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# **Growth Classification Systems for Red Fir and White Fir in Northern California**

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## IN BRIEF ...

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Ferrell, George T. **Growth classification systems for red fir and white fir in northern California.** Gen. Tech. Rep. PSW-72. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1983. 18 p.

*Retrieval Terms:* *Abies concolor*, *Abies magnifica*, California red fir, Shasta red fir, white fir, basal area increment

Growth classification systems were developed for red fir and white fir in northern California. Discriminant equations with selected crown and bole characteristics were used to predict the tree's growth class. The growth classes are defined on the basis of percent annual basal area increment (PCTBAI) of the tree as: Class 1 ( $\text{PCTBAI} \leq 1$  pct), Class 2 ( $1 \text{ pct} < \text{PCTBAI} \leq 3$  pct), and Class 3 ( $\text{PCTBAI} > 3$  pct). The predictor variables are crown class, live crown percent, ragged percent (percentage of crown dead or missing), and stem diameter-at-breast-height (d.b.h.). Additional predictors for red fir are branch angle percent (percentage of crown with branches oriented horizontally or upswept) and cortex percent (percentage of stem length covered by smooth juvenile bark or cortex). An additional predictor for white fir is bark fissures (whether living inner bark is visible in bark crevices at breast height).

To develop the systems, a total of 1125 red firs and 2239 white firs at least 4 inches (10 cm) in d.b.h. were characterized on 36 1-acre (0.4-ha) plots in northern California. The plots were distributed from Lassen Peak, north to the Oregon border and sampled most stand types and site qualities within this range. Additional stand types and sites were sampled, both within this range and in the central Sierra Nevada, to test the systems. A check of the predicted growth class against actual PCTBAI for trees in both the original plots and the test stands indicated that the systems correctly classify about 75 percent of all trees.

The systems are considered applicable to all red fir and white fir 4 inches (10 cm) d.b.h. and larger in northern and central California. Because the systems could not be tested under all growing conditions occurring throughout the geographic ranges of these firs, directions are given for checking predictions by calculating the tree's PCTBAI on the basis of its d.b.h. and radial growth.

General descriptions of the growth classes are provided, but are expected to be of less predictive value than the equations because the equations integrate the separate variables.

The growth classification equations and the equation for calculating actual PCTBAI can be programmed into pocket calculators for field use. Thus implemented, the classification equations are faster and less laborious than increment borings, particularly when numerous trees must be evaluated. Also, equations predicting the risk of death of these firs (Ferrell 1980) use virtually the same variables as the growth equations. Combined programs, therefore, can be designed so that both risk and growth can be predicted in a single operation. This may be necessary for some stand analyses because estimates of both tree growth and survival are needed, yet are not always strongly correlated.

If PCTBAI, as measured and predicted, indicates the future growth capacity of trees, the systems should be of value in marking stands for partial cuttings intended to maintain acceptable growth in the residual stand. Predictions for trees, if integrated with height growth data and summarized on a stand-wide basis, could also be useful in predicting stand growth and yield.

California red fir (*Abies magnifica* A. Murr.) and white fir (*A. concolor* [Gord. & Glend.] Lindl. ex Hildebr.) occupy broad, partially overlapping geographic ranges in California (Griffin and Critchfield 1972). Within these ranges, site conditions and logging histories vary widely. As a result, stands holding these firs often show great irregularity in structure, composition, and stocking. In such stands, individual tree vigor classifications, such as those developed by Dunning (1928) for ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) have proven useful, but do not predict tree growth precisely enough for most growth analyses. To be useful for this purpose, tree classification should predict tree growth on the basis of easily observed phenotypic traits, and predictions should be readily verifiable in the field. Also, to justify the uncertainty inherent in prediction, the growth classification system should be faster and less laborious to apply than it would be if growth were measured directly.

This report describes growth classification systems developed for 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.

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## PROCEDURES

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### ***Stand and Tree Selection***

Red firs and white firs were evaluated on 36 1-acre (0.4-ha) plots at locations ranging from Lassen Peak in the Cascade Range north to the Klamath Mountains in northern California. Red fir normally occurs as Shasta red fir (var. *shastensis* Lemm.) in this area (Griffin and Critchfield 1972). The plots were originally established to develop risk-rating systems for these firs. Stands and sites sampled by the plots and the criteria by which they were selected have been fully described elsewhere (Ferrell 1980); only a brief synopsis is provided in this report. Sampled stands had red fir, white fir, or both, comprising at least 30 percent of the overstory. The stands were either virgin or had not been logged within the preceding 10 years. Twenty-eight of the stands were classified as mature, meaning that the original sawtimber overstory remained at least partially intact. The remaining eight stands were released; that is, they held primarily young, former understory

trees released by overstory removal. Site quality ranged from Dunning Site Class IA to III (Dunning 1942, MacLean and Bolsinger 1973). The sampled stands were considered to be a representative cross-section of most stands holding red fir, white fir, or both in the region except for even-aged pole stands, which were not sampled in developing the systems.

