fir system. Criteria for setting lower limit of live crown can be found in discussion of Live Crown Percent.

In crowns that are ragged because of one-sidedness and scattered branch death, it is frequently convenient to estimate the combined Ragged Percent as follows: 1) Estimate the percentage of crown missing because of the one-sidedness (R^1); 2) then estimate the raggedness because of dead and dying (flagged) branches as a percentage of the crown still present (R_{df}). R_{df} is then multiplied by the proportion of the entire crown still present (P) to obtain the contribution of the scattered branch die-back to the combined estimate of raggedness for the entire crown. The two estimates are then summed to obtain RPCT. The process is expressed by the formula: $RPCT = R^1 + (P \times R_{df})$.

Branch Angle Percent—Percentage of the total length of live crown with upswept to horizontal branches estimated to nearest 10 percent of crown. Branch tips should equal or exceed height at which branches join with bole. Criteria for setting lower limit of live crown can be found in discussion of Live Crown Percent.

Top Condition—For use in Award-Penalty System, only if the tree is recently topkilled; recent topkills retain faded foliage. Ignore killed tops

Appendix Table 1—*Award-Penalty Risk System for mature red fir*

Crown Class			Award
Suppressed			0
Intermediate			2
Codominant			4
Dominant			6
Live Crown Percent (to nearest 10 percent of tree height)			
5 points for each 10 percent			____
Total Award			____
Top Condition			Penalty
Recent topkill			1
Ragged Percent (of crown missing, dead, and dying to nearest 10 percent)			
4 points for each 10 percent			____
Total Penalty			____
Risk Point Total			
a. Enter Total Award or Penalty (whichever larger)			____
b. Subtract smaller Total			____
c. Risk Point Total			____
Percent Mortality (within 5 years)			
a. Award equals or exceeds Penalty			0 to 20 percent
b. *Penalty exceeds Award*			
Points	Percent	Points	Percent
1 to 4	21 to 30	15 to 17	60 to 70
5 to 8	30 to 40	18 to 21	70 to 80
9 to 11	40 to 50	22 to 25	80 to 90
12 to 14	50 to 60	26+	90+

occupying less than 5 percent of the length of the live crown (that is, tip dieback).

Bark Fissures—Record as live or dead depending upon whether or not light-colored living bark is visible in most of the fissures in the dead bark when the trunk is viewed at breast height from at least 4 feet away. Ignore callous or scar tissue associated with healed cracks of injury.

Examples

Using the Point Systems, some examples of the use of the Award-Penalty Point Systems to predict risk are illustrated in *appendix figures 1 and 2.*

The red fir in *appendix figure 1A* is dominant, for which it is awarded 6 points under Crown Class *(app. table 1.)* About 60 percent of its height is in live crown, thus the Live Crown Percent award is 6 × 5, or 30 points. The Total Award is then 36 points. The top is living and so is not penalized. However, the lower crown has scattered branch dieback, amounting to about 60 percent of the entire crown, and so is penalized 6 × 4, or 24 points, which is the Total Penalty for this tree. Reference to the bottom of the table indicates that, because Award exceeds Penalty, from 0 to 20 percent of such trees are expected to die within 5 years.

