GROWTH AND YIELD MODELS --

USING THEM EFFECTIVELY AND RESPONSIBLY[1]

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Abstract--Growth and yield models generally belong to one of four classes: whole stand models, diameter distribution models, individual tree models, and height-diameter models. These model classes are similar in the types of input information and computer hardware required for execution. They differ primarily in the mathematical formulation employed in their construction. To build a useful model and use if effectively, both builders and users must exercise specific responsibilities. Builders' responsibilities are identifying the need for a model, creating the model, checking its performance, documenting and distributing the model, and revising the model. Users' responsibilities are clearly defining the intended application, considering alternative models, asking questions about candidate models and evaluating the answers, evaluating model output, providing the builder with constructive criticism, and accepting model revisions.

INTRODUCTION

Forest managers and researchers use growth and yield models to project growth, provide yield information for economic projections and analyses, and to predict responses to silvicultural treatments. To be effective for these purposes, a model must be used in a manner consistent with the assumptions made in its construction. These assumptions and the possible consequences of violating them must be stated by the model builder and understood by the user. In this paper I present general information about the types of growth and yield models available. For each type I describe inputs, outputs, and some basic assumptions made in model construction. I also suggest a division of responsibilities between model builders and model users that will assure successful application of growth and yield models.

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MODEL TYPES

Generally, growth and yield models belong to one of four classes: whole stand models, diameter distribution models, individual tree models, or height-diameter distribution models. I will briefly describe how these classes of models are constructed and indicate the inputs and outputs for each. Throughout the following discussion, dominant height refers to the average height of the 100 tallest trees per acre.

Whole Stand Models

Whole stand models are usually of the form:

$$\text{Log}(V) = a + b/A + c(s) + d(\log(N)) \quad (1)$$

where: V = yield (e. g., total volume, merchantable volume)
A = age
S = site quality (e. g., site index, dominant height)
N = stand density (e. g., basal area per acre, stems per acre)
a, b, c, d = parameters estimated from data.

An example of a whole stand model is given in Coile and Schumacher (1964). Given a specific age, site quality and stand density, this type of model provides an estimate of the total volume per acre, but does not provide a direct estimate of growth or distribute the predicted volume into size classes. Multiple regression models of this type are very sensitive to values of the input variables outside the range of data used in their construction. Therefore, predicted volumes may be inconsistent with actual stand volumes.

Diameter Distribution Models

Diameter distribution models treat the stand as a frequency distribution of diameters. Changes in frequency distribution is projected over time with parameters that are functions of age, the number of stems surviving at that age, and site quality (site index or dominant height). Inputs to these types of models are generally stand age, site index, and the number of stems per acre at that given age. Outputs from these types of models are often presented by diameter class and include survival over time (stems per acre), average height, dominant height, basal area per acre, and yield per acre at some future time. Depending on the specific model, yield may be expressed as total cubic foot volume, volume of a specific product, or weight. The average height for a given diameter class is determined from a height-diameter equation. Information for the stand as a whole is obtained by summing the information from the individual diameter classes. Examples of diameter distribution models are given in Clutter, et al (1984) and Smalley and Bailey (1974).

Individual Tree Models

Two classes of individual tree models are distance-independent and distance-dependent models. In many of these models, the input is information about individual trees on a given plot area. Output is a projection of future changes in the stand. It is converted to amounts per acre by using the appropriate plot blow-up factor.

Distance-independent models.--In a distance-independent model, the dimensions of each tree change over time according to the size of the tree relative to all trees on the plot. Large trees grow more each year relative to the smaller trees on the plot. Inputs to these kinds of models are stand table data (frequency and average height by diameter class), stand age, and site index. Tree growth is projected through time by incrementing the diameters and heights with functions dependent on age, site index or dominant height, the number of surviving stems, and the relative size of the specific individual. Outputs include survival (stems per acre), average and dominant height, basal area per acre, and yield per acre at some future time. Depending on the model, yield can be expressed as total cubic foot volume, volume of a specific product, or weight.

