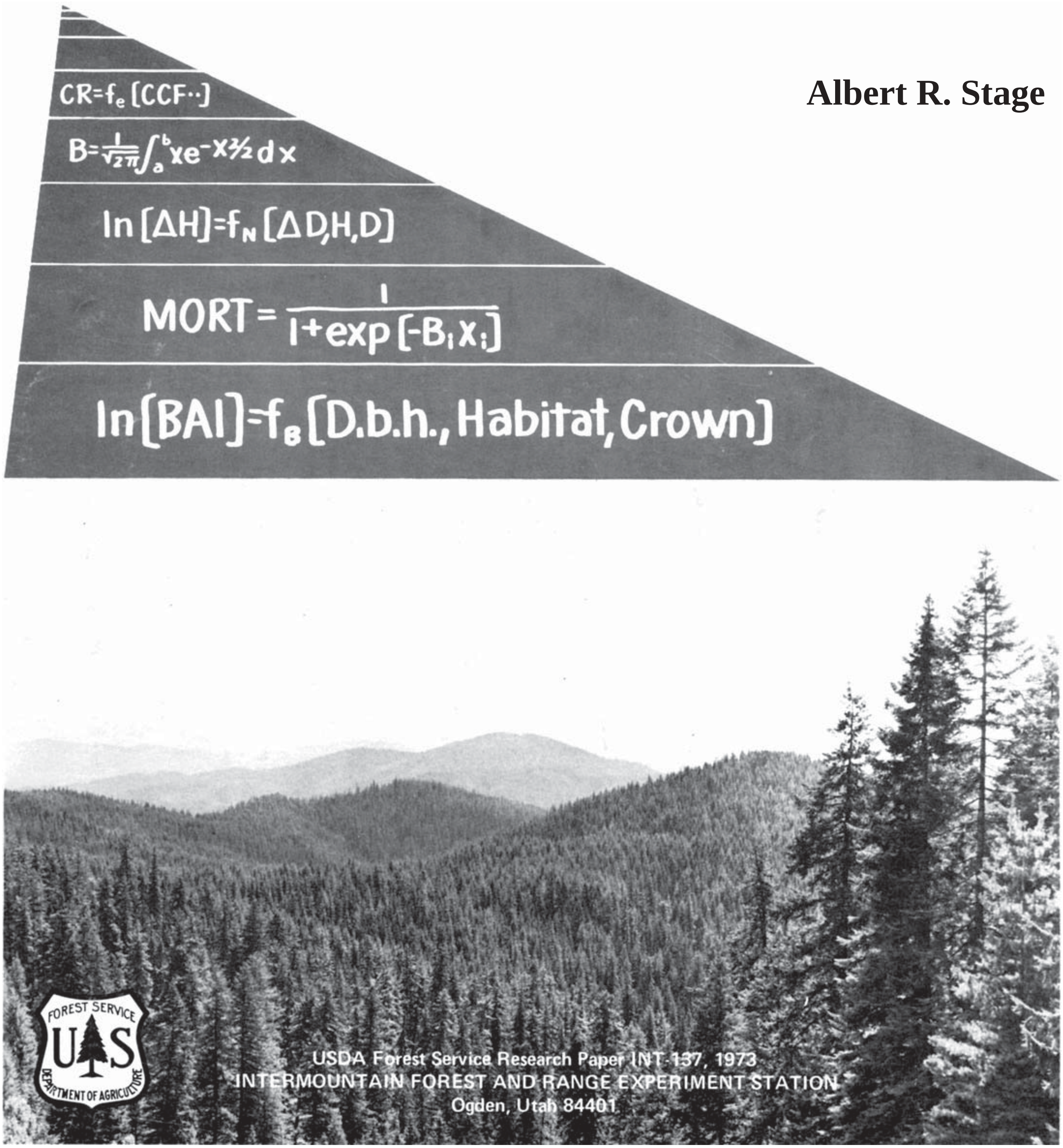
PROGNOSIS MODEL FOR STAND DEVELOPMENT

Albert R. Stage



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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Ogden, Utah 84401

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ABSTRACT

This paper describes a set of computer programs for combining quantitative silvicultural knowledge with past growth data from a sampled stand to make a prognosis of the course of development that the forest stand is expected to follow under alternative management prescriptions. An important design criterion of this procedure is that the prognosis model should apply to stands containing any mixture of species or age and size classes that grow as a community. The model simulates the deviation-amplifying aspect of the growth process by a unique procedure for introducing the stochastic elements in a deterministic computing algorithm. The growth rates predicted by the built-in models for diameter change are compared to the actual past growth of the sample trees to calibrate these models for the particular stand for which the prognosis is to be computed. Selection of trees to be cut at any period can utilize a variety of tree characters to emulate a wide range of silvicultural prescriptions.

An application of these programs to develop prognoses for lodgepole pine stands in the presence of an infestation of mountain pine beetles is described.

INTRODUCTION

What are the future impacts of present management practices on tree growth? The answers to this question, for a variety of timber-growing sites and stand structures, encompass the full range of skills of the silviculturist. Answering the question in quantitative terms also requires the means to accomplish the large volume of computations that are necessary to represent the complex biological interactions that characterize the development of a forestry community. This paper describes a set of computer programs for combining our current silvicultural knowledge with past growth data form a sample stand to make a prognosis of the course of development that the forest stand is expected to follow under alternative management prescriptions. This model is deliberately termed a prognosis rather than either a simulation or projection. Most forest stand simulators begin with hypothetical distributions of trees in space; whereas this program begins with a diagnostic description of the present forest. The result is not a projection because the course of stand development depends on the detailed interaction of growth factors rather than upon following a initial trajectory implied by current growth rates.

For many of our forest types, our ecological and silvicultural knowledge is incomplete. It follows that the programs that comprise this model are also incomplete. My hope is that the design is sufficiently flexible that new capabilities can be added as silviculturists develop better quantitative representations of the various biological aspects of tree growth. Indeed the gaps in this model call attention to corresponding gaps in silvicultural research.

An important design criterion of this model is that the prognosis should apply to stands containing any mixture of species or age and size classes that grow as a community. That is, the model should apply equally well to pure even-aged stands or stands composed of a mixture of ages, species, and sizes.

Growth models that are tree-by-tree analogs of stand development can be useful adjuncts to silvicultural research. In this context, they can be used to interpolate among the limited number of treatment combinations that can be installed in a research study of feasible scope. For this use, resolution of the model should be capable of describing tree growth in sufficient detail to demonstrate subtle differences between treatments. On the other hand, in the context of forest management planning, much less detail is required about individual trees. Consequently, the development of this program has followed a middle course between the growth simulation models (described by: Mitchell 1968; Newnham and Smith 1964; lee 1967; and Arney 1972) that maintain the map coordinates of the trees through time and the stand projection programs such as TRAS (Larson and Gogorth 1970) that combine trees from widely diverse stands into common cells. The effect of competition from neighboring trees on the growth of an individual tree is retained through the early stages of projected time by maintaining the identity of the neighboring trees sampled at the same small diagnostic plot within the stand. In addition, variables expressing competitive status are computed from the relative position in the stand table and from the crown description (Appendix I)

Diagnostic examinations of forest stands are routine in the practice of silviculture. This program is designed to use sample data from these routine stand examinations as starting values for the prognosis. Two types of stand examinations are accommodated. In the first type, which is appropriate for surveying the regeneration phase of tree development, the sampling unit is an area of land such as a 4-milacre quadrat or a 1/300-acre circular plot. For such samples, the characteristics being modeled would be the species and heights of the dominant trees, a measure of competing vegetation, and little else. In the second type, the individual sample tree is the record unit. The tree characteristics recorded in this type of inventory emphasize the information needed to estimate its future course of development. As stands described initially by the stocked quadrat survey are projected through time by the program, the records are converted to the individual tree type of data for prognosis of subsequent stand development.