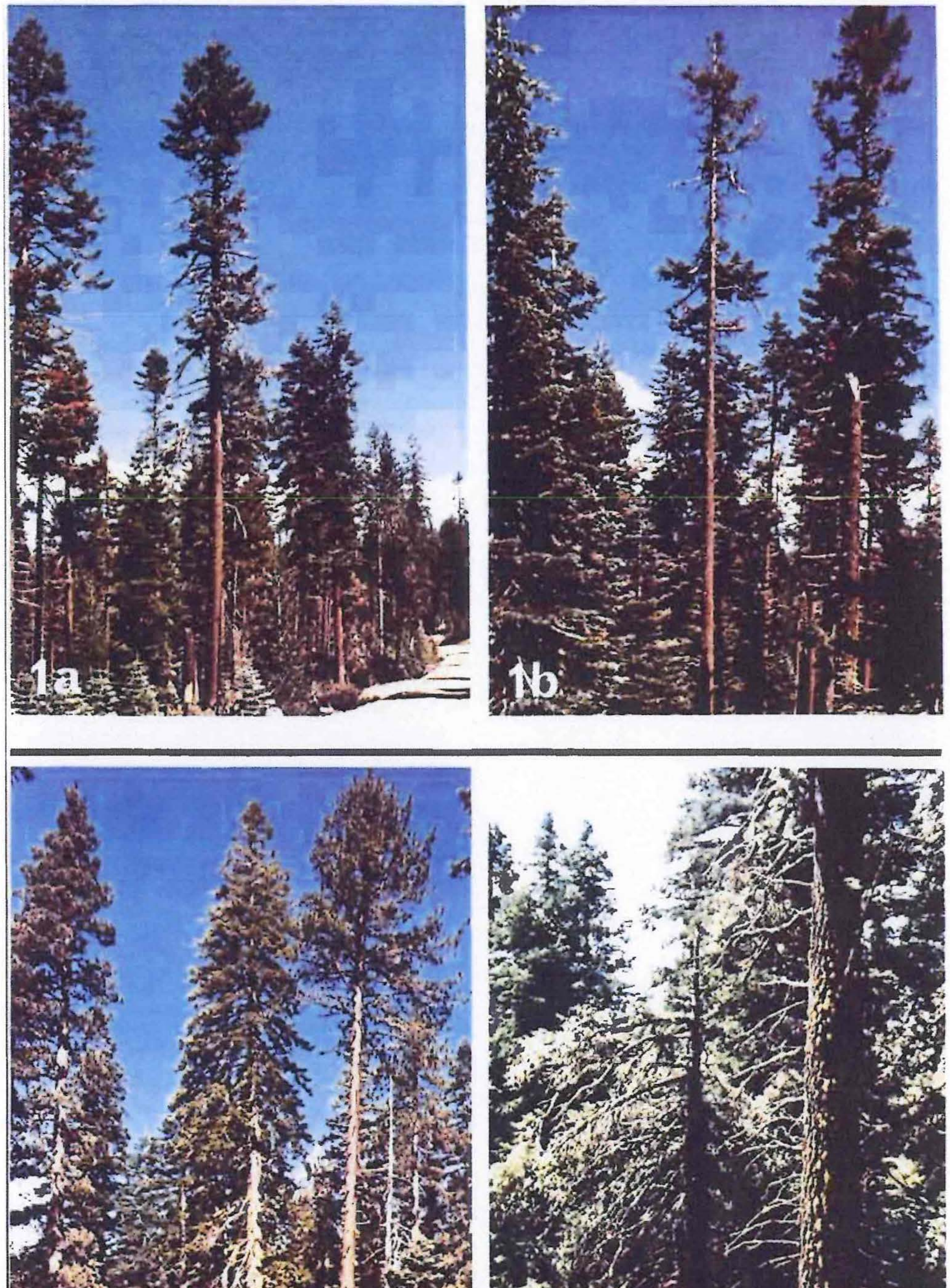
In contrast, the red fir (center) in *appendix figure 1B* is dominant (6 points) and has a Live Crown Percent of 50 (25 points), summing to a Total Award of 31 points. The top is live, and so is not penalized. The crown is ragged,

Appendix Figure 1 (top right)—Risk-rating mature red firs using the Award-Penalty Point System. Both firs (central trees in A and B) were dominant and had similar live crown percentages and so were given similar Award-Point Totals. Because of greater crown raggedness, however, tree in B had both a higher Penalty-Point Total and a higher risk of death within 5 years (30 percent), than tree in A (6 percent).