All living firs at least 10 inches (25 cm) diameter-at-breast-height (d.b.h.) were evaluated on the mature plots, while on the released plots the minimum d.b.h. was 4 inches (10 cm).

To test the classification systems, 14 additional stands were sampled, including 9 stands in the region originally sampled and 5 stands in the northern and central Sierra Nevada, at locations scattered as far south as the Stanislaus River drainage. Firs were evaluated as in the original 36 stands, except (a) trees were selected arbitrarily on meander lines and numbered from 8 to 79 per stand; and (b) the sample included a stand type (even-aged pole stand) and a site class (Dunning Class IV) not included in the original 36 stands.

Table 1—*Phenotypic traits evaluated as growth predictors for true firs*

Trait	Definition <sup>1</sup>
D.b.h.	Bole diameter-at-breast-height (inches)
Live crown percent	Percent of tree height in live crown
Cortex percent	Percent of bole height in cortex
Bark fissures	(1) open, or (2) closed, according to whether live inner bark is visible in fissures at breast height
Crown width	Maximum width of crown (ft)
Branch angle percent	Percent of crown length with upswept to horizontal branches
Ragged percent	Percent of crown missing, dead, or dying
Top condition	Shape and condition as (0) pointed, (1) round, (2) flat, (3) broken—regrowth, (4) spike—regrowth, (5) broken—no regrowth, (6) spike—no regrowth, (7) recent topkill
Crown class	(0) suppressed, (1) intermediate, (2) codominant, (3) dominant
Tree height	Total height of tree (ft)
Tree age	(1) young or (2) mature as less than, or greater than, 80 to 100 years old
Bark color	(1) light gray, (2) gray, (3) dark gray, (4) gray-brown, (5) brown, (6) red-brown
Cortex color	(1) white, (2) light gray, (3) gray, (4) dark gray

<sup>1</sup>Units of measurement and codes as indicated. All percentages estimated to nearest 10 percent.

## Tree Evaluation

Fourteen different traits were evaluated for each tree (Ferrell 1980) including crown and bole characteristics to indicate tree size, age, competitive status, and growth condition (*table 1*). The number of annual rings in the outer inch of sapwood was obtained from an increment core taken on a random radius at breast height. For slow-growing trees (>20 rings/inch or 8 rings/cm), the ring count in the outer 1/2 inch (*ca.* 1 cm) was doubled to emphasize the more recent growth.

Tree growth, for purposes of developing the classification systems, was defined as percent annual basal area increment (PCTBAI). Using the tree's d.b.h., and the number of rings per inch (RPI) as defined earlier, PCTBAI was calculated for each tree by the expression

$$\text{PCTBAI} = 100 - (100(\text{d.b.h.} - 2/\text{RPI})^2 / \text{d.b.h.}^2)$$

Reasons why PCTBAI was used included these: basal area increment (BAI) is closely correlated with volume increment during much of the life of the tree (Baker 1950) and does not require height growth measurement, which is difficult for tall, standing trees. To place the growth of different-sized trees on a common basis, BAI was expressed as a percentage of the current basal area of the tree. Another advantage of PCTBAI is that it is independent of the units in which d.b.h. and radial growth are measured.

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## GROWTH CLASSIFICATION EQUATIONS

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### Development

Tree characteristics of greatest value in predicting growth were identified by multiple linear regression (computer program BMDP P9R, Frane 1981). All possible regressions were calculated with the tree characteristics as predictor variables and PCTBAI as the dependent variable. Best subsets of predictor variables were identified for each species by Mallows' Cp Statistic (Hocking 1976). Equations containing six or fewer predictor variables were selected as practical for field use. On the basis of an analysis of 1125 red firs and 2239 white firs, crown class, live crown percent, ragged percent, and d.b.h. were selected as predictors of PCTBAI. Additional predictors for red fir were branch angle percent and cortex percent. An additional predictor for white fir was bark fissures. For either species, the selected equations statistically explained about 50 percent of the variation in PCTBAI.

To improve accuracy, trees were grouped into growth classes on the basis of PCTBAI, and linear discriminant functions (Sokal and Rohlf 1969) were used to predict a tree's growth class. Examination of PCTBAI frequency



Table 2—Percent annual basal area increment (PCTBAI) by tree age and crown class for true firs in the 36 original stands<sup>1</sup>

Species and tree age <sup>2</sup>	Crown class <sup>2</sup>			
	Suppressed	Intermediate	Codominant	Dominant
	Mean (range) <sup>3</sup>			
Red fir				
Young	1.5(0.9 to 1.8)	1.9(0.9 to 2.5)	2.2(1.1 to 2.9)	3.9(2.2 to 5.0)
Mature	.9(.6 to 1.1)	1.1(.6 to 1.5)	1.3(.6 to 1.7)	1.0(.2 to 1.2)
White fir				
Young	2.6(1.0 to 4.2)	2.4(1.0 to 3.4)	3.2(1.7 to 4.2)	4.1(1.9 to 6.4)
Mature	.9(.3 to 1.4)	1.2(.5 to 1.5)	1.4(.5 to 1.7)	1.0(.3 to 1.3)

<sup>1</sup>Stands used to develop the equations.

