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Ten-Year Risk-Rating Systems for California Red Fir and White Fir: development and use

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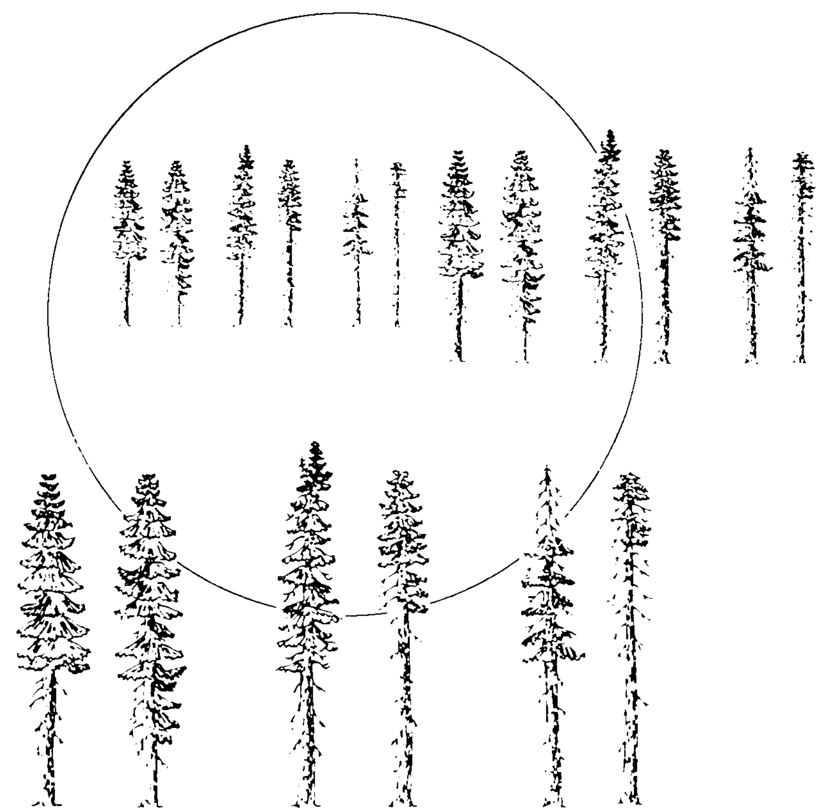

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Logistic regression equations predicting the probability that a tree will die from natural causes—insects, diseases, intertree competition—within 10 years have been developed for California red fir (*Abies magnifica*) and white fir (*A. concolor*). The equations, like those with a 5-year prediction period already developed for these species, are based on analysis of crown and bole characteristics of trees, and are readily programmed into pocket calculators for field use. For user convenience, the equations are formulated into Award-Penalty Point Systems, in which a tree is awarded or penalized points on the basis of ratings of its crown characteristics. The resulting Risk Point Total is related to the percentage of a hypothetical population of identical trees expected to die within 10 years. Three risk classes (low, medium, and high) are defined and depicted for rapid visual estimation of risk in applications where a more precise estimate is not required.

Previous systems for these firs applied only to trees at least 10 inches (25.4 cm) in d.b.h. growing in mature stands. These new systems are applicable to firs down to 4 inches (10 cm) in d.b.h., growing in stands with a wide variety of size and age structure, in northern California. Outside this range, in central and southern California, the systems may be used tentatively, pending testing in these regions.

Retrieval Terms: Abies concolor, Abies magnifica, California, mortality, risk-rating, bark-boring insects, tree diseases

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INTRODUCTION

Risk-rating systems developed previously for California red fir (*Abies magnifica* A. Murr.) and white fir (*A. concolor* [Gord. & Glend.] Lindl.) predict the probability that a tree will die within 5 years (Ferrell 1980). These systems apply to mature trees at least 10 inches (25.4 cm) d.b.h., growing in stands with the original overstory at least partially intact. Potential users, however, may want to predict risk over a somewhat longer time period and to use systems applicable to wider ranges of tree size, age, and stand structure.

This report describes the development and use of risk-rating systems with a 10-year prediction period for California red fir and white fir. Based on ratings of crown characteristics, the systems predict the probability that a tree will die from natural causes—insects, diseases, intertree competition—within 10 years. These risk-rating systems are applicable to trees at least 4 inches (10 cm) d.b.h., growing in natural stands with a wide variety of structure and composition.