The functions that drive the prognosis are expressions for finite differences--that is, for the periodic rates of change of the various aspects of tree growth. Coefficients in the tree growth functions are estimated from past records of growth. Sources may include growth recorded in management inventories, and in research studies of silvicultural treatments for of insect and disease impacts. However, at the start of the prognosis, these coefficients based on prior analysis of growth are modified if the growth records of the stand being modeled provide sufficient evidence that the growth rated specified by the growth functions are not appropriate. Through this process of "self-calibration," the model can accommodate itself to local peculiarities of site quality, genetic character, and tree vigor. In fact, the calibration variable can be interpreted as a measure of local site quality in healthy stands, or as a measure of impact of insect or disease outbreaks on the rate of accretion.

Growth is a process that amplifies the effects of previous departures from the mean growth level. To incorporate this characteristic of the growth process, special techniques of computation have been developed to retain the effects of the stochastic aspect of the growth process in the prognosis program.

The prognosis is developed by first estimating the changes to be expected in the tree conformation--diameter, height, and crown--during the next growth period. Then, the trees-per-acre corresponding to each sample-tree record is reduced for the expected mortality rate appropriate to a tree of its characteristics growing in such an environment. The tree projection process is repeated for successive growth periods and appropriate displays of the stand's development are produced for each period along the way.

Harvests (i.e. partial cuts, thinnings, or cleaning) can be scheduled at the start of any growth period. Selection of trees to be cut can utilize any of the characteristics describing the sample tree and the stand to simulate a variety of silvicultural prescriptions. If these silvicultural prescriptions are keyed to the timber classes and management alternatives specified for the Timber RAM Matrix algorithm (Navon 1971), then this growth prognosis model can be used to provide the yield schedules required by RAM for scheduling timber harvests.

INFORMATION PRODUCED

A surfeit of detail about the tree development is available within the computer data files. How to assemble this detail into information useful to the manager in compact form is no small problem. Certainly, numbers of trees, their distribution by size, the volume of scheduled harvests, and its species composition are essential elements of the output. Stand and stock tables-arrays of numbers of trees and volumes by diameter classes-are the customary means of presenting such information. However, diameter-class intervals appropriate to one stage of development of a stand would either provide excessive detail at later stages, or insufficient detail at earlier stages. Instead, the distribution of any attribute with regard to diameter is displayed by printing the lowest diameter such that a given fraction of that attribute for the stand is entirely contained in trees of that diameter and larger. For example, figure 1A is a portion of the output from a lodgepole pine stand as it is expected to develop from 1969 to the year 2020. In 1969 there was a total of 509 trees per acre. Of these, 10 percent were larger then 8.9 inches d.b.h., 50 percent were larger than 6.8 inches d.b.h., and 90 percent were larger than 5.7 inches d.b.h. At the same time, 50 percent of the total volume (which was 4,775 cu.ft./acre) was contained in stems larger than 7.3 inches d.b.h.

The periodic mean annual accretion (growth on surviving trees) and mortality from 1969 to 1980 are indicated as 110 and 61 cubic feet per acre per year, respectively. The distributions of growth and mortality by size classes are provided with the same interpretation described for numbers of trees and volume. In 1990 the stand was thinned from below to a residual density of 300 trees per acre. Volume removed was 535 cu.ft.

Species composition is indicated by displaying the percentages of the total volume (cu.ft.) that represent each of the three most plentiful species. Species composition is displayed for only those stand attributes that are measured in units of cubic feet.

Yields in units of merchantable product are, of course, vital to the utility of this program for management planning. Grosenbaugh (1954) and Bruce (1970) have shown how summaries of the primary units of volume (cu.ft.), bole surface area (sq.ft.) and bole length (ft.) can be used to predict yields when the wood is manufactured into a wide variety of products. Furthermore, the conversion from the trio of primary units to product yield is linear and additive. Consequently, sums of the volumes, surfaces, lengths, and numbers of stems can be accumulated by species over many stands in a population before the conversion in computed.

Growth trends of the individual trees of interest to supplement the stand summaries described above. By following individual tree records through the cycles of predicted growth, we can gain additional insight into the prognosis model. The second output table shows the development of the five sample trees that occur at the boundaries of the fractions of the initial diameter distribution (percentile). Species, d.b.h., height, crown ration, past diameter growth, and trees-per-acre associated with each of the five sample tree records are shown, along with the relative density of the stand (fig. 1B).

1A STAND DATA CARD:
2506316 4121 11210 2124329119006 62020 0 80 45 100 0.0

STAND ID= 1 FAB=21 AREA =119 POINTS= 6 ELEV=43 S.I.= 80 AGE= 45

YEAR	ATTRIBUTE	FRACTION CF STAND .9	.7	.5	.3	.1	TOTAL		SF ECIES COMPOSITION		
		(LOWEST DBH IN STAND FRACTION)									
1969	STAND- TREES	5.7	6.2	6.8	7.7	8.9	509.	NO/A			
	VOLUME	5.8	6.8	7.3	8.5	9.2	4775.	CUFT	100.% LP,	0. % --,	0. % -
	SURFACE						39577.	SOFT			
	LENGTH						31635.	FEET			
	ACCRETION	6.2	7.3	8.2	9.2	10.2	100.	CUFT/YR.	100.% LP,	0. % --,	0. % -
	MORTALITY	5.7	6.2	6.8	7.6	8.7	61.	CUFT/YR.	100. % LP,	0. % --,	0. % -
1980	STAND- TREES	6.1	6.8	7.4	8.4	9.6	426.	NO/A			
	VOLUME	6.2	7.2	8.2	9.2	10.1	5203.	CUFT	100. % LP,	0. % --,	0. %-
	SURFACE						40217.	SOFT			
	LENGTH						29738.	FEET			
	ACCRETION	6.7	7.7	8.8	9.8	10.9	98.	CUFT/YR.	100. % LP,	0. % --,	0. % -
	MORTALITY	6.1	6.8	7.3	8.2	9.4	65.	CUFT/YR.	100. % LP,	0. % --,	0. % -
1990	STAND- TREES	6.4	7.2	7.8	9.1	10.3	364.	NO/ A			
	VOLUME	6.7	7. 7	8.8	9.8	I0.8	5536.	CUFT	100. % LP,	0. % --,	0. % -
	SURFACE						40318.	SOFT			
	LENGTH						27865.	FEET			
	REMOVAL						64.	NO/A			
	VOLUME	6.2	6.3	6.4	6.5	6.6	535.	CUFT	100.% LP,	0. % --,	0. % -
	SURFACE						5123.	SOFT			
	LENGTH						4526.	FEET			
	RESIDUAL	7.0	7.6	8.4	9.4	10.5	300.	NO/ A			
	ACCRETION	7.7	8.6	9.6	10.5	11.7	88.	CUFT/YR.	100. % LP,	0. % --,	0. %-
	MORTALITY	7.0	7.6	8.1	9.1	10.1	62.	CUFT/YR.	100. % LP,	0. % --,	0. % -
2000	STAND- TREES	7.5	8.1	9.0	10.1	11.1	257.	NO/ A			
	VOLUME	7.7	8.6	9.6	10.4	11.6	5258.	CUFT	100.% LP,	0. % --,	0. % -
	SURFACE						34945.	SOFT			
	LENGTH						21738.	FEET			
	ACCRETION	8.2	9.2	10.4	11.1	12.5	89.	CUFT/YR.	100. % LP,	0. % --,	0. % -
	MORTAL ITY	7.5	8.1	8.8	9.7	10.7	66.	CUFT/YR.	100. % LP,	0. % --.	0. % -
2010	STAND- TREES	7.9	8.7	9.6	10.6	11.9	221.	NO/ A			
	VOLUME	8.1	9.2	10.4	11.1	12.5	5493.	CURT	100. % LP,	0. % --,	0. % -
	SURFACE						34440.	SOFT			
	LENGTH						20098.	FEET			
	ACCRETION	8.7	9.9	11.1	11.8	13.4	87.	CUFT/YR.	100. % LP,	0. % --,	0. % -
	MORTALITY	7.9	8.5	9.3	10.5	11.5	70.	CUFT/YR.	100. % LP,	0. % --,	0. % -
2020	STAND- TREES	8.3	9.2	10.2	11.3	12.8	189.	NO/A			
	VOLUME	8.6	9.8	11.0	11.7	13.3	5671.	CUFT	100. % LP,	0. % --,	0. %-
	SURFACE						33577.	SOFT			
	LENGTH						18420.	FEET			