Distance-dependent models.--In distance-dependent models, each tree is grown according to its size relative to that of its neighbors. This requires that the location of each tree, the distance to each of its neighbors, and information regarding the size of the area of influence of each tree be input and maintained. The area of influence of a given tree is determined primarily by size. That is, large trees generally influence larger areas (and more trees) than do the smaller trees. A tree that is larger than the trees within that individual's area of influence grows relatively more than those smaller trees. Diameters and heights of individual trees are increased by means of functions dependent on age, site index or dominant height, size and location of the tree and its neighbors, and the number of surviving stems. Typical input to this type of model is a tree list containing the diameter, height, and relative location of each tree on the plot. Outputs include survival (stems per acre), average and dominant height, basal area per acre and yield at some future time. Depending on the model, yield information can be expressed as total cubic foot volume, volume of specific product, or weight. Distance-dependent models generally demand more computer resources than other types of growth and yield models because of the additional storage and calculations necessary to maintain the location and determine the area of influence of each tree. Examples of distance-dependent models for loblolly pine are given in Daniels and Burkhart (1975) and Daniels, et al (1979).

Height-Diameter Distribution Models

Height-diameter distribution models treat the stand as a frequency distribution of heights and diameters, somewhat similar to a two-way stand table. Such a joint distribution is called a bivariate distribution. The bivariate frequency distribution or stand table is projected through time by using parameters that are functions of age, dominant height and the initial stand density. Inputs to this type of model are generally age, site index, and the number of stems per acre at that given age. Outputs are given by diameter and/or height class and include survival (stems per acre), average and dominant height, basal area per acre and yield per acre at some future time. Depending on options chosen by the user, yield can be given as total cubic foot volume, volume of a particular product, or weight. Information for the entire stand is obtained by summing the information from each height-diameter class. An example of a height-diameter distribution model is given in Hafley and Buford (1985).

What's the Difference?

Treatments such as thinning, spacing, and weed control can be accounted for in the types of models described above. All four model types are available for mainframe computers and microcomputers. Whole stand models are also available on hand-held calculators. As discussed above, these models have essentially the same input requirements and provide similar information as outputs. The question is "What's the difference among the models?" or "What difference does it make which I choose?".

These types of models differ primarily in the assumptions made about stand growth, in the mathematical forms incorporating these assumptions, and in the detail or resolution of the model. The assumptions made about stand growth and the detail necessary to describe it determine, to a large extent, the functions used to describe the stand over time (model construction) and the detail of the information available as output (model resolution). A brief summary of the assumed advantages for each type of model are:

1) Whole stand models provide a mechanism for predicting overall yields for some existing conditions.

2) Diameter distribution models can give more detail about stand structure than whole stand models.

3) Distance-independent models compute stand-level information obtained by summing individual tree yields. It is assumed that they provide greater statistical precision than stand-level models.

4) Distance-dependent models may provide more precise predictions of tree growth because size and location of competing neighbors are known (Clutter and others, 1983).

5) Height-diameter distribution models account for the distribution of tree heights which should be considered in silvicultural decisions such as thinning.

Discussion of specific assumptions and decisions regarding stand dynamics and the mathematical functions used in each model is outside the scope of this paper and can be found in the given references.

RESPONSIBILITY

In simple terms, the world of models is inhabited by two groups: the builders and the users. These groups overlap when a builder uses a model or a user takes some part in model construction. However, large segments of both groups view the other group as an unknown and perceive the boundaries between groups to be concrete. This perception causes the attitude of "It's <u>not my</u> job!" to surface when users are asked to critically examine model behavior and predictions or when builders are asked to be more responsive to particular needs of users. A major goal of growth and yield model building is to provide a realistic model for yield prediction and economic analysis. Such a model can only be obtained by the interaction of both users and builders with the attitude that "It <u>is</u> my job!" The following sections describe what I believe to be the main responsibilities of both builders and users.

