User's Guide to the Stand Prognosis Model

**William R. Wykoff
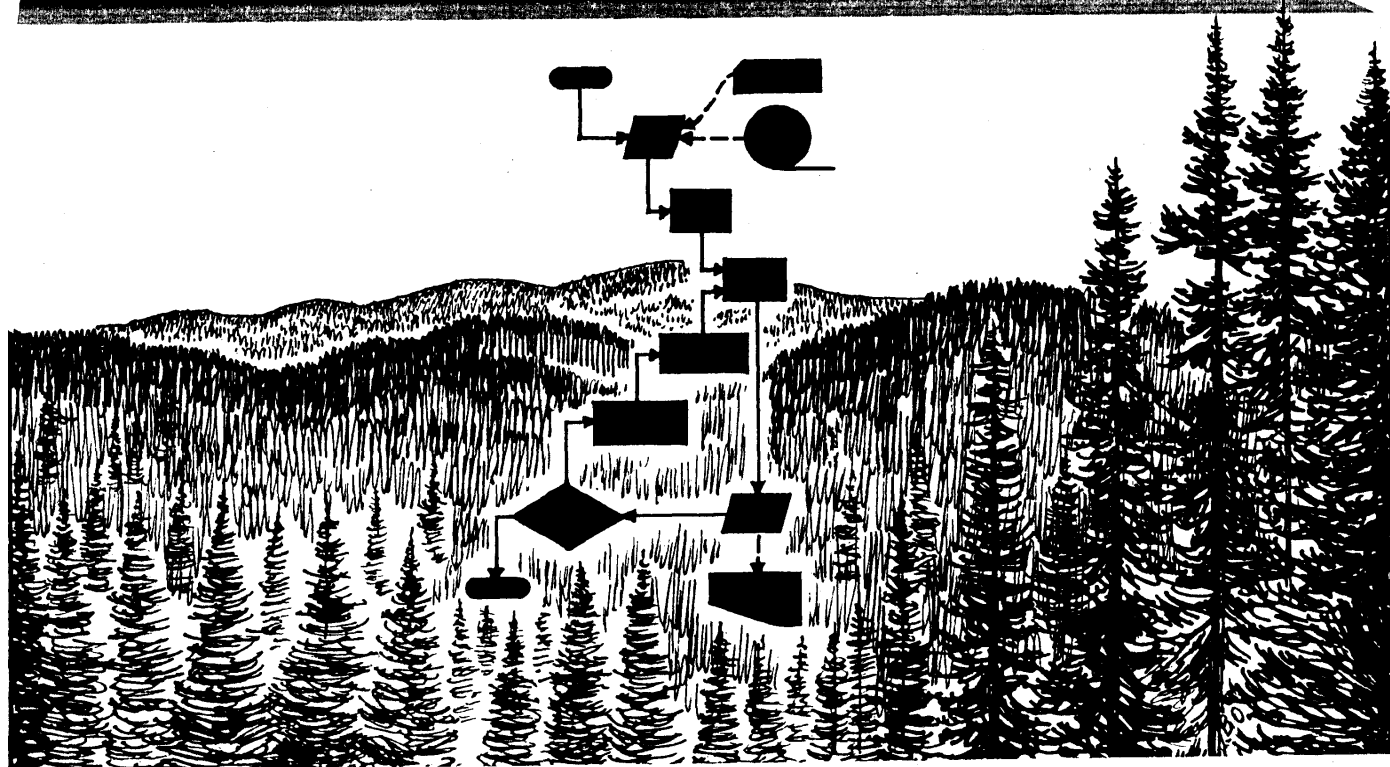Nicholas L. Crookston
Albert R. Stage**

$$CR = f_e [CCF \cdot \cdot]$$

$$B = \frac{1}{\sqrt{2\pi}} \int_a^b x e^{-X^{3/2}} dx$$

$$\ln [\Delta H] = f_N [\Delta D, H, D]$$

$$MORT = \frac{1}{1 + \exp[-B_i X_i]}$$

$$\ln [BAI] = f_8 [D.b.h., Habitat, Crown]$$

PREFACE TO THE SECOND PRINTING

This reprinting of the User's Guide to the Prognosis Model describes the Prognosis Model as released in September, 1981 (Version 4.0). Although we will soon release version 5.0, most of the material in this guide will remain applicable to the new version. There will be, however, modifications in the small tree growth models and in the crown-dubbing and crown-changing procedures that improve model behavior. These modifications will necessitate revisions of pages 52, 65-67, and 77-80.

These revisions, and descriptions of new features, are contained in a supplement to this guide that will be released with the new version. The new features include:

—A regeneration establishment component;

—SHRUB and COVER extensions;

—An event monitor for dynamic activity scheduling;

—A classification algorithm used to shorten the tree record list by combining like records;

—Expansion of management options.

We have endeavored to make changes in such a way that the procedures for using version 4.0 will operate the same way in version 5.0.

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THE AUTHORS

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RESEARCH SUMMARY

The Inland Empire version of the Prognosis Model, a computer program designed to simulate the development of forest stands, is described. The Inland Empire version is calibrated for eleven tree species occurring on over 30 habitat types. The individual tree is the basic unit of projection and most combinations of species and age classes can be accommodated. Available thinning options allow considerable latitude for simulation of management strategies.