<sup>2</sup>See *table 1* for definitions.

<sup>3</sup>Ranges include 60 percent of trees.

distributions for trees grouped by age and crown class failed to reveal any natural grouping for either tree species (*table 2*). Consequently, growth classes for each fir were based on intervals of PCTBAI designed to be of general use in growth analyses. The three growth classes were 1 ( $\leq 1$  pct), 2 ( $> 1$  pct and,  $\leq 3$  pct), and 3 ( $> 3$  pct). Analysis of variance indicated that variation among classes was significant for every tree characteristic studied, with values of F ranging from 5.06 to 228.57 (df = 2, 1122) for red fir and from 41.45 to 473.66 (df = 2, 2236) for white fir (*table 3*). Predictor variables identified in the regression models were included in the discriminant equations (computer program BMDP P7M, Jennrich and Sampson 1981). The equations are of the form

$$Y = \beta_0 + \beta_1 x_1 \dots \beta_n x_n,$$

in which Y is the classification score,  $\beta_0$  is a constant, and  $\beta_n$  is the coefficient of the nth predictor variable. Three equations (one for each Class) were obtained for each species of fir (*table 4*).

## Validation

The accuracy of the classification equations was tested against trees evaluated in all 50 stands (*table 5*). For either species, the equations correctly classified about 75 percent of both Class 1 and Class 3 firs in the 36 original stands. Only about 50 percent of Class 2 firs were correctly classified because many had PCTBAIs near the Class limits.

Improved results were obtained, however, when the classification equations were tested against trees in 14 stands other than those used to develop the system. About 76 percent of the Class 1 trees were classified correctly, as were 71 percent of the Class 2, and 85 percent of the Class 3 trees. Because stands and trees were not selected at random, as required to

Table 3—Mean growth class values (standard deviations) for true fir traits

Species and trait <sup>1</sup>	Growth class		
	1	2	3
<b>Red fir</b>			
Bark fissures	1.9( .02)	1.8( .04)	1.7( .05)
Top condition	1.2( .14)	.8( .13)	.3( .7)
Crown class	1.5( .10)	1.3( .9)	1.5( .9)
Age class	.6( .5)	.4( .5)	.2( .4)
Live crown percent	54 ( 16 )	60 ( 16 )	73 ( 12 )
Cortex percent	29 ( 19 )	52 ( 21 )	67 ( 18 )
Height (ft)	90 ( 47 )	61 ( 33 )	49 ( 26 )
Crown width (ft)	19 ( 11 )	12 ( 7 )	10 ( 4 )
D.b.h. (inches) <sup>2</sup>	21 ( 13 )	12 ( 7 )	10 ( 4 )
Rings per inch	47 ( 29 )	28 ( 18 )	13 ( 7 )
Bark color	3.1( .10)	2.6( .11)	2.2( .7)
Cortex color	1.6( .8)	1.4( .7)	1.3( .5)
Branch angle			
percent	24 ( 20 )	34 ( 23 )	42 ( 21 )
Ragged percent	30 ( 26 )	24 ( 22 )	14 ( 17 )
PCTBAI <sup>3</sup>	.6( .2)	1.7( .5)	4.2( 1.2)
<b>White fir</b>			
Bark fissures	1.9( .3)	1.5( .5)	1.2( .4)
Top condition	1.1( 1.5)	.5( .5)	.3( .4)
Crown class	1.7( .9)	.3( .5)	.1( .3)
Age class	.7( .4)	.3( .5)	.1( .3)
Live crown percent	62 ( 16 )	64 ( 15 )	72 ( 15 )
Cortex percent	26 ( 17 )	46 ( 31 )	62 ( 31 )
Height (ft)	97 ( 38 )	68 ( 29 )	43 ( 21 )
Crown width (ft)	22 ( 12 )	16 ( 18 )	10 ( 5 )
D.b.h. (inches)	24 ( 11 )	14 ( 6 )	8 ( 4 )
Rings per inch	43 ( 33 )	21 ( 13 )	13 ( 6 )
Bark color	2.4( .7)	2.1( .5)	1.8( .6)
Cortex color	1.6( .8)	1.4( .6)	1.2( .4)
Branch angle			
percent	26 ( 39 )	39 ( 27 )	48 ( 25 )
Ragged percent	25 ( 23 )	19 ( 21 )	12 ( 17 )
PCTBAI <sup>2</sup>	.6( .2)	1.8( .6)	4.6( 2.4)

<sup>1</sup>See *table 1* for definitions.

<sup>2</sup>Percent annual basal area increment.

fully validate the systems, the user should sample at random when verifying the growth classification.