DEVELOPING THE RISK-RATING SYSTEMS

Plot Selection

Thirty plots, each 1-acre (0.4 ha), were established from 1975 to 1977 to characterize living firs and monitor their survival in subsequent years. Twenty-two of the plots were in "mature" stands, that is, stands retaining the original mature overstory at least partially intact. These plots were part of the sample base used previously to develop risk-rating systems for mature red fir and white fir. Methods by which they were selected and surveyed are fully described elsewhere (Ferrell 1980), and are only briefly summarized here. Each plot was in a natural forest stand of at least 20 acres (8.1 ha), with forest cover as uniform as possible. Red or white fir, or both, comprised at least 30 percent of the overstory. The plots were located in the Cascade and Siskiyou

Mountains of northern California from the vicinity of Lassen Peak north to the Oregon border.

All living firs at least 10 inches (25.4 cm) in diameter at breast height (d.b.h.) were marked and rated for 22 crown and bole characteristics. The remaining eight plots sampled "released" stands, that is, stands comprised of former understory trees remaining after overstory removal. Methods by which they were selected and surveyed were identical to those of the mature plots, except all living firs at least 4 inches (10 cm) d.b.h. were characterized. All plots were resurveyed in each of the first 5 years and again in the 10th year after plot establishment. Mortality of marked trees, together with their probable cause of death (i.e., insects, diseases, intertree competition, or other), were recorded. Pest complexes, which were the proximal agents of the mortality, were the same as described previously (Ferrell 1980) and will therefore not be described here.

Data Analysis

Methods of data analysis were the same as those used previously in developing risk-rating systems for mature red fir and white fir (Ferrell 1980). Tree characteristics of greatest value as risk predictors were identified using the computer program SCREEN (Hamilton and Wendt 1975). This program screens the tree variables in step-wise fashion, selecting at each step the most significant predictor variable based on user-supplied levels of chi-square probability. In both tree species, more tree variables were significant at the 95 percent level of probability than were usable in a practical risk-rating system. Only those variables selected early in the step-wise process, and convenient for field estimation, were used as predictor variables in the computer program RISK (Hamilton 1974).

RISK estimates the coefficients of a logistic regression which has the form:

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

in which P is the predicted probability of individual tree death, e is the base of natural logarithms, and X is a vector of the risk predictors of the form:

$$B_0 + B_1X_1 + ...B_nX_n$$

where $B_0...B_n$ are regression coefficients. Graphically, the logistics equation is usually a sigmoid curve that is frequently more appropriate for predicting tree death than either discriminant or probit analysis as neither the multivariate normal assumption or continuous predictor variables are required (Monserud 1976).

RISK EQUATIONS

Red Fir

On the basis of screening the characteristics of the sample of 1125 red firs (1045 live, 80 dead) for association with tree death, three were selected as risk predictors:

Live Crown Percent (CPCT)—percentage of tree height in living crown.

Crown Density (CDEN)—as one of the following codes:

0—Dense (normal) foliage.

1—Ragged, one-sided. Crown missing on one or more sides because of competition with neighboring trees or other causes.

2—Ragged, dead and flagged. Crown ragged because of dead and/or dying (flagged) branches, either scattered throughout crown or concentrated in killed top.

3—Ragged because of combination of (1) and (2).

4—Thin. Crown uniformly thinner than normal.

Results of the screening analysis indicated this class variable could be used as a regressor as coded above with little loss in predictive power.

Ragged Percent (RPCT)—combined percentage of crown raggedness because of scattered missing, dead or dying branches, and one-sided crown.

From regression analysis of this sample of firs, the relationship for X in the equation $P = 1 / (1 + e^{X})$, predicting the probability of death within 10 years was:

$$X = 0.749 + 0.058 \text{ CPCT} - 0.286 \text{ CDEN} - 0.022 \text{ RPCT}.$$

A chi-square goodness-of-fit test (*table 1*) indicated that the probability distributions of predicted and observed mortality did not differ significantly ($0.990 < p < 0.995$), and from a practical standpoint the equation adequately predicted the observed distribution of mortality in the sample.

White Fir

On the basis of screening the characteristics of the sample of 2239 white firs (2149 live, 90 dead) for association with tree death, CPCT, CDEN, and RPCT were selected as risk predictors for this species also.