	Rating	
Predictor	A	B
Crown Class	Dominant	Dominant
Live Crown Percent	60	50
Top Condition	Live	Live
Ragged Percent	60	90

Appendix Figure 2 (bottom right)—Risk-rating mature white firs using the Award-Penalty Point System. Dominant white fir in A (center) had a higher Point-Award because of horizontal to upturned branches in the upper crown, and a lower Penalty-Point total because of less crown raggedness, than the suppressed fir in B with a completely sagging, ragged crown. The 5-year risk of death for tree in A is nearly zero, compared with the 5-year risk of death for tree in B, which is 43 percent.

	Rating	
Predictor	A	B
Branch Angle Percent	20	0
Crown Density	Ragged (dead branches)	Ragged (one-sided and dead, dying branches)
Ragged Percent	20	90
Bark Fissures	Dead	Dead


1a
1b
a
2b

Appendix Table 2—*Award-Penalty Risk System for mature white fir*

Branch Angle Percent	Award
(to nearest 10 percent of crown length)	
3 points for each 10 percent	____
Total Award	____
Crown Density	Penalty
Dense	0
Ragged, due to:	
a. One-sidedness	1
b. Dead and dying branches	2
c. Combination a and b	2
Thin	3
Ragged Percent (of crown missing, dead and dying to nearest 10 percent)	
5 points for each 10 percent	____
Bark Fissures	
a. Living inner bark visible	0
b. No living inner bark visible	28
Total Penalty	____
Risk Point Total	
a. Enter Total Award or Penalty (whichever larger) . . .	____
b. Subtract smaller Total	____
c. Risk Point Total	____
Percent Mortality (within 5 years)	
a. Award equals or exceeds Penalty	0 to .03 percent
b. Penalty exceeds Award	

Points	*Percent*	*Points*	*Percent*
1 to 50	.03 to 5	71 to 74	30 to 40
51 to 57	5 to 10	75 to 77	40 to 50
58 to 65	10 to 20	78 to 80	50 to 60
66 to 70	20 to 30	80+	60+

however; 40 percent is missing on the near side ($R^1 = 40$), and in the remaining 0.6 of the crown about 90 percent of the branches are dead or fading ($R_{df} = 90$). Combining these, RPCT = 40 + (0.6 × 90) = 40 + 54 = 94, which rounded to the nearest 10 percent, is equal to 90 percent. The Total Penalty is 9 × 4 = 36 points, which exceeds Total Award by 5 points. The 5-year risk falls into the interval of 30 to 40 percent. Results of our study suggest that 30 to 40 percent of such trees can be expected to die within 5 years.

The white fir (center) in *appendix figure 2A* has a long crown, especially if the lower limit is set at the lowest clump of living foliage on left. In this instance, only the upper 20 percent of the length of the crown is occupied by horizontal or upturned branches and, consulting *appendix table 2*, the tree is awarded 2 × 3, or 6 points under Branch Angle Percent. Interpreted this way, the crown is ragged because of included dead branches in the lower crown, and so is penalized 2 points under Crown Density. The dead and missing branches comprise about 20 percent of the crown, for which the tree is penalized an additional 2 × 5, or 10 points under Ragged Percent. Living inner bark was not visible in the fissures between the plates of dead, outer bark when the bole was examined at breast height. The tree, therefore, was further penalized 28 points under Bark Fissures. The total Penalty (40) exceeded the Total Award (6), by 34 points. The tabulated 5-year risk is low, somewhere in the interval of 0.03 to 5 percent. Had the scattered living branches in the lower crown been ignored when setting the lower limit of the live crown, the tree would have about 50 percent of the height in living crown. In this instance, horizontal or upturned branches occupy 30 percent of the crown, and the tree is awarded 2 × 3, or 9 points under Branch Angle Percent. Because the lower ragged portion of the crown is now excluded from consideration, the crown is rated as dense under Crown Density, with a Ragged Percent of zero. Bark Fissures are unchanged, rated as dead. Using this interpretation, the Total Penalty (28) exceeds the Total Award (9) by 19 points. The resulting risk estimate varies little, however, from that obtained by means of the first crown interpretation.

