INTERNAL REPORT 98

STAND STRUCTURE SIMULATION BASED ON INDIVIDUAL TREE UNITS

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ABSTRACT

A model is developed to simulate basal area growth and mortality for forest stands using individual trees as the basic units. Yearly diameter increment, probability of death, and height-diameter relationship are computed from a competition measure which is based on crown overlap. This model is used to simulate the growth of two plots for which five remeasurements were available. Correlations between actual and simulated values were .9584 and .9979 for basal area growth for the two plots while correlations for number of live trees were .9949 and .9972. Directions of future development are discussed.

INTRODUCTION

The growth and development of a forest stand through time is dependent on the development of the individual trees within the stand. Various stand parameters, number of live trees, volume growth, and basal area are merely summations over the individual trees. Therefore modelling single tree growth based on position within the stand structure is a logical way to simulate the development of the entire stand. However, since the goal is the prediction of stand characteristics, the individual trees may be treated in a stochastic manner in order to increase the overall flexibility of the model.

MATERIALS AND METHODS

For the purpose of this model a stand is characterized by a length, width, and number of live trees. Stands of any size or number of trees are allowed but they must be rectangular in shape. Individual trees are characterized by a location (x coordinate and y coordinate), diameter at breast height, species, and age. A subsampling of heights is helpful but not necessary. At the present level of development at least one remeasurement is required.

In order to simulate a continuous forest, plot edge effects are eliminated by mirroring the stand along the 4 sides and in each corner as shown in Figure 1. While this technique removes any stand-wide bias due to the edge effect, individual trees near the plot boundary are made to compete with trees other than their real competitors. The proportion of trees affected by this error is greatest in small uneven aged stands and least in large uniform ones.

A competition model for individual trees developed by Bella (1971) was used in this program. Briefly, this model assumes that every tree influences a circular area about itself and that the size of this area is related to the stem diameter of the tree. This circle of influence has a radius at least as large as the crown radius of an open grown tree of the same stem diameter. Thus

$$CR = a + b_1 DBH + b_2 DBH^2 \qquad (1)$$

$$R = (FC)(CR) \qquad (2)$$

where CR is the open grown crown radius, DBH is stem diameter at breast height, FC is a multiplicative constant indicating how far beyond the crown edge a tree's influence extends, and R is the radius of the circle of influence. The constants a, b_1, b_2 are determined by regression of open grown crown radius on stem diameter at 1.37 meters (4.5 feet). Bella (1971) has determined these coefficients for Douglas fir.

The competition index for an individual tree, denoted by CIO, illustrated in Figure 2, is given by

$$CIO_i = \sum_{j=1}^{n} (ZO_{ij}/ZA_i)(DBH_j/DBH_i)^{EX} \qquad (3)$$

where n is the number of trees on the plot, ZO_{ij} is the overlap of circles of influence of trees i and j, ZA_i is the area of the circle of influence of tree i, and EX is an exponent determined by non-linear regression. Thus the simple area of overlap for the two trees is weighted by the ratio of their stem diameters in order to account for the superior competitive ability of the larger tree. An open grown tree would have a CIO of unity.

At the current stage of development yearly diameter increment for each tree is given by

$$DIN_i = a - b_1 DOMCIO - b_2 CIO_i + b_3 CIO_i^3 \qquad (4)$$

where DIN_i is the diameter increment of tree i, CIO_i is defined by (3), and DOMCIO is the average CIO value of the dominant trees in the stand and is a measure of stand density at any point in time. Thus the diameter growth of a tree is inversely related to both stand density and competition.

This diameter increment function is species specific and, as the model stands now, valid only for specific stands. Future work will be directed at developing a function which is valid for a given species over wide areas.

Also developed for this model was a new height-diameter relationship based on the observation that trees grown in dense stands where competition is great tend to be tall and thin, while those grown subject to little competition, say open grown trees, are short and squat in form. Equation (5) describes this relationship.

$$DBH = a + b_1 \frac{(HT-1.37)}{AVCIO} \qquad (5)$$

where HT is height in meters, 1.37 meters is breast height, DBH is diameter at that height, and AVCIO is the average competition (CIO) measure of the tree over its entire life.

