Northern California Forest Yield Cooperative
Department of Forestry and Resource Management
University of California, Berkeley, Ca. 94720

Research Note No. 24 January 12 , 1989

Individual Tree Mortality Models for Northern California Mixed Conifer Species

by

Greg S. Biging and Timothy A. Robards[1]

[1] Associate Professor and Post Graduate Researcher, Department of Forestry and Resource Management, University of California, Berkeley

ABSTRACT

Preliminary mortality models were developed based on analysis of a five-year remeasurement of the Coop's permanent plot data base. A logistic model which predicts the annual probability of mortality was developed for six species. The variables that were typically found important for prediction included crown ratio, DBH and a measure of individual tree competition. Simulations were performed to assess the numbers of trees predicted to die, and their associated volumes. These values were compared with actuals. The estimates of mortality volume ranged from an underestimate of 7 percent for white fir to an overestimate of 29 percent for Douglas-fir. More reliable estimates of mortality require observing tree mortality over a longer period than five years.

INTRODUCTION

The purpose of this study was to develop and report on individual tree mortality models for use in CACTOS, the California Conifer Timber Output Simulator. Previous to the implementation of these models an interim mortality model of north coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) was used (Krumland, Dye, and Wensel, 1977). The use of this model was expected to produce under-estimates of mortality for the intolerant ponderosa and sugar pine and over-estimates for the tolerant white and red fir (Wensel and Koehler, 1985). It was included in the simulator, but users were instructed not to place great credence in the mortality estimates until better predictors were available.

A variety of methodologies for modelling mortality exist in the literature (Monserud, 1976; Pinder, Wiener, and Smith, 1978). These include deterministic models which predict a tree's death when some attribute which describes the condition of the tree falls below some threshold such as when growth falls below a certain percentage of tree size or crown ratio falls below a specified level. For even-aged stands a fitted distribution such as the Weibull distribution may be used satisfactorily to predict survivorship. Stochastic mortality models, in contrast to deterministic models, reduce the per acre expansion of a tree by it's probability of mortality rather than kill the tree outright. This later scheme is implemented in the CACTOS growth and yield projection system.

The most common mortality model used in forestry is the logistic equation (cf e.g. Buchman, 1983, Hamilton, 1986, and Hamilton and Edwards, 1976). The logistic function may be used with either deterministic or stochastic models. The characteristic of the logistic function which makes it desirable for use in mortality modelling is that it produces a probability of mortality (bounded by 0 and 1) rather than simply a relative index of mortality. The general form of the logistic equation is:

$$F(X,b) = \frac{1}{(1 + e^{-(b_0 + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n)})}$$

where $F(X, b)$ = the annual probability of mortality $0 \leq F(X, b) \leq 1$

- X = the independent variables such as tree diameter
- b = the coefficients
- e = the base of the natural logarithm

To implement a deterministic mortality model using the logistic function, a uniform random variable may be compared with the probability of mortality, F(X, b), and if it falls on or below F(X, b) then the tree is considered dead. CACTOS does not use the deterministic method, but rather uses the stochastic method of reducing the tree expansion factor by the probability predicted by the logistic model.

The accuracy of the stochastic method is difficult to assess because CACTOS growth projections are concurrently required. Because of this, the predicted mortality volume depends on the growth models themselves. Hence it is difficult to know if the differences between actual and predicted mortality volumes are due to mortality projections, growth projections or a combination of these two factors. In this paper we will analyze the results using a deterministic method because of the difficulties of comparing the stochastically generated predictions of mortality with actual mortality.

DATA

Permanent plots located throughout the mixed conifer region of Northern California were established from 1978-1980 and remeasured from 1983-1985 by the Northern California Forest Yield Cooperative. For a more complete description of the inventory design and scope see Koehler, Biging, and Wensel (1983). A five year remeasurement of the permanent plots allows the estimation of models which may be tested and improved as more remeasurements are made and as the conditions of the forest change. Table 1 provides a summary of the survivor and mortality trees in the data base by species.