## Application

In practice, the tree is rated by the appropriate species equations and allocated to the growth class with the highest classification score (Y). Pocket calculators can be programmed to simultaneously evaluate the equations and



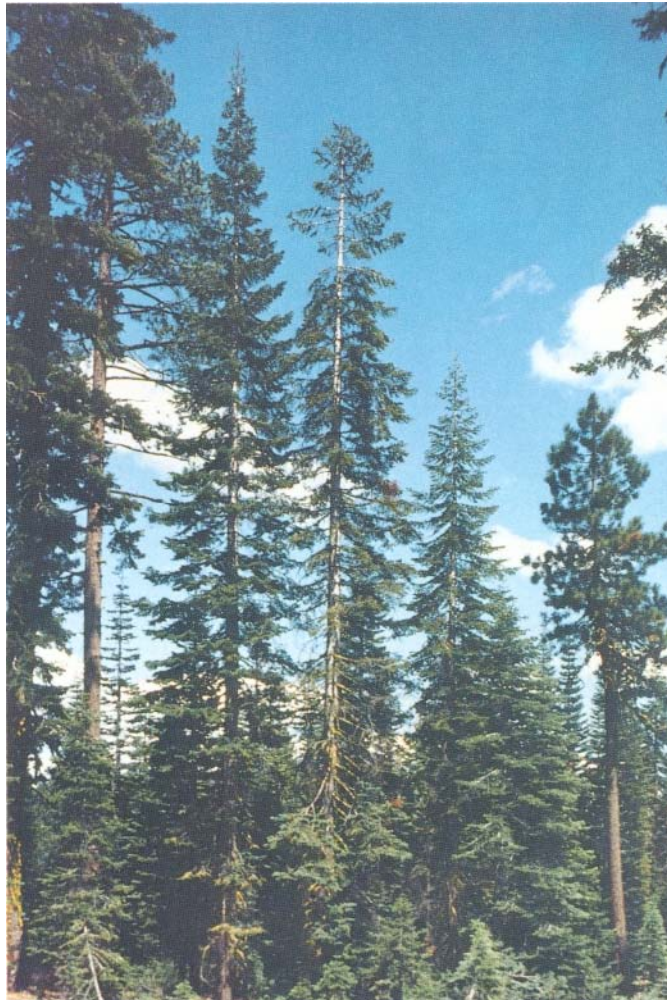
**Figure 1**—Effect of crown raggedness on predicted growth class of red fir. Because of extensive branch death in lower crown (ragged percent = 60), predicted growth for long-crowned red fir at center is Class 2 ( $1 \text{ pct} < \text{PCTBAI} \leq \text{pct}$ ). If no branch death were present (ragged percent = 0), predicted growth would be class 3 ( $\text{PCTBAI} > 3 \text{ percent}$ ). Actual PCTBAI is 2.21 percent.

Trait	Crown interpretation	
	With branch death	Without branch death
Crown class	Codominant	Codominant
Live crown percent	80	80
Branch angle percent	30	30
Ragged percent	60	0
Cortex percent	50	50
D.b.h.	18	18
Rings per inch	10	10
Classification scores		
Y <sub>1</sub>	22.66	15.46
Y <sub>2</sub>	23.04	17.04
Y <sub>3</sub>	22.22	17.42



**Figure 2**—Variation in defining the lower limit of the live crown does not affect predicted growth class of mature dominant white fir. Whether or not isolated lower branches on left side of crown are included in the crown, predicted growth is Class 1 (PCTBAI  $\leq 1$  pct) as the resulting variation in estimates of crown predictor variables tend to compensate one another. Actual PCTBAI is 0.98 percent.

Trait	Crown interpretation	
	Branches included	Branches excluded
Crown class	Dominant	Dominant
Live crown percent	80	40
Ragged percent	30	10
Bark fissures	Closed	Closed
D.b.h.	34	34
Rings per inch	12	12
Classification scores		
Y <sub>1</sub>	27.69	17.89
Y <sub>2</sub>	25.48	15.28
Y <sub>3</sub>	22.29	10.89



**Figure 3**—Both red firs at center are dominant, and have the same live crown percent and d.b.h. Because of differences in branch angle percent, ragged percent, and cortex percent, however, tree on the left is predicted to be Class 3 (PCTBAI > 3 pct) and tree on the right is Class 2 (1 pct < PCTBAI ≤ 3 pct). Actual PCTBAI are 3.10 percent (left) and 1.56 percent (right).

Trait	Trees	
	Left	Right
Crown class	Dominant	Dominant
Live crown percent	80	80
Branch angle percent	30	10
Ragged percent	10	40
Cortex percent	50	30
D.b.h.	16	16
Rings per inch	8	16
Classification scores		
Y <sub>1</sub>	13.71	14.31
Y <sub>2</sub>	16.05	14.65
Y <sub>3</sub>	16.87	13.87





**Figure 4**—Growth class prediction for young red fir after release by overstory removal. On the basis of tree's diameter-at-breast-height (d.b.h.) and radial growth before release, PCTBAI was 1.80 percent. After 17 years release, predicted growth is Class 3 (PCTBAI > 3 pct). Actual PCTBAI = 4.18 percent.

Trait	Tree after release
Crown class	Dominant
Live crown percent	100
Branch angle percent	100
Ragged percent	0
Cortex percent	80
D.b.h.	19
Rings per inch	5
Classification scores	
Y <sub>1</sub>	7.34
Y <sub>2</sub>	32.39
Y <sub>3</sub>	35.39



**Figure 5**—Young white fir (center) is growing in an uneven-aged stand. In this stand, crown class interpretation may be difficult because of unevenness of the canopy. Whether rated intermediate or dominant, however, equations predict crown as Class 3 (PCTBAI > 3 pct). Actual PCTBAI = 3.60 percent.