A stochastic device for simulating mortality was the last function developed for this program. Keister (1972) has shown that mortality due to suppression may be predicted for southern pine from a competition measure similar to the one employed here. Botkin et al. (1970) stressed the stochastic nature of mortality, especially with regard to catastrophic events. Mitchell (1969) used a stochastic procedure based on the ratio of a tree's crown width to the crown width an open grown tree of the same stem diameter would have. The method employed in this model combines these approaches by increasing the probability of death for trees with higher CIO values, but still having a non-zero probability of death for trees with even the smallest measures of competition. Thus each tree is placed in a certain class by its CIO value and then a probability of death in a given year is assigned to that class. Table 1 shows this relation for one of the plots simulated to date. While this method has been quite successful for individual plots, it lacks generality. Future development will be directed at overcoming this shortcoming.

The above functions were combined in an overall program to trace stand development over time. At the beginning of each growing period, which could be a single year or longer, competition (CIO) values are computed for each tree. Based on this CIO value, each tree is assigned a probability of death and then "killed," that is, not grown, using Monte Carlo techniques. The surviving trees are then grown according to equation (4). For growth periods longer than one year, diameter measurement is considered to be a linear multiple of the one year growth. Finally the height and circle of influence of each tree are updated according to (5) and (1) and (2). Stand characteristics of number of live trees and basal area are computed at the end of every growth period.

Permanent plot data were obtained from the Weyerhaeuser Corporation for mixed Douglas fir and red alder stands at their Clemons tree farm. A total of five measurements on these plots had been made covering one 5- and three 4-year growth periods. The stands were about 25 years old at the first measurement and 42 at the last. Site index was about 39.6 meters (130 feet). For each plot at each measurement a complete tabulation of diameters was available as were some heights. Tree locations were obtained from a plot map. Exact locations of trees which died during the first growth period were not given on this map and thus their coordinates had to be estimated. Plots were square and 404.7 square meters (1/10 acre) in area.

RESULTS

The goal of the model is to simulate the development of the stand structure over time. While individual trees are the basic unit, prediction of their growth is less accurate than prediction of stand characteristics due to the effect of stochastic mortality, edge effect and lack of exact location information for all trees. That is, the growth of any given individual tree will be, say, overestimated because the mortality simulator "killed" its chief competitor or because its chief competitor was a large tree just outside the plot boundary. Over the whole stand these differences should even out allowing accurate stand prediction.

Figures 3 through 6 show simulated and actual values for number of live trees and basal area for the two plots simulated to date. Agreement is quite close over this 17-year period. The correlations between actual and simulated data for number of live trees are .9949 and .9972 for the two plots, while the correlations for basal area are .9584 and .9979.

Results from the regressions of DBH on height and AVCIO support the observation that increasing competition increases the ratio of height to diameter. Multiple correlation coefficients were .98 and .97 for equation (5) for the two plots simulated to date.

Even at this early stage of development this model should be useful in examining the effect of changes in stand structure in a stand for which some past remeasurements are available. Different thinning and spacing alternatives can be simulated and their effect on basal area or some other measure of yield can be predicted. At the present time simulating a stand of 37 trees for four growth periods costs $2.32 including compiling time. Cost is proportional to number of trees and growth periods.

Future development of the model will be in the direction of obtaining functions of wider applicability and incorporating some measure of site productivity. Additional stand measurements such as bole volume or total biomass could be added quite easily. A completed model of this type may be able to predict stand characteristics based on an estimate of site quality and a single measurement in time.

REFERENCES

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KEISTER, T. O. 1972. Predicting individual tree mortality in simulated southern pine plantations. Forest Science 18:213-217.

MITCHELL, K. J. 1969. Simulation of the growth of even-aged stands of white spruce. Bull. Yale School of Forestry, No. 75.

Table 1. Probabilities of an individual tree dying in a single year by CIO class for Weyerhaeuser plot 4045.