1B STAND ID= 1 SAMPLE TREE RECORDS SITE= 80.0

YEAR	%TILE	SPECIES	DBH (INCHES)	HEIGHT (FEET)	CROWN RATIO	PAST DBH GROWTH	TREES/ ACRE	STAN AGE	MEAN DBH	TREES/ ACRE	BASAL AREA	STAND REL DEN
1969						(10 YRS)						
	.9	LP	5.7	53.0	33	0.30	18.811					
	.7	LP	6.2	63.0	34	0.30	15.899					
	.5	LP	6.8	67.0	35	0.30	13.217					
	.3	LP	7.7	61.0	36	0.40	10.308					
	.1	LP	8.9	65.0	38	0.40	7.716					
								45	7.3	509.486	146.662	169.1
1980						(11 YRS)						
	.9	LP	6.0	60.4	33	0.31	14.240					
	.7	LP	6.5	70.2	33	0.35	12.506					
	.5	LP	7.2	74.2	34	0.38	10.852					
	.3	LP	8.1	68.4	35	0.44	8.920					
	.1	LP	9.4	72.5	37	0.53	7.133					
								56	7.8	426.398	142.766	158.9
1990						(10 YRS)						
	.9	LP	6.3	66.9	34	0.29	11.145					
	.7	LP	6.9	76.6	34	0.31	10.088					
	.5	LP	7.5	80.6	35	0.34	9.041					
	.3	LP	8.5	75.0	36	0.39	7.791					
	.1	LP	9.9	79.1	38	0.47	6.594					
								66	8.7	300.005	124.406	132.4
2000						(10 YRS)						
	.9	LP	7.0	73.9	37	0.68	0.174					
	.7	LP	7.1	82.9	36	0.28	7.937					
	.5	LP	8.2	87.3	37	0.65	7.348					
	.3	LP	8.9	81.5	38	0.39	6.680					
	.1	LP	10.3	85.6	40	0.41	6.024					
								76	9.3	257.446	120.780	125.3
2010						(10 YRS)						
	.9	LP	7.2	80.2	38	0.26	0.136					
	.7	LP	7.8	89.5	37	0.63	6.228					
	.5	LP	8.4	93.3	38	0.22	6.039					
	.3	LP	9.3	87.8	39	0.35	5.665					
	.1	LP	10.8	92.1	40	0.53	5.467					
								86	9.9	220.776	117.363	118.9
2020						(10 YRS)						
	.9	LP	7.6	86.5	43	0.37	0.105					
	.7	LP	8:3	95.9	41	0.49	4.888					
	.5	LP	8.8	99.5	42	0.39	4.859					
	.3	LP	9.9	94.4	43	0.60	4.757					
	.1	LP	11.6	9P.7	44	0.72	4.920					
								96	10.5	188.809	113.379	112.3

Figure 1.--Output for a pure LODGEPOLE pine stand to be thinned to 300 trees per acre in 1990.

INPUT VARIABLES

The variables used to describe the stand at the start of the prognosis are listed below. Some of these items may be omitted if the growth functions for a particular forest type do not use them. A specific format for the input of these variables is given in Appendix II.

Sample design (see Appendix III):

Stand expansion factor or sampling weight

Number of plots in the stand

Type of stand examination (quadrat description vs. tree enumeration)

Fixed-area-plot size

Variable-radius-plot basal area factor

Tree d.b.h. dividing fixed form variable plot tally

Management class code designating recently cut tree or recent mortality tree

Period for measurement of radial or height increment

Site characters:

Site index	Aspect
Elevation	Slope
Latitude	Physiographic site
Habitat type	Stockability[1]
Competition from nontree species	

Stand characters:

Timber class	Stand origin
Age (if even-aged)	Total stand area
Proposed management prescription	

Tree characters:

Plot identification

Species

Number of trees represented by this record on the plot

D.b.h.

Height[2]

Live crown percentage[3]

Radial increment and bark thickness at b.h.[3]

Management class

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[1]A.K. Wilson. Yield and productivity problems in Rocky Mountain States inventories. Intermt. For. and Range Exp. Stn., Ogden, Utah (In preparation)

[2]Can be included as a subsample.

[3]Can be omitted or included as a subsample.

COMPONENT MODELS

Full implementation of this prognosis algorithm requires three kinds of models for:

Development of individual trees

Development of regeneration stands including ingrowth into existing stands

Transition from regeneration phase to individual tree phase

Only the model for the first of these three processes is described in this paper. The latter two processes will require some additional silvicultural research before general models can be derived. Growth functions should be based on data derived from the area to which the model is to be applied. The self-calibration feature of this model only partially mitigates this admonition.

Models for Development of Individual Trees[4]

The growth model for saplings and larger trees is a set of functions that predict the rate of increase of tree d.b.h., the rate of increase in tree height, the change in crown dimensions, and the change in bark thickness. The change in number of trees per acre represented by each sample tree is based on a function estimating the mortality probability.

The nature of the variables that should be included in the growth functions is controlled by the purposes for which the prognoses are to be used. For example, if the only course of development to be modeled is the unmanaged trends of natural stands, without catastrophic disturbance, then a variable representing past growth rate would be a very effective predictor of succeeding growth rates. It would include most of the effects of site, stand density, individual tree vigor,

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[4]The logic of the program provides for distinct functions for 11 different species or species groups. To increase the number of species would not be particularly difficult.

and more. But if we wished to model the effects of thinning or partial cutting, then the prognoses would be inadequate because the changes in stand density would not be reflected in changes in growth rates. The past growth variable would be an alias for stand density effects. Similar difficulties could arise from the combination of age and size in the prediction because size divided by age is, in effect, a measure of past growth.

The key growth function predicts the rate of increase of tree d.b.h. The dependent variable is the logarithm of the annual increase in the square of d.b.h. in inches; thus, this variable is equivalent to the logarithm of the basal area increase. Basal area was selected because its increase is most frequently linear with time. This linearity facilitates projection for intervals different from the growth interval over which the parameters of the model were estimated. If basal area increase is measured without bark, then the ration of basal area outside bark to basal area inside bark is used to convert the increment to outside-bark measure.

The logarithmic transformation is used here for two reasons: First, diameter growth rate distributions are bounded by zero at the lower end (ignoring the effects of bark sloughing) and so tend to be quite skewed; hence, the arithmetic mean is an inefficient estimator. Second, the variability of diameter growth rates about their mean tends to increase as the mean increases. The logarithmic transformation in most cases has resulted in a uniform variance. The method of Oldham (1965) is used to estimate the arithmetic mean of the diameter growth from the logarithmic model. A further refinement developed by Bradu and Mundlak (1970) was considered unnecessary because the standard errors of estimate are usually small enough that the differences between the two methods are trivial.

Predictor variables that are available include the site and tree characters listed previously. Additional variables that measure stocking or relative stand density such as crown competition factor, basal area, or stand density index can be computed from the distribution of the tree diameters. Variables that measure the competitive relations between trees in the stand include the percentile in the basal area distribution or the ration of tree d.b.h. to mean stand diameter (Appendix I). In addition, predictions for rates computed earlier in the sequence of calculations can be used as predictors. These models are summarized as follows:

Tree growth components	*Predictor variables*	*Data source*
Annual basal area increment (b.a.i.)	D.b.h., relative stand density, site, elevation, habitat type, percentile in basal area distribution, crown ratio	Increment cores, remeasured plots
Height increment	Radial increment, habitat type, d.b.h., height	Stem analyses
Crown dimensions	Relative density, percentile in basal area distribution, d.b.h.	Temporary plots
Bark ratio	Same as b.a.i.	Temporary plots or tree samples
Mortality rates	Same as b.a.i. and radial increment plus pest population models where applicable	Remeasured plots, “last *n* years mortality”, “years since death” (truncated)

Procedures for estimating the functional forms and their coefficients are readily available in many texts on multiple linear or nonlinear regression for models with continuous dependent variables such as height and diameter increment, and for crown and bark dimensions.

