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# INDIVIDUAL TREE MORTALITY MODELS FOR THE NORTH COAST REGION OF CALIFORNIA

by

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## ABSTRACT

This note reports the development of models to predict the probability of mortality of individual trees. The basic model used was the logistic equation. Equations were developed for 5 north coast species as part of growth and yield studies currently in progress for the region.

## I. Introduction

This report describes the development of models to predict the probability of mortality for individual trees in the north coast region of California. Models were developed for coastal redwood, douglas fir, other whitewoods[1/], alder, and tanoak. These models were developed in conjunction with growth and yield studies currently under way in this region. The major focus in these efforts is to develop equations to predict the growth of individual trees in response to site factors, characteristics of stands in which trees are growing, and factors attributable to the trees themselves. The various tree growth equations are imbedded in a simulation model to provide an overall prediction of stand development. The models described in this note will be used to provide the mortality component of simulation models.

## II. Model Formulation

To predict probabilities, a nonlinear function which limits the prediction to the interval [0,1] is highly desirable, intuitively and statistically (Neter & Maynes, 1970). After considerable experimentation, the logistic equation as suggested by Walker & Duncan (1967),and as applied to tree mortality by Hamilton (1974) and Hamilton & Edwards (1976) was chosen as the most appropriate model. This model can be represented as:

$$P = \frac{1}{1 + e^{-\beta x}}$$

where $P$ = probability of mortality $0 \leq p \leq 1$
$\beta$ = vector of nonlinear regression coefficients
$x$ = vector of independent variables correlated with mortality probabilities
$e$ = base of natural logarithms

## III. Analysis

The data used in this study were derived from 506 permanent plots located in Humboldt, Del Norte, and Mendocino counties. The plots ranged in size from 1/10 to 1/2 acre and were representative of conditions currently found in young growth stands, ages from 10 to 100 years, in this region. The numbers of sampled trees are found in Table 1. The measurement interval on these plots averaged about 10 years. Plots that had been logged between measurements were

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1/ Other whitewoods consist of the following species: lowland white fir, hemlock, and Sitka spruce.

not included. The plots were divided into two catagories: (1) those which had been logged from one to ten years before the first measurement and (2) plots which were unlogged.

Table 1. Numbers of sample trees and observed mortality by species.

| species | total | mortality |
|---|---|---|
| redwood | 8198 | 141 |
| douglas fir | 2449 | 94 |
| other whitewoods | 474 | 20 |
| alder | 295 | 40 |
| tanoak | 1619 | 34 |
| other hardwoods 2/ | 354 | 32 |

Trees on each plot were segregated by species and assigned an annual mortality rate (rmort) of zero if they were still alive at the end of the measurement interval or a value equal to the reciprocal of the number of years in the growth interval if they died. Variables which could be correlated with mortality such as tree size, stand density, site index, and relative tree size, were also coded for each tree. Analysis indicated that the variables producing the most consistent predictions of mortality were:

rba = relative basal area 3/
dbh = diameter at breast height
rn = stems per acre for the stand

The form of the equation that was fitted was:

$$\text{rmort} = \frac{1}{1+e^{-(\beta_0 + \beta_1 \text{rba} + \beta_2 \text{dbh} + \beta_3 \text{rn})}}$$

Parameters were estimated using nonlinear regression. The coefficients for each species are shown in Table 2. These coefficients were derived from the unlogged data classes only. Separate analysis of the logged data indicated that mortality in cutover stands is extremely erratic. It is generally agreed that low thinnings tend to reduce

2/ Other hardwoods consist, primarily, of the following species: madrone, bay and big leaf maple.

3/ rba = (quadratic mean dbh of stand)$^2$ / dbh$^2$.

mortality rates. However, many of the cutover plots had been subjected to overstory removals. Lack of data concerning mechanical damage incurred during logging, possible shock impacts, and vigor of residual trees as well as the relatively small numbers of available cutover plot records has prevented any clear distinctions of differential mortality rates due to logging.