Trait	Crown interpretation	
	Intermediate	Dominant
Live crown percent	90	90
Ragged percent	0	0
Bark fissures	Open	Open
D.b.h.	11	11
Rings per inch	10	10
Classification scores		
Y <sub>1</sub>	13.05	11.77
Y <sub>2</sub>	16.88	17.00
Y <sub>3</sub>	18.30	19.38

Table 4—Coefficients of predictor variables in the true fir growth classification equations<sup>1</sup>

Species and variable	Growth class		
	1	2	3
Red fir			
Crown class (X <sub>1</sub> )	-0.73	-0.23	0.13
Live crown percent (X <sub>2</sub> )	.17	.19	.23
Branch angle percent (X <sub>3</sub> )	.06	.08	.09
Ragged percent (X <sub>4</sub> )	.12	.10	.08
Cortex percent (X <sub>5</sub> )	.15	.19	.22
D.b.h. (X <sub>6</sub> ) <sup>2</sup>	.51	.38	.34
Constant (β <sub>0</sub> )	-15.16	-16.44	-21.06
White fir			
Crown class (X <sub>1</sub> )	-.64	.06	.54
Live crown percent (X <sub>2</sub> )	.24	.26	.30
Ragged percent (X <sub>3</sub> )	.01	-.01	-.03
Bark fissures (X <sub>4</sub> )	9.51	7.70	6.12
D.b.h. (X <sub>5</sub> )	.37	.16	.03
Constant (β <sub>0</sub> )	-21.49	-16.04	-15.69

<sup>1</sup>Equations are of the form  $Y = \beta_0 + \beta_1 X_1 \dots \beta_n X_n$ .

<sup>2</sup>See table 1 for definitions.

classify trees. For use in the equations, the predictor variables are defined in table 1.

Detailed instructions for estimating the predictor variables and examples of classifying trees are given in the User's Guide in the *appendix*. Phenotypic descriptions of the growth classes are also given in the *appendix*. The descriptions are generalized, however, and therefore are expected to be less useful than the equations because of the ability of the equations to integrate the predictor variables.

Table 5—Percentage of true firs accurately classified for growth in 36 original stands and 14 additional stands

Stand and growth class	Trees	
	Evaluated <sup>1</sup>	Accurately classified
Original <sup>2</sup>		<i>Percent</i>
1	1132	73.4
2	1615	51.8
3	617	79.0
Additional <sup>1</sup>		
1	162	75.8
2	149	71.4
3	26	84.6

<sup>1</sup>Red firs and white firs combined.

<sup>2</sup>Stands used to develop equations.

<sup>3</sup>Stands used to test the equations.



Results of testing the equations indicate that the classification systems are sufficiently accurate for most growth analyses. The systems are applicable to red and white firs 4 inches (10 cm) or larger in d.b.h., growing on sites typical of these firs in the Klamath Mountains and Cascade—Sierra Nevada of California. The systems are not applicable, however, to stands seriously disturbed during the previous decade by logging, fire, or other influences. In applying the systems to any given stand, the user needs to check the accuracy of classification. This may be done by increment-boring 10 to 20 randomly selected trees and calculating actual PCTBAI to determine the frequency with which it falls into the interval the PCTBAI predicted by the classification equations. Pocket calculator programs may be written to combine both the classification and PCTBAI equations so that both values can be calculated in a single operation. If the classification equations are found to be insufficiently accurate for a particular application, the user may reduce the probability of misclassification by establishing protection zones for the classification scores (Y) within which no classification is made (Freese 1964).

It frequently is desirable to predict the risk of death and the growth of trees. Risk-rating systems were developed recently for mature red fir and white fir in northern California (Ferrell 1980). With virtually the same predictor variables as the growth classification equations, the risk equations predict the probability that a tree will die within the next 5 years. As defined here, risk and PCTBAI are related, but not identical, indicators of tree status. When both risk and actual PCTBAI were calculated for the samples of red fir and white fir used to develop the growth classifications, virtually the same low, inverse correlations were found ( $r = -0.198$ , 1123 df for red fir, and  $-0.204$ , 2237 df for white fir). These low correlations, although differing significantly from 0 ( $p \leq 0.05$ ), indicated little relationship between growth and survival of trees. Failure to find higher correlations was partly attributable to the definition used for growth. Many mature dominants with healthy crowns, for example, have slight risk of dying within a 5-year period. Yet, because of their large d.b.h., PCTBAI is frequently less than 1 percent annually, and the predicted growth is Class 1. Depending on management objectives for a particular stand, mature dominants may be unfairly penalized if marked only on the basis of the predicted PCTBAI class. In such situations it may be necessary to predict both risk and growth to obtain a more complete indication of tree status. For this purpose, pocket calculator programs can be designed so that both risk and growth class can be calculated in a single operation in the field.