The mortality models require rather different statistical techniques. One possible mortality model and an estimation procedure developed especially for that model have been describes by Hamilton (in preparation). Examples of how these models might be formulated are illustrated in a later section where the implementation of this prognosis procedure is described for lodgepole pine.

Self-Calibration of Diameter Growth Functions

The self-calibration feature is intended to scale the diameter growth functions that are contained in the program so that the predictions match the actual growth rates measured on the trees in the stand to be modeled. First, the stand stocking that existed at the start of the period during which growth was recorded is estimated. To do this, the average basal area growth percentage is calculated for the growth-sample subtracting the product of present basal area times the mean ratio of past basal area increment to basal area derived from the growth-sample trees. The sum of diameters if similarly reduced using the square root of the ratio. Then, the stocking at the start of the period is computed from the number of trees, and the reduced sums of diameters and of their squares. Trees removed or dying during the calibration period are included in the prior stocking with no growth adjustment. All other stand parameters are assumed to have remained constant.

Deviations between predicted and recorded growth rates (scaled in units of the logarithm of change in the square of diameter) are then sorted and the median deviation calculated. The value of the median is subtracted from the constant term of the logarithmic growth function to calibrate it. Thus, the effect is to multiply each prediction by a correction factor.

The median was selected as the location parameter for the adjustment rather than the mean because it is less likely to be influenced by occasional outliers due to measurement errors or abnormalities of growth (Barrodale 196; Forsythe 1972).

STOCHASTIC FEATURES

Random variation about a statistical mean is a characteristic of all growth phenomena. In modeling procedures, the primary objective is to produce estimates of future yields that are the expectations of the overall stand growth process. The approach that is generally used is to assign a random error drawn from an appropriate distribution to each prediction.

The nature of the distribution of the random component depends intimately upon the resolution of the estimation function with which the random variable is associated. In addition, the self-calibrating feature of this prognosis program influences the distribution of the unexplained variation that is to be represented by the random variable. For example, in the function for diameter change, there are variables that change from tree to tree; other variables change from period to period for the same plot and a few variables that quantify unchanging characteristics of the stand such as site, elevation, or habitat. Consequently, the unexplained variation about the regression surface will have three components; among trees, among periods, and among stands. The self-calibration procedure serves to remove the “among stand” component of the residual variation, leaving the other two components to be represented by the distribution of the random variable.

To appreciate the effect of resolution of the estimation function of the distribution of the random variable, consider two functions for diameter changes that differ only by including or excluding a variable that evaluates a significant effect of crown development. Crown development changes slowly with time; therefore, as an explanatory variable it has a high serial correlation from period to period for a single tree. A stand-growth model could use either function (assuming the simulation is not intended to compare pruning alternatives). However, if the function without the crown development variable were used, the variance of the random variable would have to be larger, and the serial correlation between the random variables assigned to each tree in successive periods would need to be larger than if the crown variable were included. Either alternative could be used to generate a stand simulation with the same expected values as long as the stand progresses in a way that does not modify the natural correlations between stand density and crown development. The difference in results between the two alternative formulations would show up only in the variability of repeated runs of the prognosis. The lower the resolution of the components, the greater would be the variability among repeated runs.

Which predictions should be subject to a random component and which can be held to their mean estimate is a choice that depends on the nonlinearity of the effects of the variation in subsequent calculations. If assessing the variability of the outcome *per se* were one of the objectives of the modeling, then most of the prediction equations would require a random component. To obtain the expected value of the random process, the whole sequence of computations would be repeated with different random errors and the process averaged over the replications. One of the drawbacks to this approach is that the volume of computations is very large if it is applied to the solution of all prediction equations that make up the overall model. Another drawback is that little is known of the serial correlation that ought to characterize the successive values of the random variables. Are large positive deviations from expected diameter increment more likely to be associated with large positive deviations from expected height increment--or with expected changes in the crown dimensions?

The approach used in the present version of this program may be considered in Monte Carlo terms, a “swindle.” The purpose is to produce a prognosis that overall is the result of averaging many replications of the random process without actually having to carry out the replications.

Random Error in Tree Development

The program assigns all random effects to the distribution of errors of prediction of the logarithm of basal area increment. Basal area increment was selected to carry the stochastic variation because the effects of differing diameter growth rates ramify in highly nonlinear way through most of the remaining components and variables such as percentile in the basal area distribution, relative stocking, the height increment model, and the crown development model. This distribution is assumed to be Normal, with a mean of zero. The variance of this Normal Distribution is computed as a weighted average of two estimates; the first such estimate is derived from the regression analysis that developed the prediction function and the second estimate is the standard deviation of the differences between the actually recorded growth (transformed to the logarithm of basal area increment) for the sample trees in the population and their corresponding regression estimates. The weights assigned to these two estimates are 100 for the prior component of error, and the number of growth-sample trees in the stand for the second component of error (Mehta 1972)

The effects of modifying the predicted change in tree d.b.h. by a random variable can then be carried into other predicted changes in tree characteristics by using the change in d.b.h. as an independent variable in each successive model. The random variable associated with each tree record is saved until the following cycle so that the appropriate serial correlation can be presered in the distribution of the random variables.

The random component of change in tree d.b.h. is treated in two ways, depending on how many tree-records make up the stand being projected. When there are many tree records, the effects of any one random deviation on the growth rate of one tree would be blended with many other trees. Consequently, the stand totals should be quite stable estimates. Accordingly, a random deviate from the specified distribution is added to the logarithm of basal area increment. Because of the logarithmic transformation, the effect on predicted diameter increment is multiplicative.

When the stand is represented by relatively few sample trees, however, a different strategy is used. In order to increase the number of replications of the random effects, each tree record is augmented by two additional records. These new records duplicate all characteristics of the tree except the predicted change in d.b.h. and the number of trees per acre represented by the source tree record. The trees-per-acre value of the source record is reduced to 60 percent of its current value. The two new records are given 15 and 25 percent of the source value; thus, the three records together still represent the same number of trees per acre.

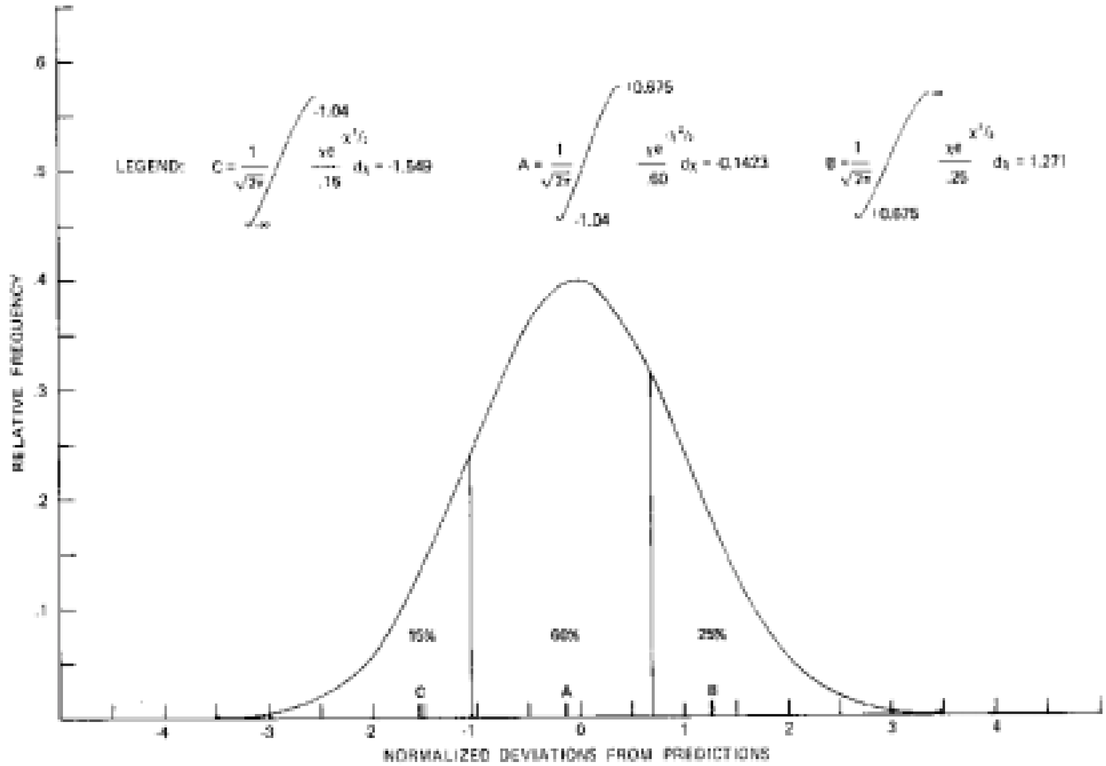

Figure 2.--Location of prediction points for three fractions of Normal Distribution.