ANALYSIS

Initial modelling efforts concentrated on developing models for two sets of plots, one for plots in which no cutting had occurred (called control plots), and one for plots in which cutting had occurred (called cut plots). On control plots the major cause of mortality would be due to suppression mortality with some underlying endemic level of mortality due to disease and insects. On cut plots an additional source of mortality would be due to damage caused by harvesting.

Discriminant analysis was used to identify candidate variables for further modelling efforts (Monserud, 1976). The primary variables identified for the majority of the species included DBH, live crown ratio and a measure of individual tree competition (CC_{66}). Models were developed for both the control plots and cut plots and then for all plots combined. Surprisingly, the models fit to the control plots and cut plots performed no better than using a model based on all plots, nor were variables such as cut percent (percent of the basal area cut) found to be significant. This may be because of the relatively few numbers of trees observed as dying. Because of these results, all further analysis is presented for all plots combined.

Models Selected

Variables correlated with mortality included: DBH, crown ratio and a measure of individual tree competition (CC_{66}). The general model termed model [1] was: (Note that not all terms appear in each species model)

$$F(X,b) = \frac{1}{(1 + e^{-(b_0 + b_1 CR + b_2 DBH + b_3 CC_{66})})} \qquad [1]$$

where CR = tree crown ratio

DBH = tree diameter at breast height

CC_{66} = crown competition at 2/3 of the subject tree's height

The coefficients and fit statistics for Model [1] for several species are presented in Table 2a. The coefficients for ponderosa pine and incense cedar are not presented, and the reasons for this will be discussed in the next section.

Model Evaluation

A simulation was performed on the measured trees at the beginning of the 5 year measurement period. The mortality models were used to assess the probability of an individual tree dying in the 5 year period ($5 \cdot F(X,b)$). A uniform random number was compared with the predicted probability of dying in 5 years. If it was less than or equal to the predicted probability then the tree was considered dead. Results of the simulation showing the predicted numbers and volumes of survivor and mortality trees versus the actual numbers and volumes of survivor and mortality trees are presented in Tables 3a and 3b. Table 3a shows the results of the best models, which was model [1] for all but ponderosa pine and incense cedar. Table 3b shows the results of using model [1] for predicting mortality for ponderosa pine and incense cedar. In comparing Tables 3a and 3b it can be seen that coastal Douglas-fir model [2] better predicted mortality numbers and volumes of ponderosa pine and incense cedar than did model [1]. The coastal Douglas-fir model coefficients are presented in Table 2b and its general form is:

$$F(X,b) = \frac{1}{(1 + e^{-(b_0 + b_1 RBA + b_2 DBH + b_3 N)})} \qquad [2]$$

where RBA $= \dfrac{\text{quadratic mean stand diameter}^2}{DBH^2}$

DBH = tree diameter at breast height
N = number of trees per acre

In general it can be seen that it is extremely difficult to predict mortality correctly. In fact very few trees were correctly identified as dead when they actually died over the five year period. Because of this it becomes important to examine the trees classified as dead which were really alive, and compare this with the trees which were classed as alive, but died. Hopefully the numbers and volumes of trees in these two categories are counter-balancing. This was an important consideration in selecting the mortality model for each species. We found that with the exception of ponderosa pine and incense cedar, model [1] did a fair job of balancing the numbers and volumes in these two categories. Because model [2], the coastal Douglas-fir model, did a superior job of balancing the numbers and volumes in these classes in comparison with model [1], we decided to retain the coastal Douglas-fir model for use with these two species.

We attempted to re-fit the parameters of the coastal Douglas-fir model [2] using our remeasurement data for ponderosa pine and Douglas-fir. This produced a higher percentage of volume being classified correctly overall, but did not balance the error. There is no readily plausible reason why these anomalies should occur. As more data become available (from another remeasurement, or analyzing other permanent plot data) we should be able to develop a model for these two species that out-performs the coastal Douglas-fir model.

Another measure of the adequacy of the mortality models is given in Tables 4 and 5. In these tables the ratio of total predicted mortality volume to actual mortality volume is presented using Models [1] and [2] for each species. The numerator of this ratio is the sum of the volumes of trees classified as dead, but really alive with the volumes of trees classified as dead that really died. The denominator of this ratio is the sum of the volumes of the observed dead trees. These ratios range from 0.93 for white fir to 1.29 for Douglas-fir.