The relationship for X in the regression equation predicting the 10-year probability of death was:

$$X = 1.948 + 0.043 \text{ CPCT} - 0.482 \text{ CDEN} - 0.026 \text{ RPCT}.$$

A chi-square goodness-of-fit test (*table 1*) indicated that the probability

Table 1—*Distribution of fir samples in intervals of predicted probability of death within 10 years, and goodness-of-fit of observed to predicted mortality, compared by chi-square for the range of prediction*

Probability interval	Trees in interval			Chi-square
	Total[1]	Dead		
		Observed	Predicted	
		Red fir (N = 1125)		
0.00 to 0.01	125	0	0.80	0.81
.01 to .05	578	15	15.01	.00
.05 to .10	194	17	13.89	.75
.10 to .15	85	12	10.50	.24
.15 to .20	51	5	8.85	2.03
.20 to .25	23	5	5.08	00
.25 to .30	22	4	6.03	94
.30 to .35	11	5	3.64	.76
.35 to .40	11	4	4.11	.00
.40 to .45	10	5	4.23	.24
.45 to .50	6	3	2.85	.01
.50 to .55	3	0	1.57	3.29
.55 to .60	4	3	2.27	.55
.60 to .65	1	1	.62	.62
.65 to .70	1	1	.67	.49
			[2]Total chi-square = 10.74 (25 df)	
		White fir (N = 2239)		
0.00 to 0.01	508	4	3.25	0.18
.01 to .05	1159	21	28.12	1.85
.05 to .10	358	31	25.27	1.40
.10 to .15	119	18	14.27	1.11
.15 to .20	46	6	7.90	.55
.20 to .25	22	5	4.83	.01
.25 to .30	9	3	2.39	.22
.30 to .35	6	1	1.89	.61
.35 to .40	2	0	.78	1.28
.40 to .45	6	3	2.55	.14
.45 to .50	2	0	.91	1.66
.50 to .55	1	0	.51	1.05
.55 to .60	1	1	.55	.80
			[2]Total chi-square = 10.85 (21 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.

Table 2—*Award-Penalty Risk System for Red Fir*

AWARD

Live Crown Percent (to nearest 10 pct of tree height) ...... ________

Total Award (6 points for each 10 pct) .... ________

PENALTY

Crown Density

Dense (0 points) .... ________

Ragged, due to:

a. One-sidedness (3 points) .... ________

b. Dead, dying branches or top (6 points) .... ________

c. Combination of a and b (9 points) .... ________

Thin (12 points) .... ________

Ragged Percent (of crown missing,

dead and dying to nearest 10 pct) .... ________

Penalty (2 points for each 10 pct) .... ________

Total Penalty .... ________

RISK

Total Award or **Total Penalty** (whichever is larger) .... ________

Subtract smaller total .... ________

Risk Point Total .... ________

PERCENT MORTALITY (within 10 years)

Total Award exceeds Total Penalty		Total Penalty exceeds Total Award	
Risk Point Total	Percent mortality	**Risk Point Total**	Percent mortality
51- 60	0.1 - 0.3	1 - 5	34-44
41- 50	0.3 - 0.8	6 - 10	46-56
31- 40	0.9 - 2.0	1 - 15	59-68
21- 30	2.0 - 5.0	16 - 20	70-78
11- 20	6.0 - 14	21 - 25	79-85
0 -10	15 - 32	26+	86+

Table 3—*Award-Penalty Risk System for White Fir*

AWARD	
Live Crown Percent (to nearest 10 pct of tree height)	________
Total Award (4 points for each 10 pct)	________
PENALTY	
Crown Density	
Dense (0 points)	________
Ragged, due to:	
a. One-sidedness (5 points)	________
b. Dead, dying branches or top (10 points)	________
c. Combination of a and b (15 points)	________
Thin (20 points)	________
Ragged Percent (of crown missing,	
dead and dying to nearest 10 pct)	________
Penalty (3 points for each 10 pct)	________
Total Penalty	________
RISK	
Total Award or **Total Penalty** (whichever is larger)	________
Subtract smaller total	________
Risk Point Total	________

PERCENT MORTALITY (within 10 years)

Total Award exceeds Total Penalty		Total Penalty exceeds Total Award	
Risk Point Total	Percent mortality	**Risk Point Total**	Percent mortality
31-40	0.3 - 0.6	1-7	14-22
25-30	0.7 - 1.0	8-14	24-37
19-24	1.0 - 2.0	15-21	39-54
13-18	2.0 - 4.0	22-28	56-70
7-12	4.0 - 7.0	29-35	72-83
0-6	7.0 - 12	36+	84+

distributions of predicted and observed mortality did not differ significantly ($.950 < p < .975$), and from a practical standpoint the equation adequately predicted the observed distribution of mortality in the sample.