If past growth of trees reflects their future growth capacity, the classification equations should be of value in marking stands for partial cuttings designed to maintain acceptable growth in the residual stand. Integrated with height growth data and summarized on a stand-wide basis, PCTBAI class predictions for trees also could be useful in predicting growth and yield of stands. The growth classification systems, in combination with the risk-

rating systems developed previously (Ferrell 1980), should contribute to the sound management of red fir and white fir in California.

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## APPENDIX-USER'S GUIDE

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### ***Growth Classification Systems***

The growth classification systems ...

- Predict growth class on the basis of percent annual basal area increment (PCTBAI) of individual trees as one of the following:

Class 1 ( $\text{PCTBAI} \leq 1 \text{ pct}$ )

Class 2 ( $1 \text{ pct} < \text{PCTBAI} \leq 3 \text{ pct}$ )

Class 3 ( $\text{PCTBAI} > 3 \text{ pct}$ )

- Apply to white firs and red firs (including var. *shastensis* Lemm.) at least 4 inches (10 cm) d.b.h., growing in all stands except those seriously disturbed within the previous decade by logging, fire, or other influences.

- Apply to all regions tested in California from the central Sierra Nevada north through the southern Cascade Mountains to the Klamath Mountains near the Oregon border. Both inside and outside these regions, it is recommended that the systems be checked for accuracy as described later.

### ***Growth Classification Equations***

Predictor variables are estimated for each tree and entered into the growth equations (one for each class) to calculate the classification scores (Y). The Y values are compared and the trees placed in the class with the greatest score.

Most of the predictors are used in both the red fir and white fir systems, and estimating procedures are identical. Several of the predictors, estimated in the same way, are also used in the risk-rating systems developed for these firs (Ferrell 1980). All percentages are estimated to the nearest 10 percent.

**Crown class**—position of the tree's crown relative to those of adjacent trees, entered into the equations as one of the following codes:

(0) *Suppressed*—completely overtopped by nearby trees, receiving only diffuse light.

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

(2) *Codominant*—about the same height as adjacent trees, sides of crown receiving only limited direct light.

(3) *Dominant*—considerably taller than adjacent trees or isolated from competitors for light.

**Live crown percent**—percentage of the tree's total height occupied by live crown. 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 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).

To set lower limit of live crown

- Exclude single, isolated lower branches.
- For one-sided crowns, use longer side.
- For drooping branches, use projection of branch tips onto bole.
- Exclude epicormic foliage unless judged to contribute significantly to sustenance of tree.

**Branch angle percent**—percentage of the total length of the live crown with upswept to horizontal branches. Branch tips should equal or exceed height at which branches join the bole.

**Ragged percent**—combined percentage of crown missing, dead, or dying. Include missing portions of crown above lower limit of live crown, whether or not they contribute to one-sidedness. In both the red fir and white fir systems, variation in estimates of live crown percent and ragged percent tend to compensate for one another in the growth classification of any individual tree. Isolated, lower living branches in the live crown that lead to higher estimates of live crown percent are compensated for by resultant increase in estimates of ragged percent. Trials indicate that the same growth class will be obtained regardless of 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 red fir system.

In the crowns that are ragged because of both one-sidedness and scattered branch death, it is frequently convenient to estimate the combined ragged percent (RPCT) as follows: (1) estimate the percentage of crown missing because of the one-sidedness (W); and (2) estimate the raggedness because of dead and dying (flagged) branches as a percentage of the crown still present (Rdf).

Multiply Rdf by the proportion of the entire crown that is still present,  $(100-R')/100$ , to obtain the contribution of the scattered branch dieback to the combined estimate of raggedness for the whole crown. Add the two estimates to obtain RPCT. The process is expressed by the formula

$$RPCT = R' + \frac{(100 - R')}{100} R_{df}$$

**Cortex percent**—percentage of tree stem occupied by smooth, whitish, juvenile bark or cortex.

**Bark fissures**—coded (1) open, or (2) closed, depending upon whether orange, living bark (phloem) is visible in fissures at breast height when viewed from at least 4 ft (1 m) away. Ignore callous or scar tissue associated with healed cracks or injury.

**Diameter-at-breast-height (d.b.h.)** —estimated or measured to the nearest inch.

The predicted growth class may be checked by obtaining an increment core at breast height and counting the number of annual rings present in the outer inch of sapwood (RPI or rings per inch). On the basis of RPI and d.b.h., PCTBAI can be calculated by the equation

$$\text{PCTBAI} = 100 - (100 (\text{d.b.h.} - 2 / \text{RPI})^2 / \text{d.b.h.}^2)$$

## ***Examples of Predicting Growth Class***

Crown raggedness (dead, dying, or missing branches) can reduce a tree's PCTBAI. Except for dead branches in the lower crown (ragged percent = 60), the young codominant red fir depicted in *figure 1* is otherwise vigorous, with live crown percent = 80, branch angle percent = 30, and cortex percent = 50. Because of crown raggedness, predicted growth is Class 2 (1 pct < PCTBAI ≤ 3 pct) and actual PCTBAI is 2.21 percent. In the absence of branch death (ragged percent = 0), however, predicted growth would be Class 3 (PCTBAI > 3 pct).