Prognosis Model input consists of a stand inventory, including a list of sample trees, and a set of specially formatted instructions that indicate the options selected. The output includes distributions of trees per acre, volume per acre, accretion, and mortality by diameter at breast height and by species and tree value class. In addition, selected sample trees are displayed over time along with parameters that describe general stand characteristics that might influence tree growth.

The Prognosis Model can be linked to models that predict pest outbreaks and the impacts of host-pest interactions. It can also be linked to models that predict production of other forest resources. The combined outputs provides a basis for multiresource planning.

Preparation of input, interpretation of output, and model formulation are described. Guidelines are given for potential uses and limitations.

ACKNOWLEDGMENTS

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INTRODUCTION

Silviculturists planning the management of Northern Rocky Mountain forests have found the Prognosis Model for stand development (Stage 1973b) to be a useful tool for comparing different stand treatments. Since its introduction, the model has grown and evolved. Additional silvicultural treatments have been included in its scope; capability to evaluate damage to stands by several pests has been added; the geographic range for which it has been calibrated has been increased; the operating procedures have been simplified; and the information displayed about the future stand has been modified to improve economic analyses of the treatment effects.

Regional variants of the Prognosis Model have been calibrated for eastern Montana and central Idaho. These versions differ in the way that some submodels are constructed. With a few modest exceptions, however, all versions use the same input procedures and produce the same output tables. Our discussions of submodels are based on the performance of the Inland Empire version (released July 1981). This manual should serve most users as a reference for input preparation, output interpretation, and expected model behavior. Specifics on submodel structure and development are, or will be, documented elsewhere (Stage 1973b, 1975; Hamilton and Edwards 1976; Monserud 1980).

Yield Data for Forest Planning

Expectations of future stand growth and yield are the basis for investments in silviculture. Whether to retain a particular mix of tree species and sizes, to start a new stand, or to treat the existing stand with fertilizers or pesticides are choices that depend on the manager's comparisons of future stand growth in relation to the objectives for which the forest property is managed. No one choice of silvicultural treatments will be right for all objectives.

When production of timber is one of the objectives, growth predictions are the basis for estimating the yield of products that could be removed from the stand at varying times in the future. To be most useful for planning, yield forecasts comparing alternative silvicultural regimens should accurately represent the differences in expected yield among the alternatives. Accuracy of yield estimates for a single alternative is less critical than accurate comparisons of differences between alternatives because the planning process will be repeated at intervals that are short in comparison to the lifespan of most forest stands. A further consequence of this long lifespan is that a majority of the decisions to be made concerning the silviculture of a forest are choices concerning treatment of existing stands—with all their idiosyncrasies that result from pest attacks, destructive climatic events, and past use.

In our opinion, the basis for management planning decisions should be yield estimates that include properly weighted average effects of all factors that influence the growth of stands. The Prognosis Model incorporates the average effect of factors such as insect and disease damage, variation in climate, and silvicultural activities to the extent that these factors are represented in the data to which the models were fitted. For the most part, the growth sample was selected independent of pest activity or treatment history, and the data were not screened to remove any specific effects. When management actions can be shown to modify the effects of particular factors, the Prognosis Model should be modified to explicitly represent those factors. The only management activity explicitly recognized by the current version of the Prognosis Model is stocking reduction. The model, however, can be linked to "extensions" that predict insect outbreaks, shrub development, and the establishment of regeneration stands (see section titled USING THE PROGNOSIS MODEL AS A COMPONENT IN A PLANNING SYSTEM).

Consequences for streamflow from the forest, for wildlife populations, and for pest populations that inhabit the forest, as well as the capability of the forest to yield timber or provide recreation—all depend on how the dominant vegetation changes and is changed. Unfortunately, yield forecasts have traditionally emphasized the merchantable harvest that might be obtained, either immediately or as a sequence of yields obtainable at intervals of time into the future. Volumes of merchantable timber have been the most common units of measure because timber products have usually been the primary reason for investment. As other uses for the forest become more important, however, growth forecasts need to be stated in more fundamental descriptions of the future forest stand. Too often, evaluation of trade-offs among conflicting activities or objectives for use of forest resources has been hampered by lack of sensitivity of the forecasts to the interactions among ecosystem components. One objective for development of the Stand Prognosis Model is to so characterize stand dynamics that the model will provide a sensitive basis for representing ecosystem interactions involving the tree species.

Design Criteria for Development of Prognosis Model

The nature of the Inland Empire forests and the complexity of their management have influenced the design of the Prognosis Model. Early logging in the Northern Rocky Mountains removed mostly the high value species—western white pine (*Pinus monticola*) and western larch (*Larix occidentalis*)—leaving irregular stands of the more tolerant grand fir (*Abies grandis*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*).

Later many stands were partially cut for special products, such as transmission poles of western red cedar and western larch. Diseases, such as blister-rust and pole-blight, selectively killed western white pine. Root rots infected many species, creating openings in stands. Insects (including mountain pine beetle on ponderosa pine [*Pinus ponderosa*] , lodgepole pine [*Pinus contorta*], and western white pine, the Douglas-fir beetle, and the fir engraver) also were responsible for creating openings in stands. These influences resulted in forests in

which practically every stand is a unique mixture of species and age classes. Consequently, traditional mensurational parameters such as site index and stand age are either impossible to determine correctly or are inappropriate values for representing yields.