LITERATURE CITED

Biging, Greg S. 1983. Volume tables for young-growth mixed conifers of Northern California based upon the stem analysis data. Part I: Volume tables for mixed conifers. Part II: Taper equations for mixed conifers. (Revised draft). Research Note #7. Northern Calif. Forest Yield Cooperative, Dept. of Forestry and Resource Mgmt., Univ. of Calif., Berkeley. 59 pages.

Buchman, Roland G. 1983. Survival predictions for major lake states tree species. USDA For. Serv. NC For. Exp. Stn. Res. Paper NC-233. 7pgs

Hamilton, David A. Jr., and Bruce M. Edwards. 1976. Modelling the probability of individual tree mortality. USDA. For. Serv. Res. Paper INT-185. 15pgs.

Hamilton, David A. 1986. A logistic model of mortality in thinned and unthinned mixed conifer stands of Northern Idaho. 1986. For. Sci. 32(4): 989-1000.

Koehler, James R., Greg S. Biging, and Lee C. Wensel. 1983. Summary of the Coop's databases. Res. Note #5. Northern Calif. Forest Yield Cooperative, Dept. of Forestry and Resource Mgmt., Univ. of Calif., Berkeley. 14 pages.

Krumland, Bruce E., Joel Dye, and Lee C. Wensel. 1977. Individual tree mortality models for the north coast region of California. 1977. Res. Note #6. Co-op Redwood Yield Research Project, Dept. of Forestry and Resource Management, Univ. of Calif., Berkeley 7 pgs.

Monserud, Robert A. 1976. Simulation of forest tree mortality. For. Sci. 22: 438-444.

Pinder, John E III, James G. Wiener, and Michael H. Smith. 1978. The Weibull distribution: a new method of summarizing survivorship data. Ecology 59(1): 175-179.

Wensel, Lee C., and James R. Koehler. 1985. A tree growth projection system for Northern California coniferous forests. Res. Note #12. Northern Calif. Forest Yield Cooperative, Dept. of Forestry and Resource Mgmt., Univ. of Calif., Berkeley. 30 pages.

Wensel, Lee C., Walter J. Meerschaert, and Greg S. Biging. 1987. Tree height and diameter growth models for northern California conifers. Hilgardia. 55(8): 1-16.

Table 1. Tree statistics for the remeasurement database by species.

Ponderosa Pine

	Survivors			Mortality		
Variable	N	Mean	Std dev	N	Mean	Std dev
DBH	4496	10.9	7.06	228	5.9	4.08
total height	4496	55.6	32.76	228	35.4	22.73
crown ratio	4496	.489	.1753	228	.331	.1962
CC66	4496	.4258	.2233	228	.606	.2641

Sugar Pine

	Survivors			Mortality		
Variable	N	Mean	Std dev	N	Mean	Std dev
DBH	1142	13.2	8.64	53	8.0	6.49
total height	1142	60.5	34.40	53	40.0	27.63
crown ratio	1142	.511	.1672	53	.442	.2070
CC66	1142	.490	.2860	53	.7136	.3445

Incense Cedar

	Survivors			Mortality		
Variable	N	Mean	Std dev	N	Mean	Std dev
DBH	2608	9.6	7.06	75	6.7	4.33
total height	2608	36.3	23.38	75	30.7	21.99
crown ratio	2608	.491	.2013	75	.338	.2181
CC66	2608	.600	.2880	75	.656	.3041

Douglas-fir

	Survivors			Mortality		
Variable	N	Mean	Std dev	N	Mean	Std dev
DBH	3138	10.2	6.63	61	6.3	4.56
total height	3138	56.9	30.05	61	40.0	25.79
crown ratio	3138	.529	.1874	61	.394	.2041
CC66	3138	.576	.3368	61	.711	.3977

White fir

	Survivors			Mortality		
Variable	N	Mean	Std dev	N	Mean	Std dev
DBH	6638	9.5	6.63	178	8.9	6.70
total height	6638	47.2	30.00	178	42.4	29.97
crown ratio	6638	.514	.1976	178	.399	.2117
CC66	6638	.568	.3025	178	.658	.3624