Builders' Responsibilities

Builders have the responsibility to 1) formulate, 2) create, 3) validate, 4) document and distribute, and 5) reevaluate the model. To formulate the problem, the builder must state the reasons for building a new model, pose the questions to be answered in the building process, and specify the hypotheses to be tested regarding tree and stand growth. In creating the model, the builder must state the assumptions made about stand development, determine the mathematical functions that match those assumptions, and fit the functions to the data. The builder has a responsibility to validate the resulting model. Validation here means testing the predictive ability of the model against data that were not used in model construction and checking the behavior of the model at extreme conditions (at especially high or low densities and/or at especially high or low site indexes) to determine if the model's behavior makes sense. A practical and straightforward effort in model validation is presented by Smith and Hafley (1986).

After validation, the builder has the responsibility to document the process of model building and to distribute both the model and the documentation to interested users. The documentation should include both the known strong and weak points of the model. Distribution may be in the form of articles in scientific journals, through workshops, or by communication with a specific user group. The builder then has the responsibility to consider both the validation work and any feedback obtained from the users in reevaluating the original model. Builders should be responsive to comments from the user. Some questions that might be asked and should be addressed at this time are: 1) "Does the model behave as forest stands behave?" 2) "Does the model address the needs of the intended users?" and 3) "Can additional silvicultural treatments be included in the model?"

Users' Responsibilities

The responsibilities of the user are to 1) define the objective to be met in using a model, 2) consider alternative models, 3) ask questions about the candidate models, 4) evaluate the answers to the questions and the output of the models, 5) provide the builder with constructive criticism, and 6) accept model revisions. The user must determine the objective to be met in using a growth and yield model. Objectives may vary from obtaining simple yield information for given stand conditions to predicting the size class distribution at age 30 resulting from a complicated series of thinning and weed control treatments. After clearly stating the objective, the user should consider alternative models that provide the same level of detail. Guidance in finding candidate models may be obtained from Extension Foresters, selected faculty members at colleges or universities, and knowledgeable consultants. Once candidate models have been located, the user should direct questions about them to other users and to the builder of the model. Questions may range from how a model may be implemented on a particular computer system to very specific questions about the behavior and construction of individual model components.

The user has a responsibility to evaluate the quality of the answers to the questions asked and a responsibility to evaluate the model output. There is no universally accepted set of "correct" functions or assumptions among builders. Therefore, the user must evaluate the model in light of his or her own experience with forest stands. Regardless of statistical or mathematical expertise, the user should be able to draw on his or her experience or the experience of colleagues to determine whether or not the output and behavior of the model make sense. The user who obtains a growth and yield model and accepts it without some measure of evaluation is likely wasting his or her time and money. If a builder provides unsatisfactory answers to questions regarding model behavior or output, or if a model consistently produces volumes or size class distributions that do not match what exist in the stands of interest, then the user should choose another model. There should be no "black boxes." That is, the builder should be able to explain in common terms the assumptions underlying the model, the basic model construction, and why a model behaves in a given way under specific conditions. If a builder cannot do this, then the user should probably choose another model.

The user has a responsibility to provide constructive criticism to the builder. A detailed letter or a telephone call can alert the builder to an unknown problem with a model and may initiate a profitable interaction for both builder and user. Once the builder has reevaluated and revised the model, the users should accept the revision and begin the evaluation process with the revision. Since all models are approximations to reality, a revised model does not mean that the original was "wrong," but that the revision is an improvement and represents the builder's response to the users' comments.

SUMMARY

A major goal of model building is to produce a realistic model for yield prediction, and a major goal in using a growth and yield model is to obtain accurate information about yield under given management practices. As outlines above, both builders and users have responsibilities in the process of achieving these goals. Both groups have the responsibility to seek out and question the other group, and must increasingly interact if the goal of useful models is to be reached.

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