AWARD-PENALTY POINT SYSTEMS

The risk equations were translated directly into point systems, thereby enabling the calculation of risk by simple arithmetic. In the point systems, the tree is awarded points on the basis of the estimate of live crown percent (CPCT), and penalized points based on estimates of crown density (CDEN) and ragged percent (RPCT). The difference between award and penalty point totals—the risk point total—is expressed as the percentage of a hypothetical population of identical trees expected to die within 10 years (*tables 2, 3*).

VISUAL RISK CLASSES

Low, medium, and high risk classes were defined, enabling rapid visual estimation of relative risk in applications where a more precise estimate is not required. The risk classes are broad, allowing a single classification to be used for both tree species. The risk classes were based on mortality ratios, defined as the percentage of mortality in a class divided by the percentage of the class in the original stand (Dunning 1928, Keen 1936). For the fir risk classes, mortality ratios were calculated from the distribution of the fir samples in intervals of predicted probability of death within 10 years (*table 1*). The mortality ratio of each interval was calculated as its percentage of predicted mortality divided by its percentage in the fir sample, and the intervals were combined into the following classes:

Low risk:

Mortality ratio (MR) < 0.4

Probability of death within 10 years (P_{10}) < 0.05

Approximate percentage of the fir sample (pct. sample) = 60 percent

Medium risk:

$0.4 < MR < 2.0$

$0.05 < P_{10} < 0.15$

Pct. sample = 22 percent

High risk:

$MR > 2.0$

$P_{10} > 0.15$

Pct. sample = 18 percent

Representative trees in each of the risk classes are illustrated (*fig. 1*), enabling rapid classification without recourse to numerical estimation procedures. Trees with Live Crown Percentages of 80, 60, 40, and 20, and Ragged Percentages of 0, 20, 40, 60, and 80 are depicted, but trees with other estimates of these variables may be classified by interpolation or extrapolation.

USING THE RISK-RATING SYSTEMS

Applicability

These risk-rating systems predict the probability of individual tree death within 10 years as a result of natural causes—insects, diseases, or intertree competition (fire, windthrow, or other are not included). The systems apply to firs at least 4 inches (10 cm) d.b.h., growing in natural stands with a wide variety of age, size, and species composition. Geographically, the systems are applicable to the southern Cascade Mountains from Lassen Peak north to Mt. Shasta and to the eastern Siskiyou Mountains near the Oregon border. Based on similarity in weather patterns, pests complexes, and tree growing sites, 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 northwestern California, and in the Sierra Nevada north of Lake Tahoe. Outside this region, they should be used only tentatively, pending studies to test them in other regions.

Estimating Crown Condition

Estimation procedures are identical for red fir and white fir, and are the same as used in the risk-rating and growth classification systems developed previously for these species (Ferrell 1980, 1983).