CIO Class	Probability of Death
CIO < 10.0	0.01
10.0 < CIO < 15.0	0.02
15.0 < CIO < 20.0	0.15
20.0 < CIO < 25.0	0.20
CIO > 25.0	1.00

FIGURES

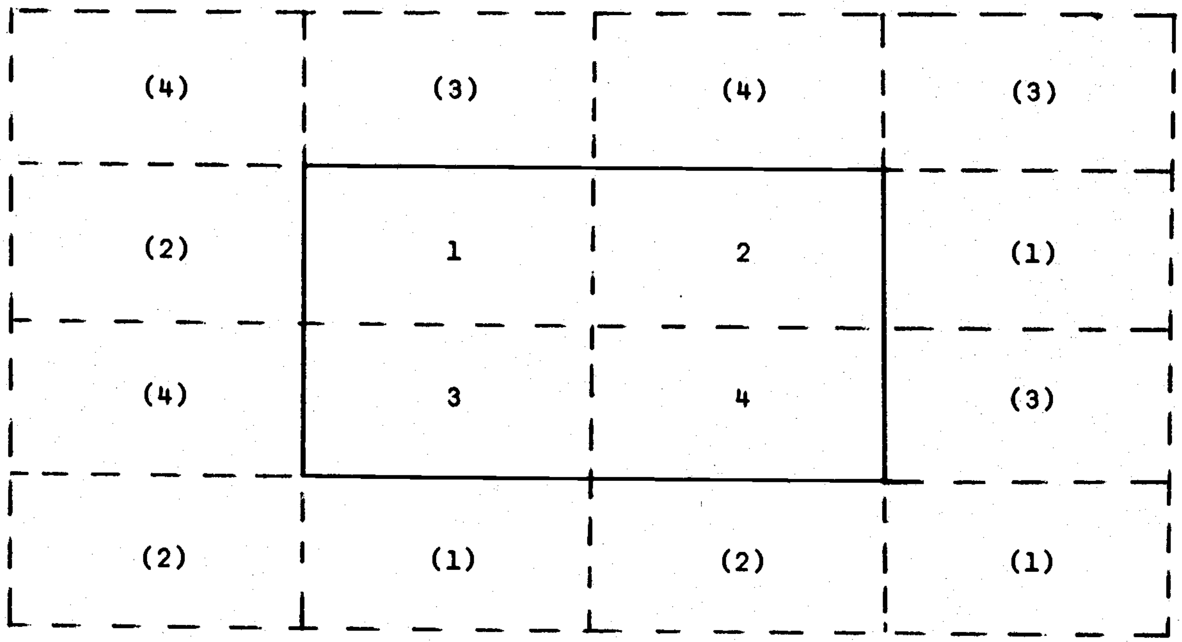

Figure 1. The stand (outlined in solid lines) is divided in quarters which are then used to fill in the plot boundaries and corners.

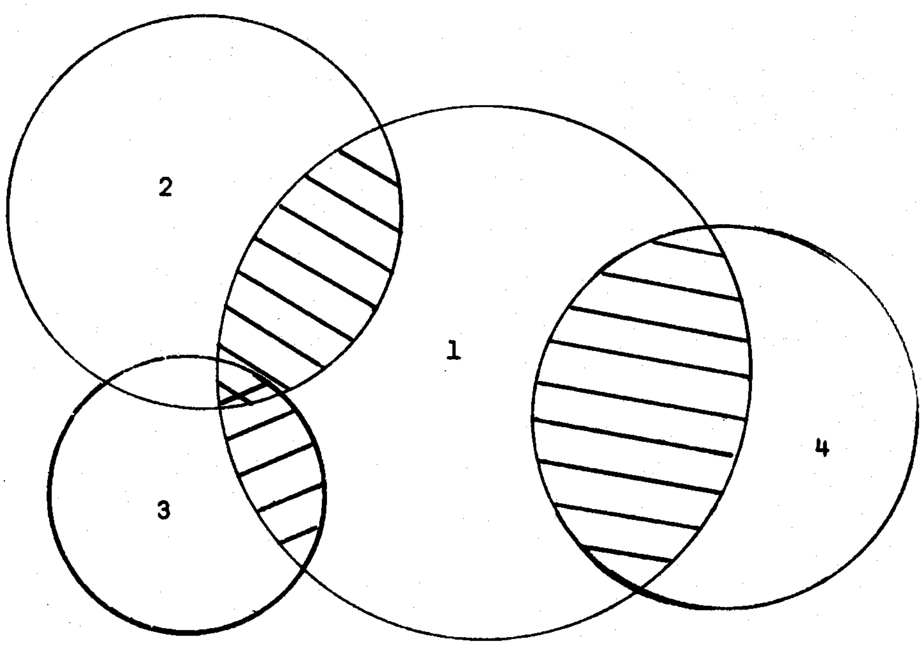

Figure 2. Circles of influence overlaps between a tree (No. 1) and its three competitors (Nos. 2,3,4). Adopted from Bella (1971).