Recognizing the features that call for differing treatment calls for a high degree of silvicultural skill. Likewise, recording these features in the inventory process so that the consequences of the alternative treatments can be estimated, calls for close coordination between inventory methods and the process for developing forecasts of subsequent yields.

These circumstances led to the following criteria for constructing the Prognosis Model.

1. Use existing inventory methods as sources of input and produce initial estimates of volume and growth that are consistent with estimates calculated with standard inventory compilation techniques. This criterion ensures that the data obtained in detailed silvicultural examination procedures, as well as in nationwide forest inventories such as those conducted by Forest Resources Evaluation units, can be used to initiate prognoses. When the yields estimated by the model are used in harvest-scheduling, there will be no need to resolve troublesome differences between the inventory compilation of forest-wide volumes and growth and the initial values for the same statistics derived from the yield tables. Methods of growth prediction that ignore the detail obtained by modern stand examinations bury the diversity and problems that are keys to effective management. It is more critical to evaluate schemes for recouping the productivity of stands afflicted with white pine blister rust, spruce budworm, or larch casebearer, than to evaluate the relatively minor effects of stocking control on the distribution of increment. To evaluate such schemes, however, requires close coordination in inventory and growth methodology.

2. Applicable in all timber types and stand conditions encountered in the inventory; growth predictions are consistent with growth rates measured in the inventory. Effective allocation of management funds depends on correctly identifying stands where treatment would most nearly achieve the objectives of management. To properly identify these stands, we need projection methods that are consistent in their estimates across a wide variety of species types, age structures, and site conditions. For example, decisions to convert from one species type to another can be rational only if methods for estimating yield for each of the types are based on the same assumptions and are expressed in the units. This feature also assures that each and every stand encountered in the inventory can be accommodated by the program without forcing stands into inappropriate species composition or age structure classes.

3. Treat stands as the basic unit of management; growth projections are dependent on interactions between trees within stands. A stand is defined as an area of forest bounded by discontinuities in cover characteristics that are visible on aerial photographs at scales of approximately 1:15,840. The goal of stand delineation is to define a portion of the forest that can be treated by one silvicultural prescription and respond in a way that can be related to the characteristics of the stand. A stand is comprehensible to other specialists—pathologists, entomologists or any of the many special disciplines from whom we seek advice—and it is possible for these specialists to interpret our predicted forest in the light of their discipline.

4. Incorporate growth of the current inventory into projections. This criterion serves two applications. First, for analyses of individual stands, the samples of current increment localize the projections to allow for unique variations in site and environment that are not represented in the model parameters. The calibration procedures that use these increment data reduce the need for variables representing site index, site stockability, and age structure that are so difficult to define for the complex stands of the Inland Empire. Second, for forest-wide planning, the increment samples ensure consistency with inventory compilations of current annual increment and provide essential feedback of effects of past management planning. For example, consider an effect analogous to the "allowable cut effect"; the "error allowable cut effect." Suppose that when calculating the allowable cut, we use a yield estimate that is erroneously high. Then, the cut calculated for the coming planning

period will be too high. Conversely, a low yield estimate will lead to a lower cut than desired (Stage 1973a).

5. Provide links to other biotic and hydrologic components of the ecosystem and to economic analysis procedures for selecting the most appropriate regimens of management. By maintaining individual-tree resolution throughout the period of simulated time, estimates of future interactions between the stand and other components of the ecosystem can be based on as much detail as is available from inventories of the present situation. The tree species, however, are only part of the vegetation. Shrub and herbaceous species also compete with the conifers and may be valued in their own right for forage and shelter for wildlife. Therefore, we designed the Prognosis Model to provide linkages to submodels that predict understory development. An understory development submodel has been calibrated for the grand fir-cedar-hemlock ecosystems of northern Idaho. It provides sufficient detail about the total vegetation to facilitate estimates of effects on streamflow, quality of wildlife habitat, and forage production.

What Management Actions can be Represented?

Silvicultural treatments that can be evaluated include stocking control, regeneration methods, site preparation, and pest management.

THE BASE MODEL

Stocking control options can represent:

1. Thinning from above or below to a user-specified residual basal area per acre.
2. Thinning from above or below to a user-specified residual trees per acre.
3. Removal of a user-specified segment of the d.b.h. distribution.
4. Specific tree selection where cut or leave designations are entered on the input tree records.

The user can combine options to implement special thinning strategies and, in addition, can control the species composition of the stand to favor desirable trees.

EXTENSIONS AND USER SUPPLIED MODIFICATIONS

Management activities that are not explicitly included in the stocking control options are represented in two ways. One way uses extensions to the base model containing additional submodels. The other way modifies the submodels for diameter growth, height growth, and mortality.

To evaluate silvicultural treatments related to pest management, the Stand Prognosis Model must be linked to models that predict pest outbreak and development. Models for Douglas-fir tussock moth (Monserud and Crookston 1982) and mountain pine beetle (Crookston and others 1978) are currently available, and a western spruce budworm model is under development by the CANUSA program.[1]

Within the grand fir-cedar-hemlock ecosystem, it is possible to simulate the establishment of seedlings following regeneration treatments. This requires, however, that the Prognosis Model be linked to a submodel that predicts regeneration establishment (Stage and Ferguson 1982).