Red fir

	Survivors			Mortality		
Variable	N	Mean	Std dev	N	Mean	Std dev
DBH	478	12.9	8.27	11	13.1	6.24
total height	478	58.1	33.71	11	57.4	27.55
crown ratio	478	.491	.1866	11	.363	.1227
CC66	478	.504	.3434	11	.528	.3928

Table 2a. Coefficients and fit statistics by species for model [1].

$$F(X,b) = \frac{1}{1+\exp(-(b_0+b_1 \cdot CR+b_2 \cdot DBH+b_3 \cdot CC_{66}))}$$

Species	b_0	b_1	b_2	b_3	$S_{y.x}$
SP	-3.633	-2.124	-0.062	1.003	0.041
DF	-2.882	-4.928	-0.090	0.000	0.026
WF[1]	-3.493	-4.333	0.000	0.000	0.031

1/ The white fir model is used for red fir due to the small number of mortality trees in red fir.

Table 2b. Coefficients and fit statistics by species for the coastal Douglas-fir model [2].

$$F(X,b) = \frac{1}{1+\exp(-(b_0+b_1 \cdot RBA+b_2 \cdot DBH+b_3 \cdot TPA))}$$

Species	b_0	b_1	b_2	b_3
PP & IC	-3.823	0.0112	-0.121	-0.000365

Table 3a. Error matrices for the final models using: the logistic model [1] for sugar pine, Douglas-fir, white fir and red fir; and using the coastal Douglas-fir model [2] for ponderosa pine and incense cedar. For these species model [1] was estimated and used in this analysis, but the coefficients were not printed in Table 2a since we are not recommending their use.

Predicted live actually alive		N	volume
	PP	4,272	617,027
	SP	1,094	254,427
	IC	2,459	165,638
	DF	3,088	390,475
	WF	6,469	771,276
	RF	469	120,043

Predicted live actually dead		N	volume
	PP	211	5,428
	SP	48	3,500
	IC	70	1,298
	DF	58	2,063
	WF	171	18,443
	RF	11	1,479

Predicted dead actually alive		N	volume
	PP	222	6,402
	SP	45	3,709
	IC	146	1,276
	DF	50	2,659
	WF	163	17,166
	RF	9	1,805

Predicted dead actually dead		N	volume
	PP	17	97
	SP	5	244
	IC	5	67
	DF	3	14
	WF	7	1,016
	RF	0	0

Table 3b. Error matrices for the logistic model [1] for Ponderosa pine and incense cedar.

Predicted live actually alive		N	volume
	PP	4,333	619,661
	IC	2,542	164,470

Predicted live actually dead		N	volume
	PP	198	5,373
	IC	71	1,282

Predicted dead actually alive		N	volume
	PP	161	3,769
	IC	63	2,444

Predicted dead actually dead		N	volume
	PP	30	151
	IC	4	83

Table 4. Predicted and actual board foot volumes to a 6 inch top (Biging, 1983) of mortality trees using the coastal Douglas-fir mortality model [2] used in Version 4 of CACTOS.

Species	Actual	Predicted	Predicted / Actual
PP[1]	5,525	6,499	1.18
SP	3,744	1,584	0.42
IC[1]	1,365	1,343	0.98
DF	2,077	4,524	2.18
WF	19,459	10,294	0.53
RF	1,499	366	0.24

1/ For these species the coastal Douglas-fir model was used because it provided better results than model [1] (see Table 5).

Table 5. Predicted and actual board foot volumes to a 6 inch top (Biging, 1983) of mortality trees using: the logistic model [1] for all species.

Species	Actual	Predicted	Predicted / Actual
PP[1]	5,525	3,920	0.70
SP	3,744	3,953	1.06
IC[1]	1,365	2,527	1.91
DF	2,077	2,673	1.29
WF	19,459	18,182	0.93
RF[2]	1,499	1,825	1.22

1/ For these species the logistic model [1] provided poorer results than using model [2] (see Table 4). For these species model [1] was estimated and used in this analysis, but the coefficients were not printed in Table 2a since we are not recommending their use.

2/ Because there were so little data for red fir, the white fir model was used to predict red fir mortality.