The suppressed white fir in *appendix figure 2B* can also be risk-rated by the system, if desired. None of the branches are horizontal or upturned, therefore, Branch Angle Percent is zero and the Total Award is also zero points. Under Crown Density, the crown is ragged because of a combination of one-sidedness, and dead and dying branches (2-point penalty). The combined Ragged Percent is estimated at 90 percent (50 + 0.5 × 80) and for this the tree is penalized another 45 (9 × 5) points. The Bark Fissures are dead at breast height (28 penalty points), thus the Risk Point Total sums to 75 penalty points. This penalty corresponds to a tabulated risk of 40 to 50 percent. Our study suggests that 40 to 50 percent of such trees are expected to die within 5 years.

Appendix Table 1 —*Award-Penalty Risk System for mature red fir*

Crown Class	Award
Suppressed	0
Intermediate	2
Codominant	4
Dominant	6
Live Crown Percent (to nearest 10 percent of tree height)	
5 points for each 10 percent	____
Total Award	____
Top Condition	**Penalty**
Recent topkill	1
Ragged Percent (of crown missing, dead, and dying to nearest 10 percent)	
4 points for each 10 percent	____
Total Penalty	____

Risk Point Total

a. Enter Total Award or Penalty (whichever larger) ____

b. Subtract smaller Total ____

c. Risk Point Total ____

Percent Mortality (within 5 years)

a. Award equals or exceeds Penalty .... 0 to 20 percent

b. Penalty exceeds Award

Points	Percent	Points	Percent
1 to 4	21 to 30	15 to 17	60 to 70
5 to 8	30 to 40	18 to 21	70 to 80
9 to 11	40 to 50	22 to 25	80 to 90
12 to 14	50 to 60	26+	90+

Ferrell, George T.

1980. **Risk-rating systems for mature red fir and white fir in northern California.** Gen. Tech. Rep. PSW-39, 29 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

On the basis of crown and bole characteristics, risk-rating systems to predict the probability that a tree will die within 5 years were developed for mature red fir and white fir in northern California. The systems apply to firs at least 10 inches (25.4 cm) in diameter-at-breast-height (d.b.h.), growing in mature stands, with the original overstory at least partially intact. From 1975 to 1977, 1012 red firs (851 live, 161 dead) and 2571 white firs (2430 live, 141 dead) were examined in virgin and cutover stands. Tree characteristics were selected and used as predictor variables in regression equations. The risk equations were then translated into Award-Penalty Point Systems for field use. A tree is awarded points on the basis of ratings of some characteristics, and penalized points on the basis of ratings of others. The difference between the Award and Penalty Point Totals—the Risk Point Total—is the value used to predict a tree's death within 5 years. This report describes studies designed to develop, test, and extend the risk-rating systems. Properly used, these systems should contribute to the sound, long-term management of California's true firs.

Retrieval Terms: Abies concolor, Abies magnifica, California, mortality, risk rating, bark boring insects.

Appendix Table 2—*Award-Penalty Risk System for mature white fir*

Branch Angle Percent	Award
(to nearest 10 percent of crown length)	
3 points for each 10 percent	____
Total Award	____
Crown Density	Penalty
Dense	0
Ragged, due to:	
a. One-sidedness	1
b. Dead and dying branches	2
c. Combination a and b	2
Thin	3
Ragged Percent (of crown missing, dead and dying to nearest 10 percent)	
5 points for each 10 percent	____
Bark Fissures	
a. Living inner bark visible	0
b. No living inner bark visible	28
Total Penalty	____
Risk Point Total	
a. Enter Total Award or Penalty (whichever larger)	____
b. Subtract smaller Total	____
c. Risk Point Total	____
Percent Mortality (within 5 years)	
a. Award equals or exceeds Penalty	0 to .03 percent
b. Penalty exceeds Award	

Points	*Percent*	*Points*	*Percent*
1 to 50	.03 to 5	71 to 74	30 to 40
51 to 57	5 to 10	75 to 77	40 to 50
58 to 65	10 to 20	78 to 80	50 to 60
66 to 70	20 to 30	80+	60+