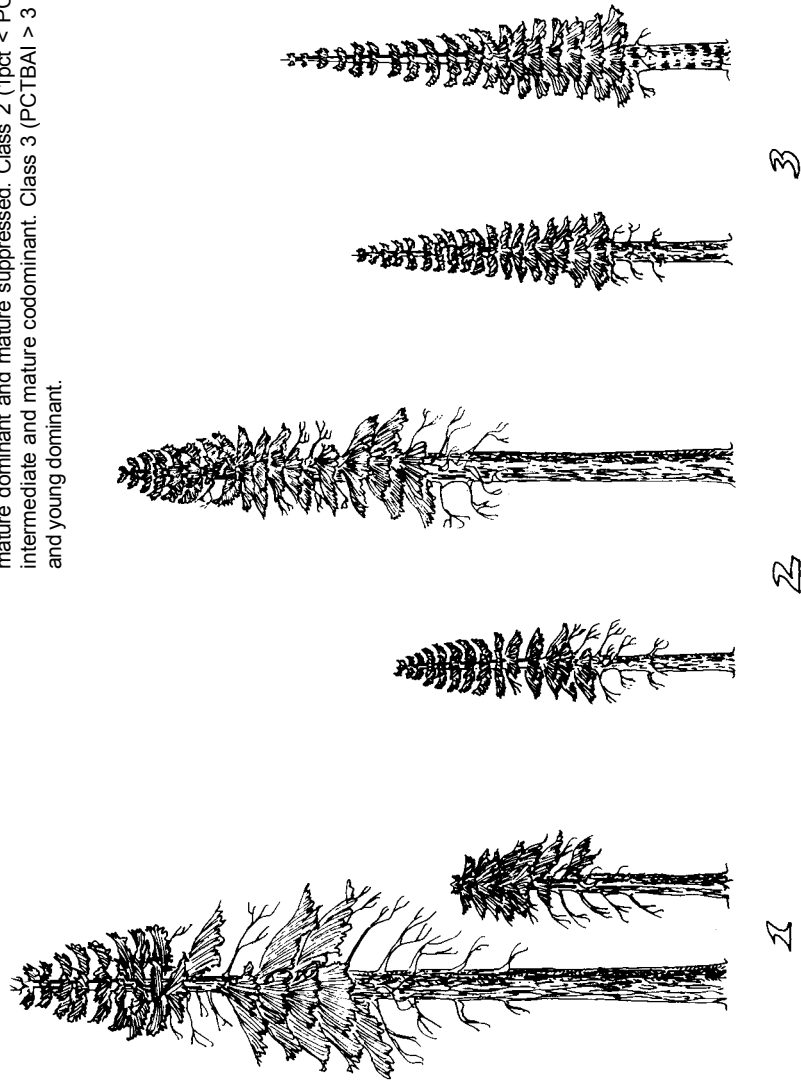
Minor variation in defining the lower limit of the live crown affects several predictor variables, but these variations tend to be compensatory, so that the predicted growth class is unchanged. In the case of the mature dominant white fir shown in *figure 2*, for example, including isolated lower limbs in the live crown leads to a live crown percent of 80, a ragged percent of 30, and predicted growth is Class 1 (PCTBAI ≤ 1 pct). Excluding the lower branches from the crown decreases both live crown percent (40) and ragged percent (10). In the equations, however, these changes tend to compensate one another so that predicted growth remains unchanged (Class 1). Actual PCTBAI is 0.98 percent. Crown predictor variables used in the red fir classification equations similarly compensate one another.

The equations can accurately predict growth class differences between trees that are similar in overall phenotype. Both red firs in *figure 3* are dominant and have the same live crown percent and d.b.h. Because of differences in branch angle percent, ragged percent, and cortex percent, however, one tree is predicted to be Class 3 (PCTBAI > 3 pct) and the other Class 2 (1 < PCTBAI ≤ 3 pct). Actual PCTBAIs are 3.10 percent for the Class 3 tree and 1.56 for the Class 2 tree.

The equations can accurately predict the growth class of residual trees after logging or other major stand disturbances, providing enough time has elapsed for phenotypic changes to occur. The young red fir in *figure 4* is now dominant after release by overstory removal 17 years ago. Before release, actual PCTBAI was 1.80 percent. On the basis of present phenotype, growth is predicted to be Class 3 (PCTBAI > 3 pct) and actual PCTBAI is 4.18 percent.

The equations can accurately predict the growth class of trees even though crown class interpretation may be difficult in uneven-aged stands

**Figure 6**—Typical trees in each of the true fir growth classes. Class 1 (PCTBAI  $\leq 1$  pct); mature dominant and mature suppressed. Class 2 (1 pct < PCTBAI  $\leq 3$  pct); young intermediate and mature codominant. Class 3 (PCTBAI > 3 pct); young dominant and young dominant.



because of unevenness in the stand canopy. The young white fir in *figure 5* is growing in such a stand, but whether the tree is rated as intermediate or dominant, predicted growth is Class 3 (PCTBAI > 3pct). Actual PCTBAI is 3.60 percent.