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[1] CANUSA: The Canada/United States spruce budworms program cosponsored by the USDA Forest Service and the Canadian Department of Environment, Canadian Forest Service.

What Data are Required to Describe the Stand?

The model is designed to start with sample inventories of actual stands. To begin the projection, the model needs data on:

1. Inventory design used to measure the stand:
   a. Basal area factor for variable radius plots
   b. Fixed plot area
   c. Critical diameter when fixed plots are used to measure small trees and variable radius plots are used to measure large trees
   d. Number of inventory plots
   e. Number of non-stockable plots.
2. Site conditions:
   a. Slope
   b. Aspect
   c. Elevation
   d. Habitat type
   e. Location (nearest National Forest).
3. Characteristics of each tree measured in the inventory:
   a. Variables that must be recorded for all trees:
      i.   Identification for plot on which the tree was measured
      ii. Species
      iii. Current d.b.h.
   b. Variables that may be subsampled or omitted:
      i.   Number of trees represented by a record (when a single record is used to represent a class of trees)
      ii.   Periodic diameter increment
      iii. Crown ratio
      iv.   Tree height
      v.   Periodic height increment for seedling and sapling-sized trees
      vi.   Tree value class
      vii. Cut or leave designation (used when specific trees are selected for removal).

The model will work if given only a description of the inventory design and information on diameter, species, and plot identification for each inventoried tree. The other variables, however, serve to better describe unique site and tree characteristics and will improve the resolution of the projection.

Organization of the Model

Figure 1 illustrates the flow of information through the Prognosis Model. Although the diagram is at a low level of resolution, it does show the relationship between major phases of the program. In the sections that follow, these phases will serve as the background for describing input requirements, growth model behavior, and the inter-pretation of output.

A projection begins by reading the inventory records and the descriptions of selected management options. If periodic increment is measured on a sample of the tree records, the increment equations will be adjusted to reflect unique growth characteristics of the stand. The inventory is then compiled to produce tables that describe initial stand condi-tions. When this summary is complete, the first projection cycle begins.

Each projection cycle starts with the simulation of silvicultural actions that have been scheduled for the cycle. Next, periodic diameter increment, periodic height increment, periodic mortality rate, and change in crown ratio are computed for each tree record in the inventory. Then, the tree attributes are updated, tree volumes are calculated, and tables that summarize projected stand conditions are compiled.

START

CONTROL INSTRUCTIONS

INPUT

INVENTORY RECORDS

CALIBRATE MODELS

COMPILE INVENTORY

PREDICT STAND DEVELOPMENT

SIMULATE MANAGEMENT

YES

NO

MORE GROWTH CYCLES ?

NEXT STAND

DISPLAY

STAND DEVELOPMENT THROUGH TIME
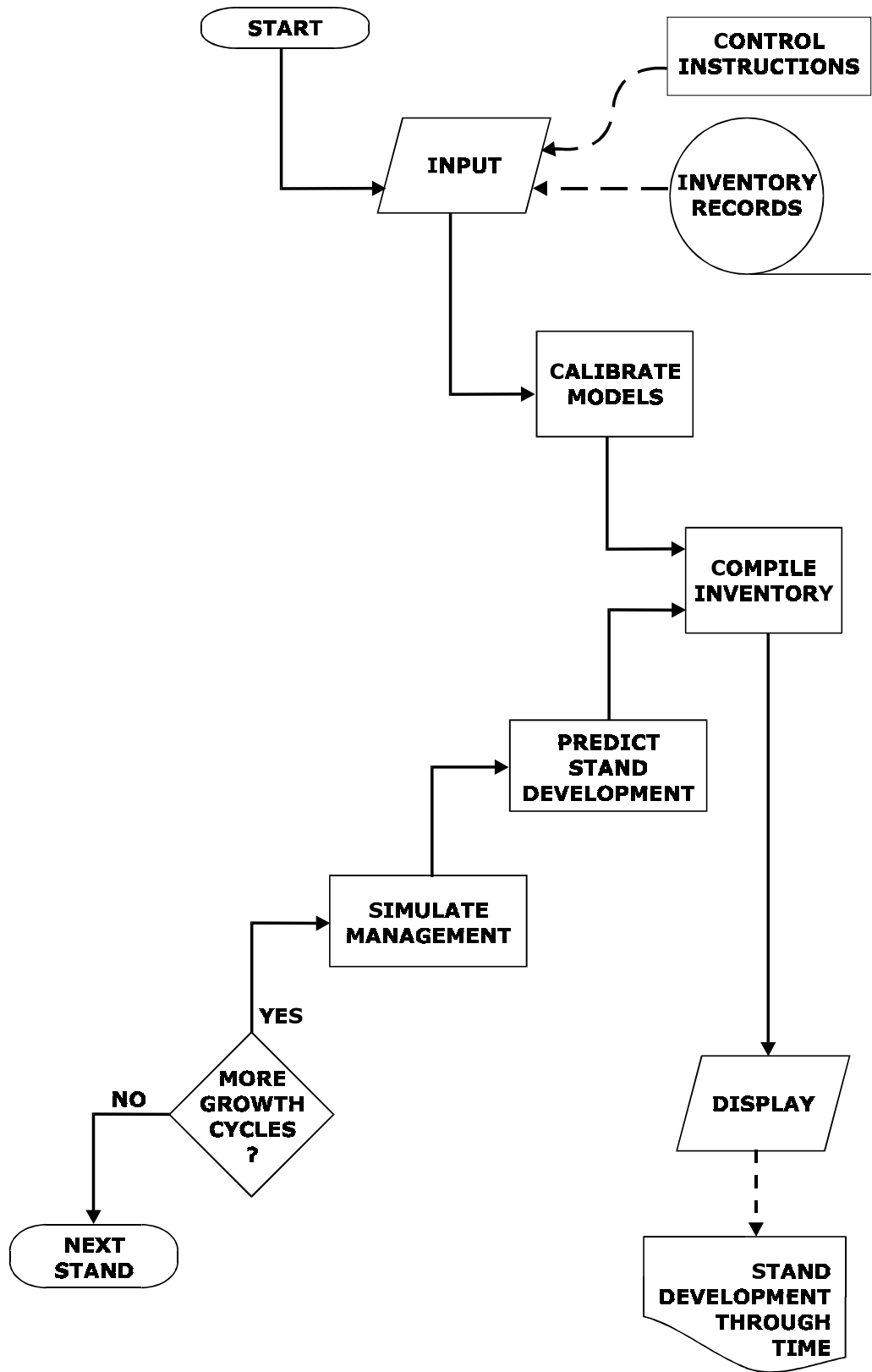
Figure 1.—A low resolution diagram
showing the logical organization
of the Prognosis Model.