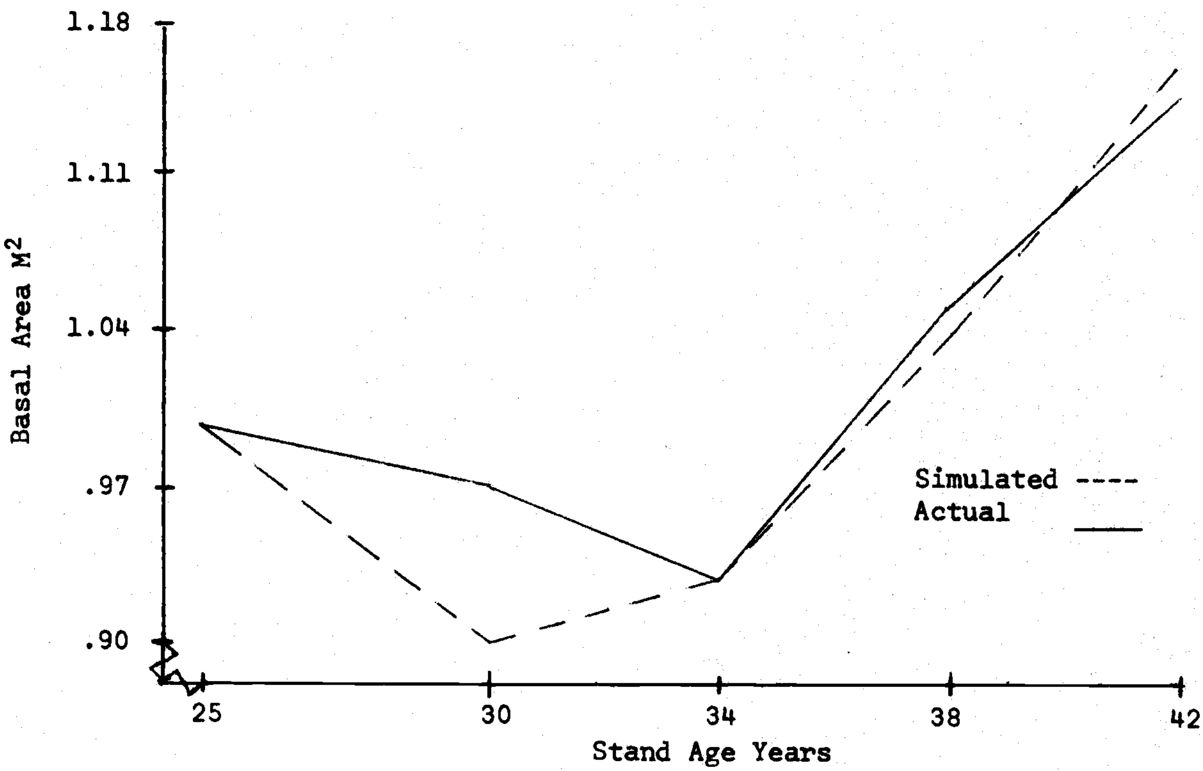

Figure 3. Basal area growth for plot 4045.