Each of these three records is associated with one of the three portions of the error distribution characterizing the deviations about prediction (fig.2). The first record representing the 60 percent of the population (approximately the center of the distribution) is given a prediction to which is added the average value of the deviations in that portion of the normal distribution. This "biased" point is indicated by A in figure 2. The second record representing the upper 25 percent of the error distribution is given a prediction corresponding to point B, and likewise, the record for the lower 15 percent is given a prediction corresponding to point C. By this method, the weighted average prediction for the three records is still unbiased.

Which of these two procedures is followed is controlled by whether the number of tree records is greater than 1,350. Hence, a stand described by 150 tree records at the start would go through two projection cycles using the record-tripling approach before switching to the use of single random deviate for each record.

Mortality

Random fluctuations in mortality are notorious problems in analyzing forest growth. Unfortunately, our records that could be used to assess the distribution of the random variable for mortality are barely adequate to estimate an average mortality rate. The variability of mortality rates through time, in response to fluctuations in climatic stress, extreme winds, and other destructive agents is currently unavailable. Later versions of stand growth prognosis programs will, we hope, be able to assess the effects of the stochastic nature of mortality.

IMPLEMENTATION OF THE MODEL FOR LODGEPOLE PINE

Lodgepole pine was the first forest type for which this growth prognosis model was implemented. This species was selected because it characteristically grows in pure, even-aged stands so that the development of the necessary component models would be simpler than would be the case for mixed stands. Data on diameter-growth rates were available for a wide range of stand densities from studies installed as part of the Intermountain Station's silvicultural research on lodgepole pine. In addition, many lodgepole pine stands had been sampled in the course of the normal timber management planning inventories conducted by the Northern Region. Interregional site curves that include adjustments for stand density had been recently derived for this species (Alexander, Tackle, and Dahms 1967). In addition, a stand density study of lodgepole pine with very detailed data on crown development was also in progress in the silvicultural research project of the Pacific Northwest Station, Bend, Oregon (Dahms 1967). Lodgepole pine is not a particularly good forest type to demonstrate the full utility of the approach used in this growth prognosis program. Stand growth models such as developed for this species by Myers (1967) at the Rocky Mountain Station would be adequate for most purposes. However, stand growth models do not seem to be adequate for forest types of highly variable species composition or highly variable age class composition. Nor do stand growth models offer as much flexibility for comparing alternative silvicultural prescriptions as is possible with models treating individual tree records. Also, though the procedure may be overly detailed for a simple type such as lodgepole pine, the purposes for which this model has been developed would best be met by a unified approach applicable to all species and types.

Diameter Change Model

The data for estimating the change in d.b.h. are derived from three sources: The levels-of-growing-stock studies established in 1957 by David Tackle, formerly of Intermountain Station; the permanent sample plots established for management planning inventory on the Helena, Beaverhead, and Bitterroot National Forests; and the levels of growing stock studies established by the Pacific Northwest Station in the vicinity of Bend, Oregon. The steps followed in developing this model are described elsewhere.[5] The model is given by the following expression:

$$DG = \sqrt{DBH^2 + DDS} - DBH$$

where:

$$DDS = BKR \cdot FINT \cdot \exp(-1.66955 + 0.4143 \ln(SI) - 0.004388\ EL - 0.3781 \ln(CCF) + 0.4879 \ln(CR) + 0.9948 \ln(DBH) + 0.006141\ (PCT)$$

SI = Site index (Alexander, Tackle, and Dahns 1967)

EL = Elevation in 100's of feet

CCF = Crown competition factor

CR = Crown ratio ($0.0 < CR < 1.0$)

DBH = Diameter at 4.5 feet, in inches (o.b.)

PCT = Percentile in basal area distribution (see Appendix I)

BKR = Bark ratio = $(\frac{dob}{dib})^2$

$FINT$ = Projection interval in years

$\exp(A)$ = Exponential function of A

$\ln(A)$ = Natural logarithm of A.

Equation for Predicting Height Increment

The data necessary to predict height increment from stand density, crown ratio, diameter increment, etc., were derived from data collected by destructive sampling in the course of management sampling inventories. Trees to be felled were selected by first drawing a random sample of the inventory locations that have been measured. At each location a subsample of the trees was drawn so that ultimately the trees were selected with probability proportional to their basal area. In addition to the stand characteristics described by the standard management planning inventory location data, the radial increment is measured on two radii of a trunk section at breast height.

[5] Dennis M. Cole and Albert R. Stage. Intermt. For. and Range Exp. Stn., Moscow, Idaho (Ms. In preparation)

Then by using whorl counts, the height growth of the last 10 years is determined on the felled tree. From these data the following model is developed:

$$\ln(HTGF) = c_{1i} + c_{2i} \ln(DG+0.06) + c_{3i} \ln(DBH) + c_{4i} \ln(HT)$$

where:

$HTGF$ = Periodic height increment in feet

c_{ki} = Regression coefficients for the ith species

HT = Tree height in feet

DBH = Diameter at 4.5 feet, in inches

DG = Periodic diameter increment in inches.

Model for Crown Ratio Development

The model used to predict changes in crown dimensions is based on the rate at which the base of the live crown recedes which is expressed as a function of the height increment and the current level of stand density. For stands in which the crown competition factor is less than 125, the rate at which the crown recedes is specified to be equal to one-fifth of the increase in height for the tree. For stands having a crown competition factor greater than 125, the crown is specified to recede at a rate of 0.61 times the height increment rate.

A different model is used for trees for which no crown measurement was obtained. Under this alternative the height to the base of the live crown is predicted as a function of tree height, tree diameter, the relative position in the diameter distribution at the start of the prognosis, crown competition factor; and habitat type. The function is:

$$HCB = -29.26 + 0.61\ HT + 9.178 \ln(CCF) - 0.222\ EL - 5.80\ DBH/RMSQD + HAB$$

where the variables are as defined previously with:

$RMSQD$ = Diameter of the tree of mean basal area in inches

$$HAB = \begin{cases} 0.0 & \text{for Abies/Xerophyllum habitat} \\ -4.74 & \text{for Abies/Vaccinium habitat} \\ -3.86 & \text{for Abies/Pachistima habitat} \\ -5.47 & \text{for Pseudotsuga/Calamagrostis habitat} \end{cases}$$

Models for Mortality

Two alternative models for mortality rates were developed for lodgepole pine stands. One of these is based on the mortality study of Lee (1971). The other model is based on the dynamic relation between a population of mountain pine beetle (*Dendroctonus ponderosae* Hopk.) and the developing stand of lodgepole pine. The model for beetle-induced mortality was developed in cooperation with, and using data from studies by Walter E. Cole and Gene D. Amman, on file at Intermountain Station, Ogden.

Endemic Mortality

Mortality rates were derived by Lee from yield tables for Alberta and verified by him using data from remeasured sample plots. Judging by the nature of their source, his rates are presumed to apply to the development of stands in the absence of mountain pine beetle. Overall rates are highest in stands composed of small-diameter trees. The rates decline with increasing mean d.b.h., reach a minimum at 10.6 inches, and then begin increasing. The rates are independent of stand density.

In order to distribute the mortality rates over the range of diameters within the stand, Lee's rates were multiplied by a factor that depends on the percentile of the tree within the basal area distribution. The factor used was:

$$[0.25 + 1.5\ (1. - PCT/100.)]$$

where *PCT* is the percentile computed by the subroutine PCTILE which is described in Appendix I.