Table 2. Coefficients for mortality models.[4/]

| | redwood | douglas fir | other whitewoods | alder | tanoak |
|---|---|---|---|---|---|
| $B_0$ | -3.828 | -3.823 | -4.604 | -3.961 | -5.121 |
| $B_1$ | .00468 | .0112 | .00925 | .00937 | .000666 |
| $B_2$ | -.220 | -.121 | -.0773 | -.0209 | -.0183 |
| $B_3$ | -.000175 | -.000365 | -.000023 | -.000824 | -.00216 |
| $R^2$ | .39598 | .33311 | .28513 | .31475 | .17193 |
| $S_{y \cdot x}$ | .04256 | .05068 | .03557 | .08876 | .03785 |

rbh
dbh
dems

rdb = $\frac{\text{mean dbh}}{\text{dbh}}$

## IV. APPLICATIONS

The simulation approach to estimating stand growth and yield involves predicting the change in dimensions or status of individual trees over short growth cycles of one to five years. At the start of each cycle, predictions are made to determine if each tree will live or die. Trees that are survivors are incremented in diameter and height and those that are predicted to die contribute to stand mortality for that growth cycle. The factors which are then used to predict tree growth such as relative and absolute tree size, density, and age are then updated and the growth cycle is repeated.

The mortality component of stand development can be treated in two ways:

(1) Deterministic mortality. In this mode, each tree is assigned a per acre weight representing a stem count associated with the tree. This per acre weight is reduced by the predicted mortality at the start of each growth cycle. This approach will result in smooth simulated trends in mortality over time. When growth cycles longer than one year a reasonable approximation is to simply multiply the

4/ A significant model was not found for other hardwoods. The equation derived for tanoak will be used for this group in subsequent work.

predicted annual mortality rate by the years in the growth cycle.

(2) Stochastic mortality. In this procedure, predicted probabilities of mortality for individual trees are compared with a random number drawn between the interval of 0 and 1. If the prediction is greater than the random number, the tree is assumed to die. Otherwise it is a survivor. This approach is useful in analyzing possible short term variability in stand development due to the mortality component.

For most uses of growth and yield information, the deterministic approach producing smooth trends in estimated stand mortality over time will be appropriate.

## V. VERIFICATION

It is generally recognized that mortality rates for coastal stands are low, which is confirmed by the models described in this report. As trees become larger in diameter, the probability that they die during any given year becomes smaller. Similarly, trees in the upper canopy have a relatively smaller predicted probability of dying than understory trees.

Verification of these models is difficult due to the low incidence and variable nature of tree mortality. This is evidenced by the low $R^2$ values in table 2. In terms of differences among species, table 3 shows predicted mortality probabilities for different species of the same size in comparable stand conditions.

Table 3. Predicted mortality probabilities by species for trees 8 inches DBH, relative basal area of 1, and 300 stems per acre.

| | Mortality Probability |
|---|---|
| Redwood | .003543 |
| Douglas fir | .007464 |
| Other Whitewoods | .005379 |
| Alder | .02041 |
| Tanoak | .002694 |

In general, the relative ranking of these probabilities is as expected. The more tolerant the species, the lower the probability of mortality.

Despite their shortcomings, normal and empirical yeild tables are the only other source of estimated long term

mortality in coastal stands. For comparative purposes, stands with 300 stems per acre at age twenty were installed in the preliminary stand simulator described in Project Report No. 2. This is roughly comparable to a Lindquist and Palley site 180. Separate 80 year predictions were made for both redwood and Douglas Fir stands. Table 4 compares the mortality summaries of these trials with yield table estimates (Lindquist and Palley, 1963).

Table 4. Annual mortality percentages at different intervals for simulated stands and yield table estimates.

| Prediction interval (years) | Simulated Redwood | Simulated Douglas Fir | Yield Tables |
|---|---|---|---|
| 20-100 | .30 | .67 | .84 |
| 90-100 | .22 | .48 | .45 |
| 10-20 | .74 | .98 | --- |

Based on trees 4.5 dbh and larger.

Simulated mortality for redwood is substantially less than that portrayed by yield tables. Doubling and halving the initial number of stems per acre in simulation trials produced relatively constant mortality percentages regardless of density.

A traditional premise in forest management is that at a given stand age, growth is constant above certain stocking levels. If this were true, differences in mortality estimates would be of minor consequence. Past analysis, however, utilizing both stand and tree models as well as the only other growth study for the region (Lindquist and Palley, 1967) indicate that growth shows no sign of leveling off even at abnormally high density levels. In this situation, different mortality rates can have significant impacts on predicted stand yield.

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