The Keyword System

Users communicate much of the information used by the Prognosis Model through the keyword system. This system consists of a set of mnemonic words (keywords) associated with numeric data. A single keyword and its associated numeric data make up a keyword record. For example, the STDINFO record is the keyword record used to enter information about the site on which the stand is located.

The keyword always begins in the first column of the keyword record. Depending on the keyword, seven additional fields on the record may be used to transmit numeric data. These fields are referred to as parameter fields and the data are used by the program when the option is implemented. Each parameter field consists of 10 columns and, if the decimal point is included, the parameter may be entered anywhere within the field. If integer values are used, they must be right-justified. The first parameter field begins in column 11 on the keyword record (fig. 2).

```
                                    COLUMNS
            1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
================================================================================
STDIDENT
S248112    HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL-- NIG4 VERSION
COMMENT
   THE PRESCRIPTION CALLS FOR IMMEDIATE REMOVAL OF
   EXCESS TREES, A COMMERCIAL THINNING AT AGE 90
   TO REMOVE LODGEPOLE AND LARCH, A SHELTERWOOD
   REGENERATION TREATMENT AT AGE 120 FAVORING
   GRAND FIR AND DOUGLAS-FIR, AND AN OVERWOOD
   REMOVAL AT AGE 130.
END
DESIGN                                               11.0       1.0
STDINFO         18.0      570.0      57.0       8.0       3.0       34.0
INVYEAR       1977.0
NUMCYCLE         8.0
THINPRSC      1980.0      0.999
SPECPREF      2010.0        2.0     999.0
SPECPREF      2010.0        7.0    9999.0
THINBTA       2010.0      157.0
SPECPREF      2040.0        3.0    -999.0
SPECPREF      2040.0        4.0     -99.0
THINBTA       2040.0       35.0
TREEDATA
PROCESS
STOP
```

Figure 2.—Examples of keyword records. This set of records was used to simulate a prescription that is developed later in the manual. Shown are keyword records, with keywords (columns 1 to 10) and parameters (l0-column fields starting in column 11), and supplemental data records.

A simplifying feature of the keyword system is that default values exist for almost all program options. Keywords need only be used if the desired action differs from the default action. Similarly, most parameters associated with keywords have default values. If a parameter field is blank, the default value will be used. Returning to our earlier example, field 1 on the STDINFO record is used to specify the National Forest in which the stand is located. The default for this parameter is 18, the code used to represent the St. Joe National Forest. If the stand is located in the St. Joe, the first parameter field on the STDINFO record can be left blank.

The final element of the keyword system is the supplemental data record. These records are required when the information needed to implement an option is nonnumeric or exceeds seven values. The exact format of the supplemental data records is dependent on the option selected and will be described on a case-by-case basis.

We will introduce keywords in the course of describing how the Prognosis Model works and, as the keywords are presented, their function will be defined. For convenience, appendix D contains an index to the pages on which definitions of keywords are given and a summary of default conditions.

SIMULATING STAND MANAGEMENT

The Prognosis Model is primarily a tool for evaluating the biological consequences of silvicultural manipulation. When the model is used in this mode, three types of input are required. First, some simple keyword records are used to start and stop program execution and to specify the number and length of projection cycles. Another set of keywords is used to describe the stand and the sampling design. A final set of keywords controls simulation of various stand management options.

The minimum input required to run the Prognosis Model is a list of sample tree records, which are coded in accordance with the default tree record format, and a PROCESS record. The function of PROCESS is simply to terminate the input of the selected options. When PROCESS is encountered, the sample tree records are read and the projection begins.

PROCESS is the logical end of the collection of keyword records that define a single projection. Many projections may be grouped into a keyword record file. In this case, PROCESS serves to separate the projections. Each projection is completed before the keyword records for the next projection are read.