The effect of this factor is to give the lowest mortality rate to the tree of maximum d.b.h. in the stand, and to give the smaller trees a rate that increases as the percentile declines. The maximum rate for the smallest tree in the stand would be 1.75 times the average rate for the stand. The effect on introducing the *PCT* variable is to distribute the mortality more heavily among the smaller trees in the stand. Lee observed that the mean diameter of mortality trees was 2 inches less than the stand overall mean diameter, and that the distribution of the mortality appeared to follow the normal Gaussian distribution. Accordingly, he calculated the number of trees expected to die by diameter classes from the normal distribution. However, in his procedure, there would be no explicit relation to the number of trees actually in the class in a particular sample of the stand. The procedure using *PCT* provides and explicit estimate of the mortality rate for each tree record, thus overcoming the difficulty in Lee's procedure.

Beetle-Induced Mortality

Mountain pine beetle infestations are a major cause of the disintegration of lodgepole pine stands. The severity of losses depends on the ecological habitat type and elevation (Roe and Amman 1970). The probability with which a severe beetle outbreak occurs is as yet unknown. However, one of the antecedent conditions of an outbreak is that the stand must contain some trees larger than 12 inches d.b.h. Within a stand, the emerging beetles attack trees with higher probability if the tree is in the upper end of the diameter distribution. In turn, the attack density (entrance holes per square foot of bole area) is higher on the larger, thicker trees (Safranyik and Vithayasai 1971).

The size of the emerging population depends on two dominating factors; the density of attack, and the thickness of the phloem within which the larvae feed and pupate (Amman 1969). Phloem thickness is directly related to radial growth. The quantitative relation of phloem to radial growth was established by the work of D. M. Cole[6] in the research work unit studying the silviculture of lodgepole pine.

Relative losses of beetles during flight are highest when the population density is highest and when the population is in the declining stages of an outbreak.

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[6]Dennis M. Cole. Phloem thickness relationship in lodgepole pine trees. Intermt. For. and Range Exp. Stn. (In preparation.)

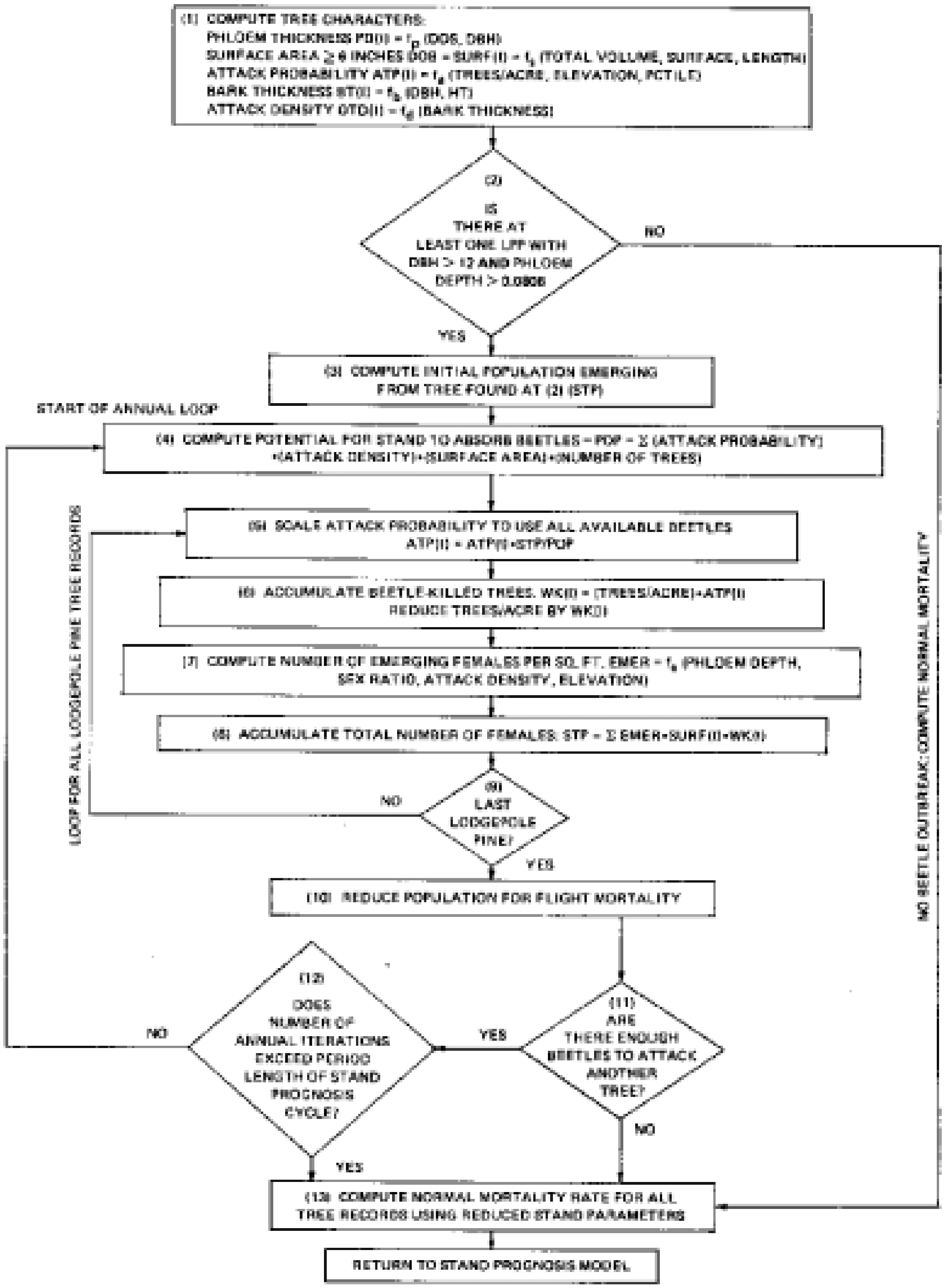

Figure 8.--Logic flow of subroutine for mountain pine beetle impact.

Rates for the various stages and aspects of the beetle population were estimated by Cole and Amman (1969) from historical records of beetle outbreaks. It remained only to combine these data with the model for the development of the tree population to generate a synthesis of the interaction of the pest and its host.

The logic of this mortality model is diagramed in figure 3. The cycle for the beetle population is 1 year in length. Annual tree mortality is deducted for each annual cycle. However, the other features of the trees are changed only at the end of the longer tree prognosis cycle.

A report being prepared by W. E. Cole and A. R. Stage[7] will provide more detail about the mountain pine beetle population model.

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[7]W. E. Cole and A. R. Stage. Intermt. For. and Range Exp. Stn., Ogden, Utah (Ms. In preparation.)

PROGRAM ORGANIZATION AND LOGIC SEQUENCES

The growth prognosis program is organized as an interrelated set of subroutines executed under the control of a very brief main program. The first few subroutines serve to read in the control information, to set up the sampling probabilities for the trees and plots (NOTRE, see Appendix III), to fill in missing data (CRATET), and to calibrate the various growth projection functions (DGCALP). Once this initial housekeeping has been accomplished, the program proceeds to cycle through the projection intervals. The first major subroutine called within the projection cycle is TREGRO. The purpose of this subroutine is to monitor the growth of individual tree records, to bring in the aspects of random variation in diameter growth rates and to deplete the stand through the expected mortality and harvest. To accomplish this task four lower level subroutines are utilized: DGF calculates the diameter increments for each tree record; MORTS decreases the number of trees per acre represented by each tree record for its expected mortality; HTGF calculates height increment and crown changes; and CUTS contains the logic for selecting trees to be harvested for the management regime proposed for the stand. The next major subroutine to be called is STAND, a subroutine that summarizes the total stand attributes implied by the new tree records. This summary includes the number of trees per acre and their distribution by tree d.b.h., the volume characteristics of the total stand as summarized by the primary units of volume in cubic feet, surface area of the boles in square feet, and the accumulated total tree height. In addition, the total cubic foot volume representing the accretion on the initial tree population and the total cubic foot volume represented by the mortality are also summarized and their distributions shown by percentile of the diameter distribution. Also at this point in the computation cycle, predictions of stand growth expressed by growth projection formulae for the stand as a whole would be applied. However, at the present time this aspect of the projection logic has not been implemented. When the stand computations have been completed, a subroutine MERGE is called to merge the stand projections with the tree projections and to provide any feedback of information that would indicate a need to modify the individual tree growth projection functions or, alternatively, the stand growth projection functions. The final subroutine in the projection cycle is DISPLY that serves to bring out the displays of the growth prognosis and to accumulate the information on growth that is to be used as subsequent input to harvest scheduling algorithms. This completed the projection cycle and the flow of control in the program returns to TREGRO to start a new growth projection cycle. When all projection cycles for this management alternative have been completed, a new management alternative is introduced for the same stand and a new projection is started.