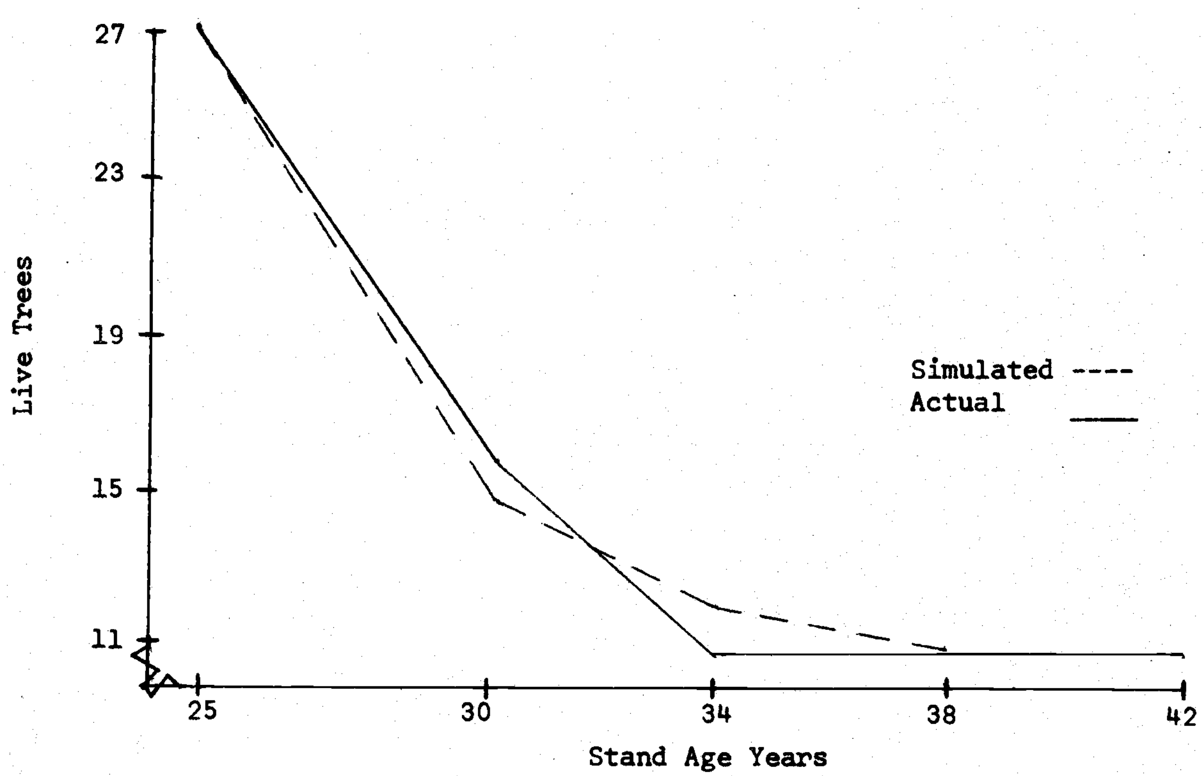

Figure 4. Number of live trees for plot 4045.