## ***Growth Class and Phenotype***

Descriptions of typical trees in each of the growth classes were based on means and standard deviations for the traits evaluated (*table 3*). The trees' ages and crown classes that typify each growth class were inferred from the means and standard deviations in PCTBAI values of trees in each age and crown class group (*table 2*). In any particular growth class the typical phenotypes for red firs were similar to those for white firs (*figure 6*). In each growth class, however, red firs on the average were somewhat smaller, had slower growth rates, and smaller and more ragged crowns than white firs.

### **Class 1 (PCTBAI < 1 pct)**

*Crown:* length short (< 50 to 60 pct of tree height), with less than 30 percent upturned and horizontal branches; ragged (often more than 30 pct of branches dead, dying, or missing). *Top:* round or flat, seldom pointed. *Stem:* diameter and height variable, but including most trees more than 20 inches (51 cm) d.b.h. and 100 ft (31 m) tall, with bark gray to dark gray or in red fir, reddish brown; fissures rarely open, and less than 30 percent of stem length in gray to white cortex. *Composition:* mainly mature suppressed and dominant trees; less frequently, mature intermediate and codominant trees, and young suppressed to codominant trees.

### **Class 2 (1 pct , 3 pct)**

*Crown:* length medium (50 to 60 pct of tree height), with 30 to 40 percent upturned and horizontal branches; somewhat ragged (20 to 30 pct of branches dead, dying, or missing). *Top:* round to pointed. *Stem :* diameter seldom more than 20 inches (51 cm) d.b.h. and height more than 100 ft (31 m), with bark gray or light gray, fissures of about 20 to 50 percent of trees open, and 30 to 50 percent of stem length in light gray to white cortex. *Composition:* mainly young suppressed to codominant trees; some mature codominant and dominant trees and some poorer-crowned young dominants.

### **Class 3 (PCTBAI > 3 pct)**

*Crown:* length long (more than 60 to 70 pct of tree height), with more than 40 percent upturned and horizontal branches and less than 20 percent of branches dead, dying, or missing. *Top:* pointed. *Stem:* d.b.h. less than 14 inches (33 cm) and height less than 75 ft (23 m), white cortex occupying over 50 percent of stem length. *Composition:* mainly young dominant and some codominant trees.

## REFERENCES

- Baker, Frederick S. **Principles of silviculture**. New York: McGraw-Hill Book Co.; 1950. 414 p.
- Dunning, Duncan. **A tree classification for the selection forests of the Sierra Nevada**. J. Agric. Res. 36(9):755-771; 1928 May.
- Dunning, Duncan. **A site classification for the mixed-conifer selection forest of the Sierra Nevada**. Res. Note 28. Berkeley, CA: California Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1942. 22 p.
- Ferrell, George T. **Risk-rating systems for mature red fir and white fir in northern California**. Gen. Tech. Rep. PSW-39. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980. 29 p.
- Frane, James. **P9R. All possible subsets regression**. In: Dixon, W. J., chief ed. BMDP statistical software 1981. Berkeley, CA; University of California Press; 1981: 264-277.
- Freese, Frank. **Linear regression methods for forest research**. Res. Paper FPL-17. Madison, WI: Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; 1964. 136 p.
- Griffin, James R.; Critchfield, William B. **The distribution of forest trees in California**. Res. Paper PSW-82. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1972. (Reprinted with supplement, 1976.) 118 p.
- Hocking, R.R. **The analysis and selection of variables in linear regression**. Biometrics 32:1-49; 1976 March.
- Jennrich, Robert; Sampson, Paul. **P7M. Stepwise discriminant analysis**. In: Dixon, W.J., chief ed. BMDP statistical software. Berkeley, CA: University of California Press; 1981: 519-535.
- MacLean, Colin D.; Bolsinger, Charles L. **Estimating Dunning's site index from plant indicators**. Res. Note PN W-197. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1973. 10 p.
- Sokal, Robert R.; Rohlf, F. James. **Biometry**. San Francisco: W. H. Freeman Co.; 1969. 776 p.

Ferrell, George T. **Growth classification systems for red fir and white fir in northern California**. Gen. Tech. Rep. PSW-72. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1983. 18 p.

Selected crown and bole characteristics were predictor variables in growth classification equations developed for California red fir, Shasta red fir, and white fir in northern California. Individual firs were classified on the basis of percent basal area increment (PCTBAI) as Class 1 ( $\leq 1$  pct), Class 2 ( $> 1$  pct and  $\leq 3$  pct), or Class 3 ( $> 3$  pct). Data from increment borings indicated that the equations accurately classified about 75 percent of trees at least 4 inches (10 cm) in diameter-at-breast-height (d.b.h.), except those firs in stands seriously disturbed within the previous decade by logging, fire, or other influences. Because the growth classification equations use the same predictor variables as the risk equations, combined calculator programs can be designed to predict both growth class and risk of tree death. Properly used, the data from these classification systems should contribute to the sound management of California's true firs.

*Retrieval Terms:* *Abies concolor*, *Abies magnifica*, California red fir, Shasta red fir, white fir, basal area increment