If the course of stand development and thinning schedule would be the same for several periods under more than one management regime, then the program would save the redundant calculations by starting the subsequent prognoses from the point where the regimes depart from one another. In turn, when all of the management alternatives have been completed, a new stand is introduced and the whole process is repeated.

In addition to these principal subroutines that contain the logic of the growth prognosis itself, there are numerous special subroutines which merely handle repetitive calculations such as sorting, ordering the data according to various attributed, determining percentile in the distribution of those attributes, and related computational details. Copies of the FORTRAN IV computer program and additional documentation can be obtained from the author:

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APPENDIX I

Field Plot and Computation Procedures for Describing Competitive Status of Growth-Sample Trees

Many of the growth functions that have been useful for predicting the growth rate of an individual tree include variables that describe the competitive status of the subject tree relative to the surrounding trees that make up the forest stand. Some of these methods require that the map-wise relations between trees be recorded in order to compute the measure of competition (Bella 1971). Others might be as simple as a variable defined by the ration of the subject tree d.b.h. to the root-mean-square d.b.h. of all trees in the stand. In my studies of growth of grand fir, and studies with D. M. Cole, of Intermountain Station, on the growth of lodgepole pine, it appears that if the crown development of the subject tree and its relative position within the diameter distribution of the stand are both included in the statistical model, then there is little added explanatory value to be derived from variables calculated from the map-wise distribution of stems. These studies admittedly were based on trees growing in undisturbed stands where the crowns had evolved in relation to local variations in stand density. However, even in stands where the equilibrium has been disturbed, there is evidence for tree-soil moisture relations that would permit trees to benefit from decreased competition for moisture in parts of the stand farther from the subject tree than is usually considered in competition models based on stem distributions is space (Bormann 1957). This view is supported by the analyses of subject tree growth showing that as the zone of competitive influence is increased, the explanatory power of the tree-centered measure of competition is increased (Opie 1968; Lemmon and Schumacher 1962).

The variable available in this prognosis program to represent the competitive status of the *i*th sample-tree record in relation to its surrounding stand are either:

$$DBH\ (I)\ /RMSQD$$

or

$$PCT\ (I)$$

where

DBH (I) = Diameter of the *i*th tree in inches

RMSQD = Diameter of the tree of mean basal area in inches

PCT (I) = Percentile in the basal area distribution

For example, *PCT (I)* = 100 implies that the *i*th tree is the tree of largest diameter in the stand. *PCT (I)* = 75 would correspond to the tree whose position in the diameter distribution was such that 25 percent of the stand basal area was in trees having a larger d.b.h. than the *i*th tree, and 75 percent was in trees having a diameter less than or equal to the *i*th tree. Percentile in the basal area distribution has a very simple interpretation when sampling with a wedge prism or other angle gage. If 8 trees were found to qualify at a point sample, then a ranking by diameter would permit one to calculate the percentile simply as 100 for the largest tree, 100 * 7/8 = 87.5 for the second largest, 100 * 6/8 = 75 for the third largest, etc. If several points are tallied in the same stand, the procedure would be the same. For the *i*th ranked tree, in the sample of *N* trees, percentile could be calculated as:

$$PCT\ (I)=(N-I+1)/N*100$$

When the calculations are based on a stand table, or a list of sample trees having varying numbers of trees-per-acre associated with each tree record, then two computer subroutines can facilitate the computation of percentile. The first routine, IDSORT, is a general sorting program that indexes an array of tree records according to a decreasing sequence of d.b.h.'s. The second routine, PCTILE, uses the indices form IDSORT to calculate the percentile in the distribution. These two routines are listed in figure 4.

The use of these two routines is illustrated in the following segment of the FORTRAN IV program:

```
C      N = NUMBER OF TREE RECORDS

C      DBH = ARRAY OF DIAMETERS OF SAMPLE TREES

C      FNO = ARRAY OF NUMBER OF TREES PER ACRE CORRESPONDING TO THE DBH
C            ARRAY

C      IND = ARRAY OF INDICES INDICATING ORDER OF SIZE (DBH)

C      BA = ARRAY OF BASAL AREAS/ ACRE

C      PCT = ARRAY OF PERCENTILE CORRESPONDING TO DBH ARRAY

C      TOT = TOTAL STAND BASAL AREA

       INTEGER * 2 IND

       DIMENTION DBH (N), FNO (N), PCT (N), BA (N), IND (N)

       DO 1 J = 1, N

     1 BA (J) = DBH (J) * DBH (J) * FNO (J) * .0054541

       CALL IDSORT (N, BA, IND)

       CALL PCTILE (N, IND, BA, PCT, TOT)
```

PCT and TOT are assigned values by PCTILE that can be utilized along with other descriptors of the tree to produce data for building growth or mortality prediction models by statistical estimation procedures.

```
      SUBROUTINE IDSORT (N, CHAR, IND)
C   SHELL SORTING ALGORITHM PROGRAMMED BY ROBERT M. RUSSELL
      INTEGER * 2 IND (N)
      DIMENSION CHAR (N)
      IF (N. LE. 0) GO TO 100
      DO 2 J = 1, N
    2 IND (J) = J
      IF (N. EQ. 1) GO TO 100
      M = 1
   20 M = M + M
      IF (M. LT. N) GO TO 20
      M = MAX0 (1, M/2 – 1)
   30 I = 1
      IM = I + M
   40 J = I
      JM = IM
      I HOLD = IND(IM)
   50 JR = IND(J)
      IF (CHAR(JR). GT. CHAR (IHOLD)) GO TO 60
      IND (JM) = IND (J)
      JM = J
      J = J – M
      IF (J. GT. 0) GO TO 50
   60 IND (JM) = IHOLD
      I = I + 1
      IM = I + M
      IF (IM. LE. N) GO TO 40
      M = M/2
      IF (M. GT. 0) GO TO 30
  100 RETURN
      END

      SUBROUTINE PCTILE (N, IND, CHAR, PCT, TOT)
C          COMPUTES PERCENTILE WITHIN THE DISTRIBUTION OF CHAR SUCH THAT
C               THE LARGEST INDIVIDUAL HAS PCT(I) = 100
C               IND = INDEX TO SORTED ORDER OF CHAR FROM SUBROUTINE IDSORT
      INTEGER * 2 IND
      DIMENSION IND(N), CHAR(N), PCT(N)
      NMI = N – 1
      PCT (IND(N)) = CHAR (IND(N))
      DO 10 I = 1, NM1
      J = N-I
      PCT (IND(J)) = PCT (IND(J+1)) + CHAR (IND(J))
   10 CONTINUE
      TOT = PCT (IND(1))
      PCT (IND(1)) = TOT / 100
      IF (TOT. LE. 0.0) RETURN
      DO 20 I = 2, N
      PCT (IND(I)) = PCT (IND(I)) / PCT (IND(1))
   20 CONTINUE
      PCT (IND(1)) = 100.
      RETURN
      END
```

Figure 4—FORTRAN IV coding of IDSORT and PCTILE

Relation of Size of Growth-Study Plots to Inventory-Plot Size

When small plots (or point-samples with large basal-area factors) are used to sample the irregular spacing of trees that characterizes most forest stands, the estimates of stand density show a wider variation than would occur if larger plots were used. Grosenbaugh and Stover (1957) discuss how small-plot estimates are related to larger, concentric plots through a distribution that has a skewness that changes with density. Jaakkola (1957) suggests that the size of the sample plot used in stand density studies may affect the magnitude of regression coefficients associated with stand density. Intuitively, there must be some optimum plot size that depends of tree size for explaining the effect of stand density on tree growth. If so, then variable plots should be better for explaining this effect than fixed-area plots if a wide range of tree sizes are to be sampled with the same plot design. In addition, there must be some optimum basal-area factor for sampling the stand density variable in tree growth studies. Unfortunately, it is also likely that this optimum size will vary by site and species.