If the record following PROCESS is anything other than an end-of-file or a STOP, the default parameter values are recalled in preparation for the next projection. The STOP record is the logical end of the keyword record file. When STOP is encountered, program execution ends. In reality, STOP functions the same as an end-of-file. It serves as a visual reminder of the extent of the keyword file and a warning message is printed if STOP is not found.

Timing

A cycle is a period of time for which increments of tree characteristics are predicted. All management activities are assumed to take place at the beginning of the cycle in which they are scheduled. An inventory report is prepared at the end of each cycle. The number of cycles and the length of each cycle are controlled by using the NUMCYCLE and TIMEINT records.

NUMCYCLE	field 1:	The number of cycles that the stand is to be projected; default = 1
TIMEINT	field 1:	Cycle number for which the cycle length is to be changed. If blank, the change will apply to all cycles.
	field 2:	The number of years to be projected in the cycles(s) referenced in field 1; default = 10 years.

An additional keyword record is needed so that options that are requested by date (as opposed to cycle) can be associated with projection cycles. This record is used to enter the starting date for the projection. The date entered is assumed to be the date that the stand was inventoried:

INVYEAR	field 1:	Starting date for the stand projection; default = 0.

Any starting date may be used. Care must be taken to assure that the dates on which options are requested fall within the range of dates defined by the parameters on the NUMCYCLE, TIMEINT, and INVYEAR records.

In the following example, we assume an inventory year of 1973, and we project to the year 2020, using a 7-year first cycle to align projection reports with decades. Subsequent cycles will all be 10 years long.

```
NUMCYCLE        5.0
TIMEINT         1.0             7.0
INVYEAR       1973.0
PROCESS
STOP
```

We use cycles to define the input parameters that relate to the growth models in order to emphasize that the models predict periodic increments. Most of the models are based on either 5- or l0-year increment data and we feel that, in most cases, a 10-year period should be used. There are legitimate reasons, as in the above example, for using other period lengths. Some bias is associated with using period lengths other than 10 years (table 1), however, and the choice of a different period length should be a deliberate decision.

Table 1.—Examples of biases in predicted stand attributes as related to period length for a 40-year projection. Stand A is an all-aged stand composed of 11 species with initial DBH's ranging from 0.1 to 35 inches (quadratic mean *DBH* = 7.0 inches). Stand B is a young, more or less even-aged stand, composed of 6 species with initial *DBH's* ranging from 4.0 to 12.7 inches (quadratic mean *DBH* = 7.2 inches)

Cycle length	Total Volume	Bias[1]	Volume to 8 in top	Bias[1]	Trees per acre	Bias[1]
Years	*Ft³*	*Percent*	*Bd.ft.*	*Percent*		*Percent*
			Stand A			
10	6,415	—	26,784	—	280	—
1	5,913	–7.8	25,655	–4.2	294	5.0
2	6,026	–6.1	25,678	–4.1	291	3.9
4	6,136	–4.4	25,528	–4.7	286	2.1
8	6,304	–1.7	26,254	–2.0	281	.4
20	7,377	15.0	32,527	21.4	284	1.4
40	16,368	155.2	82,609	208.4	280	.0
			Stand B			
10	5,829	—	23,940	—	221	—
1	6,054	3.9	25,940	5.8	219	–0.9
2	5,897	1.2	24,281	1.4	220	–.5
4	5,892	1.1	23,992	.2	221	.0
8	5,827	.0	23,836	-.4	221	.0
20	6,457	10.8	27,839	16.3	216	–2.3
40	8,385	43.8	38,941	62.7	190	–14.0

[1]Bias computed relative to prediction for 10-year projection cycles.

Entering Stand and Tree Data

The Prognosis Model is an inventory-based projection system that will accommodate a variety of sampling designs, site characteristics, and stand structures. These features are entered using seven keyword records. One record defines the parameters of the sampling design. Another record enters site characteristics such as slope, aspect, elevation, and habitat type. Four records provide control for reading the sample tree records. One record enters report labels. These records are described below.

THE SAMPLING DESIGN

The Prognosis Model will accommodate most sampling designs in which stands are delineated and individual sample trees within stands are selected with known probability. Acceptable designs include, but are not limited to:

1. One or more fixed area plots per stand.
2. One or more sample points **within a stand** where sample trees are selected using the **same** horizontal angle gauge.
3. Combinations where trees smaller than a specified diameter (*BRK*) are sampled using fixed area plots, and trees with diameter greater than or equal to *BRK* are sampled using a horizontal angle gauge (Stage and Alley 1972).

If other designs are used, preprocessing may be required to assign sampling probabilities to the individual tree records prior to submitting the stand for projection. In general, the sampling design that is most efficient for representing a given stand structure will provide the most effective input data for the Prognosis Model.

DESIGN   field 1: basal area factor for horizontal angle gauge, default = 40 (square feet/tree).

field 2: Inverse of fixed plot area, default = 300 (acre^{-1}).

field 3: *BRK*, default = 5 (inches)

field 4: Number of plots in the stand. If blank, or zero, the number of plots in the stand is determined by counting the numbers of unique plot identification codes on the tree records.

field 5: Number of nonstockable plots in the stand. These include plots falling on rock outcroppings, roads, streams, etc. If blank, count nonstockable plots on tree records (*IMC* = 8; see discussion of tree records).

field 6: Sampling weight for stand. This weight does not affect the projection but is for use in programs that aggregate many projections to produce a composite yield table; default = number of plots.