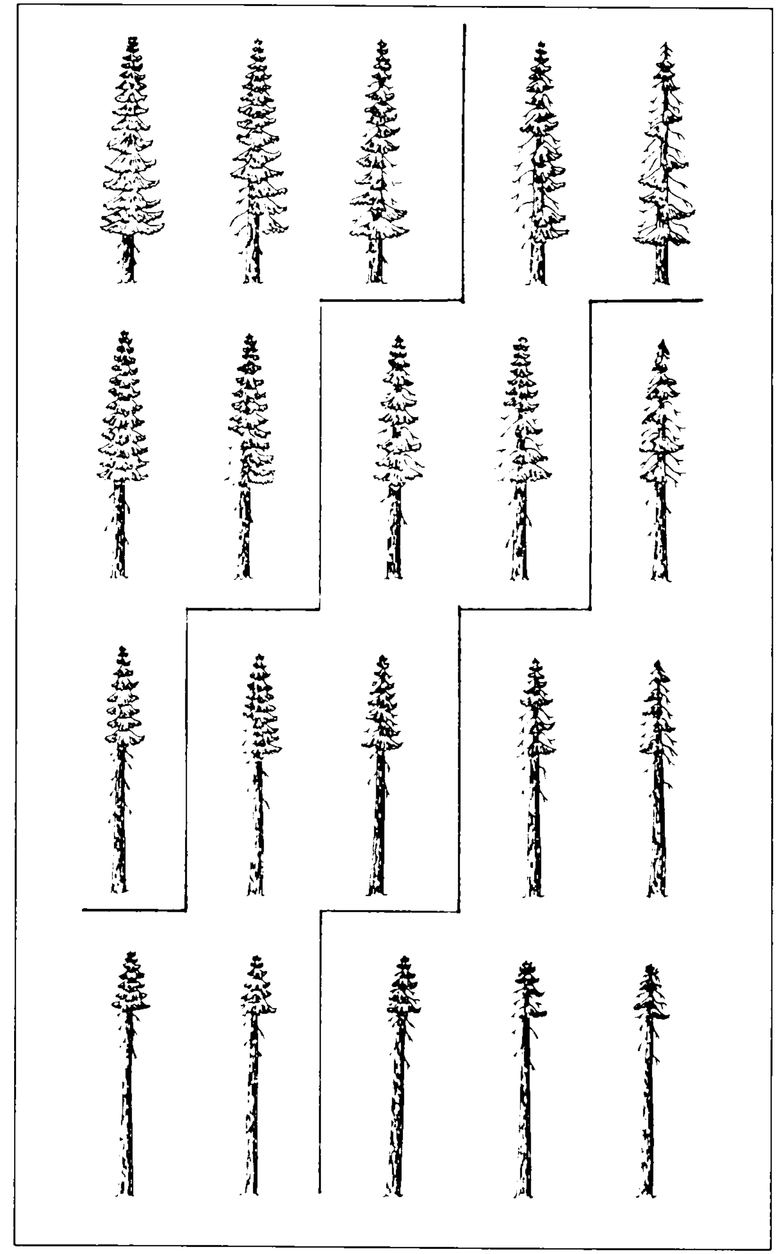

Figure 1—Risk classes for rapid visual prediction of 10-year mortality in California red fir and white fir: (left to right) low, medium, and high risk.

Live Crown Percent

Live crown percent (CPCT) is the 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 the top is missing (broken off), the live crown extends downward from the point of breakage.

To set the lower limit of live crown:

- Exclude isolated lower branches
- For one-sided crowns, use longer side
- If branches droop, use horizontal projection of branch tips onto bole.

Crown Density

Crown density (CDEN) categorizes the crown as to shape, and foliage condition and density.

Dense—foliage with needles normal in length, number, and color. Dead, dying, off-color, or thin foliage, 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 dying branches, either scattered throughout crown, or concentrated in top (topkill, spiketop) or other section of crown (ignore missing, broken tops)
- Combination of one-sidedness and scattered dead or dying branches

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

Ragged Percent

Ragged percent (**RPCT**) is the combined percentage of crown missing and 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).

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. For example, including isolated lower branches in the live crown, while leading to higher estimates of Live Crown Percent, will be compensated for by resultant increases in estimates of Ragged Percent. Trials indicate that the same, or closely similar estimates of risk will be obtained regardless of such differences in the height at which the observer sets the lower limit of the live crown.

Estimating Risk of Mortality

For field use, the risk equations are readily programmed into pocket calculators. Those which retain the program after being switched off (constant memory) are preferable, to conserve battery power. Equations for the two species differ only in their coefficients; thus a single program can be devised which will estimate risk for both. Also, as the risk equations use virtually the same predictors as the growth classification equations previously developed for these firs (Ferrell 1983), reasonably concise calculator programs can be designed to predict both risk and growth classes of either species. Pocket calculators have the advantage of providing precise estimates without the use of mental arithmetic. For applications where a less precise estimate of risk is satisfactory, either the award-penalty point systems or the visual risk classification can be used.

ADVANTAGES OF 10-YEAR SYSTEMS

These risk-rating systems have several advantages over those previously developed for California red fir and white fir (Ferrell 1980). There are fewer predictor variables requiring estimation, decreasing the time needed to rate trees. Also, the 10-year prediction period is more in concert with preferred intervals between stand entries for management purposes. Finally, to develop the 10-year systems, trees were surveyed over a longer time. The previous systems were based on a single year's survey, followed by estimation of 1-year probabilities of death, which were mathematically extrapolated to 5 years under the assumption that they remained constant from year to year. This assumption may not always be realistic, however, as fir mortality rates can vary in response to environmental variables such as weather (Ferrell and Hall 1975). And, in fact, trials suggest that for some trees, the 5-year probabilities predicted by the previous systems may be too high as they exceed the 10-year probabilities predicted by the new systems. Estimates of risk obtained with the new systems are therefore probably more reliable, as they involve no such assumption or extrapolation.

These risk systems are expected to be useful in marking trees for partial cuts intended to reduce mortality and maintain adequate stocking in residual stands. Predictions for trees, if integrated with appropriate growth data and summarized on a stand-wide basis, could also prove to be of value in stand yield prognoses.

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