An important feature of this growth prognosis algorithm is that the effect of the bias that may be present in any of the diameter-growth models is compensated by the self-calibration features that scale the median and standard deviation of the residuals in relation to the past performance of the stand as it was actually sampled. If a regression coefficient is too small in absolute magnitude, then the residual variation will be larger, and the scaling of the stochastic multipliers will modify the estimates accordingly.

Local variation in stand density is introduced in the same manner. If a sample tree is growing in an area that deviates from the average density, then its contribution to the standard deviation of residuals will be large, and the effect will persist in variation of predicted diameter increments. However, the resolution of the overall model will be best if the field inventory plot design and the plot design of the growth studies are as similar as possible and both designs are capable of reflecting local conditions that affect tree growth.

APPENDIX II

Data Input for Program TREM∅D1

Codes for species, habitat type, etc., are defined in a BLOCK DATA subroutine that can be readily modified. Definitions and units for other variables such as the index age for site only need to agree with the corresponding variables used in the growth models.

Data cards needed:

#1 & 2) The stand information format cards. These will contain the format (enclosed in parentheses) needed to read in the variables on card #7.

#3 & 4) The tree record format cards. These will contain the format (enclosed in parentheses) needed to read in the variables on card # 8.

#5) Contains the following variables:

Variables	*Columns*	*Type and format*	*Definition*
NPLT	8-15	Alphanumeric 2A4	Stand Identification
NCYC	16-18	Integer 13	Maximum number of cycles
IY (J)	19-21, 22-24, . . .	Integer array 2013	The excess of the calendar year over 1900 for successive projection cycles for J = 1,…, NCYC+1. 1900+IY (1) = year of initial inventory.

#6) Contains the following variables:

Variables	*Columns*	*Type and format*	*Definition*
ALPH	8-15	Alphanumeric 2A4	Stand Identification
CTN (J)	16-20, 21-25, . . .	Real array 11F5.0	Residual stand density to be left after thinning at the start of each projection cycle. (If CTN (J) equals or exceeds the stand density, no thinning will be performed.

#7) Contains the following variables to be read in under the format provided on data cards #1 and #2:

Variable	*Type*	*Definition*
S1	Alphanumeric	Space holder[8]
S2	Alphanumeric	Space holder
IF∅R	Integer	Forest
IBLK	Integer	Block
ICPT	Integer	Compartment
ISBCPT	Integer	Subcompartment
ISTAND	Integer	Stand
S3	Alphanumeric	Space holder
IS∅	Integer	Stand origin
S4	Alphanumeric	Space holder
IBAP	Integer	Basal area factor for variable radius plots
S5	Alphanumeric	Space holder
IPT	Integer	Number of points sampled in stand
ITYPE	Integer	Habitat type
S6	Alphanumeric	Space holder
IAREA	Integer	Total stand area
IPC	Integer	Photo interpretation class
S7	Alphanumeric	Space holder
S8	Alphanumeric	Space holder
S9	Alphanumeric	Space holder
IELEV	Integer	Elevation in 100's of feet above sea level
S10	Alphanumeric	Space holder
S11	Alphanumeric	Space holder
S12	Alphanumeric	Space holder
ISL∅PE	Integer	Slope, scaled 0 to 9
IASPCT	Integer	Aspect, scaled 0 to 8
S13	Alphanumeric	Space holder

(Block, Compartment, Subcompartment, Stand) = (NPLT on card #5, ALPH on card #6)

[8] Space holders have been inserted in the read-list to include all the fields designated on USDA Forest Service form R1-2410 (5/72).

Variable	*Type*	*Definition*
IPSITE	Integer	Physiological site class
ISITE	Integer	Measure of site quality or index
IAGE	Integer	Age of the stand in years
IFINT	Integer	Number of years for which past tree Growth has been measured
IDG	Integer	= 0 if past diameter growth is read into DG on card #8 = 1 if a past diameter growth is read into DG
SAMPR	Real	Sampling probability (inverse weight) for Stand (see Appendix III)

#8) Contains the following sample tree variables to be read in under the format provided on data cards #3 and #4:

Variable	*Type*	*Definition*
IPLT (2)	Alphanumeric	Stand identification
ITRE (I)	Integer	Point identification
PROB (I)	Real	Number of trees on plot represented by this tree record
ITH	Integer	Tree history
ISP (I)	Alphanumeric	Species code
DBH (I)	Real	Diameter breast height in inches
DG (I)	Real	Periodic diameter growth in inches or past d.b.h. depending on IDG on card #7
HT (I)	Real	Tree height in feet
ICR (I)	Integer	Crown ratio
IDCD	Integer	Damage code
IMC (I)	Integer	Management code – tree or cover class

#9) Like card #8
•
•
#K-1) Like card #8
#K) SEND to signify end of stand, in same columns as the left four placed of IPLT
#K+1) Repeat sequence of cards #5 to K as many times as needed for succeeding stands
.)
#n) Columns 8-11 contain SEND to signify end of input data.

Appendix III

Examples of Specification of Sample Design

To illustrate the use of the variables IBAP and IPT, several cases will be described that involve changes in some constants established in the BLOCK DATA subprogram.

Case 1

A stand tallied at a set of 12 points. At each point, trees less than 5 inches d.b.h. are recorded on a 1/300 acre fixed plot. Trees greater than or equal to 5 inches d.b.h. are tallied on a variable plot established by an angle gauge having a basal-area factor of 20 square feet/tree. Then:

IPT = 12 on card #7

IBAP can be set to 20 or 0. The latter will default to BAF = 20 established in BLOCK DATA.

Case 2

Same as for Case 1, except the variable plot has a basal area factor of 40 square feet/tree. Then:

IPT = 12
IBAP = 40 } on card #7

Case 3

A stand tallied at a set of 16 points. At each point, trees less than 3 inches d.b.h. are recorded on a 1/256 acre plot. Trees greater than or equal to 3 inches d.b.h. are tallied on a variable plot established by an angle gauge having a basal-area factor of 40 square feet/tree. Then:

FPA = 256.
BRK = 3.0
BAF = 40.0
} established by recompiling BLOCK DATA

IPT = 16
IBAP = 0
} on card #7

Case 4

All trees are tallied on 10 fixed-area plots of 1/5 acre. Then:

FPA = 5. (Reciprocal of 1/5 acres)
BRK = 9999.
} established by recompiling BLOCK DATA

IPT = 10 on card #7

Case 5

Plot sizes and numbers vary from stand to stand, but all trees are tallied on the same sized plot at any one sample point. Then:

FPA = 1
BRK = 9999.
} established by recompiling BLOCK DATA

IPT = 1.

$$\text{SAMPR} = -\sum_{i=1}^{n} a_i$$

} on card #7

where a_i equals the area n acres of each of the n sample plots in the stand.

Furthermore, if the sampling probability changes arbitrarily from tree to tree in the stand, PROB (I) on card type #8 can be set to the reciprocal of the sampling probability for that tree. In this way, it is possible to accommodate virtually any sampling design including 3-P samples.

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ALBERT R. STAGE
1973. Prognosis model for stand development. USDA For. Ser. Res. Pap. INT-137, 32 p., illus. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

Describes a set of computer programs for developing prognoses of the development of existing stand under alternative regimes of management. Calibration techniques, modeling procedures, and a procedure for including stochastic variation are described. Implementation of the system for lodgepole pine, including assessment of losses attributed to an infestation of mountain pine beetle, is described.

OXFORD: 5:.1 KEYWORDS: increment forecasting, yield regulation, stand projection, tree growth, modeling, lodgepole pine, mountain pine beetle impact, simulation.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)