Throughout this manual, a stand from the St. Joe National Forest (S248112)[2] is used to develop examples. This stand was inventoried using a combination of fixed and variable

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[2] The stand number can be interpreted as follows: district (working circle) 2; compartment 48; subcompartment 1; stand 12.

plots as described above. Default values were used for basal area factor, *BRK*, and the inverse of the fixed plot area. There were 11 sample plots within the stand, and 10 of the 11 were stockable. In this case, either of the following DESIGN records is correct:

DESIGN   40.0   300.0   5.0   11.0   1.0   ƀ[3]

or

DESIGN   ƀ   ƀ   ƀ   11.0   1.0   ƀ

If a fixed-area-plot sampling design was used, simply specify a value of *BRK* that exceeds the diameter of the largest sample tree selected. For example, if 10 plots of 1/20-acre size were used, the DESIGN record could read:

DESIGN   ƀ   20.0   99.0   11.0   1.0   ƀ

If, however, all sample trees were selected using 10 points and a horizontal angle gauge (basal area factor = 40), the value of *BRK* should be set to zero:

DESIGN   40.0   ƀ   0.0   11.0   1.0   ƀ

IDENTIFYING THE STAND

The STDIDENT keyword record allows you to label output tables. None of the parameter fields are used, but one supplemental data record is required. This record contains a stand identification (such as S248112) in columns l-8. This ID appears with every output table. Columns 9-80 can be used to transmit a "title" which will be reproduced at the beginning of each output table. The records

STDIDENT
S248112   STAND PROGNOSIS MODEL USER'S MANUAL EXAMPLE

identify the stand used and provide a title for the output.

In addition to a stand identification, you may enter a special code to identify the silvicultural treatment or management regimen that is simulated in a projection. The code is entered with the MGMTID record. There are no associated parameters, but the code to be used is entered in the first four columns of a supplemental record. When the supplemental record is blank, the code is not printed; when MGMTID is not used, the code "NONE" is printed. For example, the records

MGMTID
RUN1

would cause the label RUN1 to be printed with each output table.

DESCRIBING THE STAND

Many of the growth prediction equations in the Prognosis Model use stand variables such as habitat type, slope, aspect, elevation, and location. We assume that the stand is delineated so that these variables are reasonably constant. Stretching this assumption when defining stands, will increase the likelihood that projections will not be accurate. In particular, aspect is a circular function and habitat type and location are represented by discrete classes; none of these have meaningful averages.

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[3] The symbol "ƀ" is used here and elsewhere to indicate a blank field. We have made no attempt to maintain accurate spacing in our keyword examples. Instead, an entry is provided for each field.

The STDINFO record is used to supply data on stand variables:

STDINFO   field 1: Forest code (see table 2). Forest code is used as the indicator of location for growth predictions; default = 18 (St. Joe NF).

                field 2: Numeric habitat type code (see table 3); default = 260 (*Pseudotsugsa menziesii*/*Physocarpus malvaceus*).

                field 3: Stand age in years. Age is used to label output and has no effect on tree growth predictions; it is required for some extensions; default = 0.

                field 4: Aspect code: 1 = north, 2 = northeast, …, 8 = northwest, 9 = level; default = 9.

                field 5: Stand slope code: 0 = [5%, 1 = 6-15%, 2= 16=25%, …, 9 = μ 86%; default = 0.

                field 6: Stand elevation in 100's of feet. Example: 10 = 1000 ft, 35 = 3,500 ft; default = 38.

                field 7: Site index. This value is used only to label the output. At present, none of the growth or mortality predictions depend on site index. Any numeric value may be entered; default = 0.

Valid forest and habitat type codes are listed in tables 2 and 3, respectively. If the stand in question is outside the boundaries of a National Forest, select the code associated with the nearest forest. If an invalid code is given, the default value (18) will be used. If invalid aspect or slope codes are encountered, the default values (9 and 0, respectively) will be used. Invalid elevation codes are not readily detected, however, and all entries are assumed to be correct.

Table 2.—Codes for the Forests represented in the Inland Empire version of the Prognosis Model

Forest	Code	Forest	Code
Bitterroot	3	Kaniksu	13
Clearwater	5	Kootenai	14
Coeur d'Alene	6	Lolo	16
Colville	7	Nezperce	17
Flathead	10	St. Joe	18

Table 3.—Codes for habitat types represented in the Inland Empire version of the Prognosis Model [1].