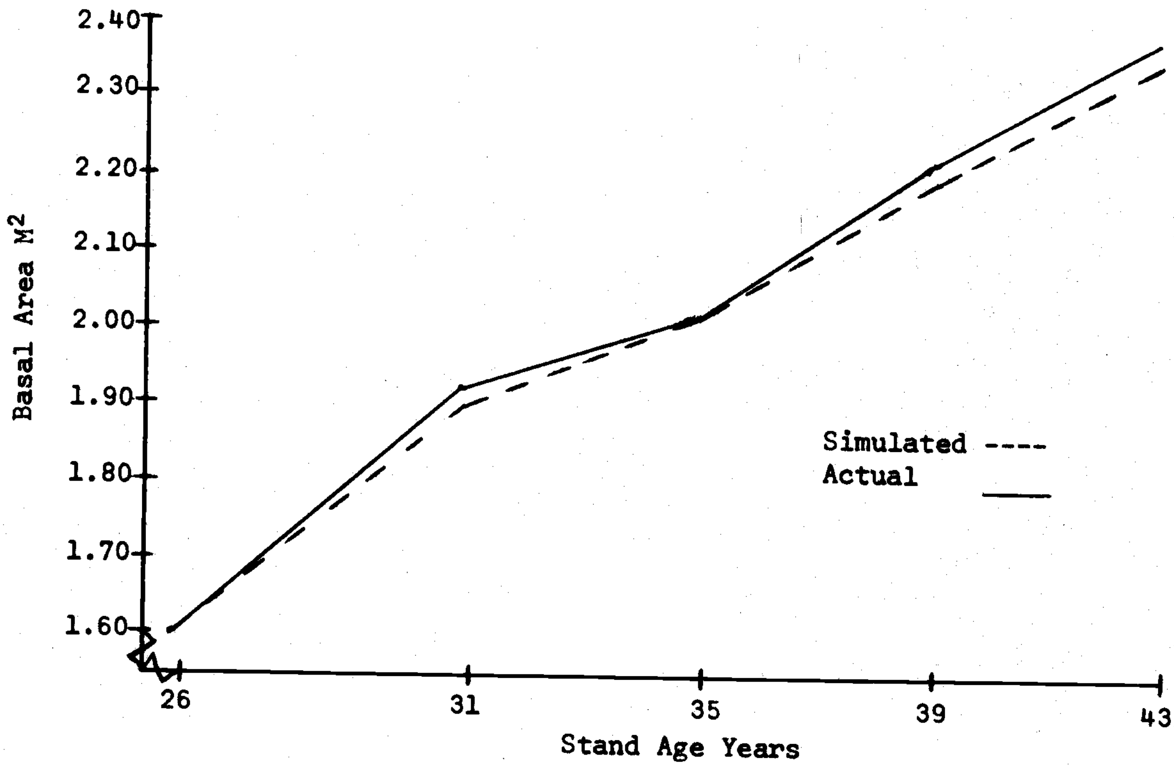

Figure 5. Basal area growth for plot 4024.

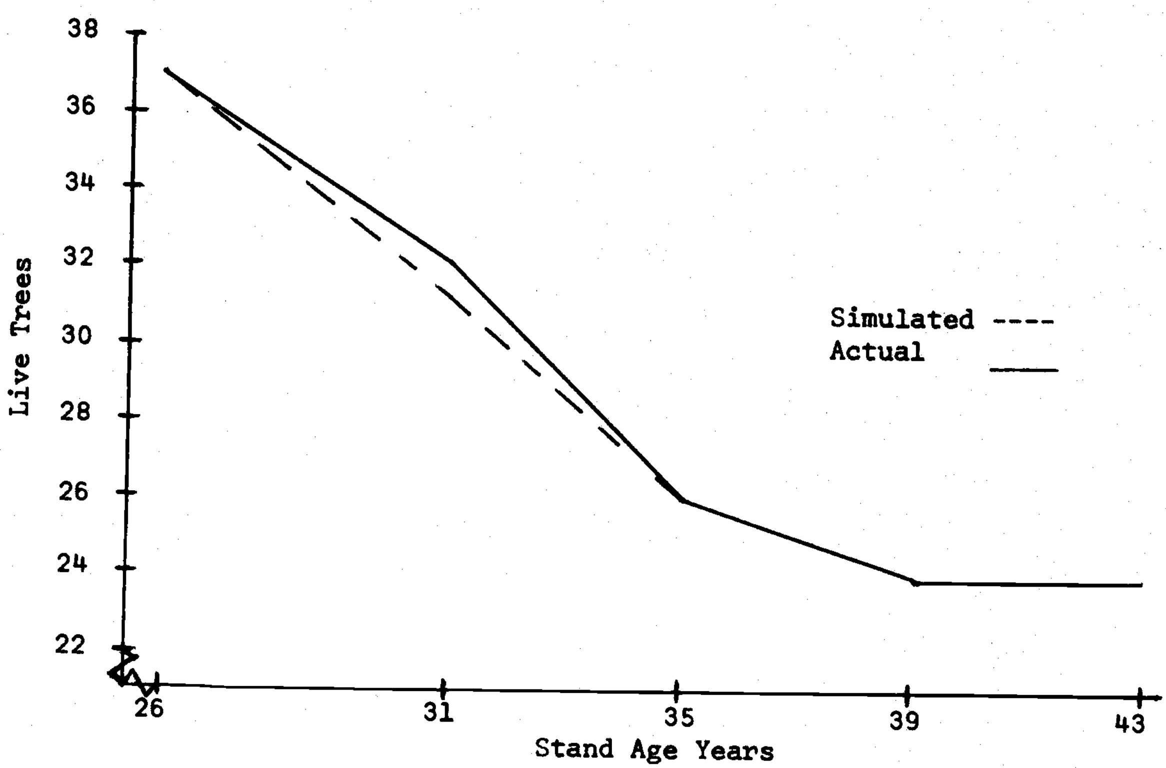

Figure 6. Number of live trees for plot 4024.