Code[2]	Abbreviation	Habitat type name
130	PIPO/AGSP	*Pinus ponderosa/Agropyron spicatum*
170	PIPO/SYAL	*Pinus ponderosa/Symphoricarpos albus*
250	PSME/VACA	*Pseudotsuga menziesii/Vaccinium caespitosum*
260	PSME/PHMA	*Pseudotsuga menziesii/Physocarpus malvaceus*
280	PSME/VAGL	*Pseudotsuga menziesii/Vaccinium globulare*
290	PSME/LIBO	*Pseudotsuga menziesii/Linnaea borealis*
310	PSME/SYAL	*Pseudotsuga menziesii/Symphoricarpos albus*
320	PSME/CARU	*Pseudotsuga menziesii/Calamagrostis rubescens*
330	PSME/CAGE	*Pseudotsuga menziesii/Carex geyeri*
420	PICEA/CLUN	*Picea/Clintonia uniflora*
470	PICEA/LIBO	*Picea/Linnaea borealis*
510	ABGR/XETE	*Abies grandis/Xerophyllum tenax*
520	ABGR/CLUN	*Abies grandis/Clintonia uniflora*
530	THPL/CLUN	*Thuja plicata/Clintonia uniflora*
540	THPL/ATFI	*Thuja plicata/Athyrium filix-femina*
550	THPL/OPHO	*Thuja plicata/Oplopanax horridum*
570	TSHE/CLUN	*Tsuga heterophylla/Clintonia uniflora*
610	ABLA/OPHO	*Abies lasiocarpa/Oplopanax horridum*
620	ABLA/CLUN	*Abies lasiocarpa/Clintonia uniflora*
640	ABLA/VACA	*Abies lasiocarpa/Vaccinium caespitosum*
660	ABLA/LIBO	*Abies lasiocarpa/Linnaea borealis*
670	ABLA/MEFE	*Abies lasiocarpa/Menziesia ferruginea*
680	TSME/MEFE	*Tsuga mertensiana/Menziesia ferruginea*
690	ABLA/XETE	*Abies lasiocarpa/Xerophyllum tenax*
710	TSME/XETE	*Tsuga mertensiana/Xerophyllum tenax*
720	ABLA/VAGL	*Abies lasiocarpa/Vaccinium globulare*
730	ABLA/VASC	*Abies lasiocarpa/Vaccinium scoparium*
830	ABLA/LUHI	*Abies lasiocarpa/Luzula hitchcockii*
850	PIAL-ABLA	*Pinus albicaulis-Abies lasiocarpa*
999	OTHER	

[1] From Pfister and others 1977.
[2] The codes given are for habitat types. Phases are treated as subsets of habitat types. For instance, the codes 261 and 262 are interpreted the same as code 260.

Our example stand, S248112, is located in the St. Joe National Forest (code 18). This stand is on a northwest-facing slope of approximately 30 percent (aspect code = 8, slope code = 3) at 3400 feet elevation (code = 34). The habitat type has been identified as *Tsuga heterophylla/Clintonia uniflora* (code = 570). This stand was inventoried in 1977, at which time its average age was 57 years. Site index is unknown. The above data could be entered into the Prognosis Model using the following keyword and supplemental data records:

```
STDIDENT
S248112          HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL
STDINFO      18.0    570.0    57.0    8.0    3.0    34.0    ɓ
INVYEAR      1977.0
```

SAMPLE TREE DATA

The sample tree records (fig. 3) are another important component of the Prognosis Model input. The model predicts future tree heights and diameters from initial stand and tree characteristics and estimates of periodic increment. Stand data were described above. There are 13 variables used to describe trees and these are entered on the tree

13

```
                                    COLUMNS
          1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890
======================================================================
      S
      T                 P
      A                 L
   R  N                 O                                    I
   E  C  D              T   P                             I  P
   C  O                 O   R  I   I   D            I     D IR     H  T
   O  R  I              I   O  T  S   B  D       H  C     C  MS     T  H
   R  D  D              D   B  H  P   H  G       T  R     D  CC     G  T
   ==  ======           ==== ============ ====   ====    ====     == ==
    1  248112           0101  011LP 11510  0734   0011     0  0
    2  248112           0102  011WH 06523  0308   0011     0  0
    3  248112           0102  031DF 001    0026   0022     0  0
    4  248112           0102  011L  07906  0753   0011     0  0
    5  248112           0102  016L  346           1032     0  0
    6  248112           0103  0111  08007  0633   7322     0 56
    7  248112           0103  011GF 06220  0385   0011     0  0
    8  248112           0103  011L  084      54   0011     0  0
    9  248112           0103  011LP 09511  0603   0011     0  0
   10  248112           0104  011DF 040    0203   0011    50  0
   11  248112           0104  011L  08212  0655   5011     0  0
   12  248112           0105  011DF 012    0116   0022    42  0
   13  248112           0105  011DF 019    0135   0022    47  0
   14  248112           0105  015LP 072           1132     0  0
   15  248112           0105  011C  001    0027   0022     0  0
   16  248112           0105  011GF 05309  0277   0011     0  0
   17  248112           0106  011DF 10010  0654   0011     0  0
   18  248112           0106  011GF 06112  0388   0011     0  0
   19  248112           0106  011DF 12716  0674   0011     0  0
   20  248112           0107                       80
   21  248112           0108  011LP 09605  0603   0022     0  0
   22  248112           0108  011DF 10409  0555   7422     0 49
   23  248112           0108  011LP 085      03   0011     0  0
   24  248112           0109  011GF 10910  0657   0011     0  0
   25  248112           0109  011DF 09418  0604   0011     0  0
   26  248112           0110  011C  03206  0175   0022    32  0
   27  248112           0110  031GF 001    0037   0022     0  0
   28  248112           0110  011C  05810  0287   0011     0  0
   29  248112           0110  011C  05010  0253   0011     0  0
   30  248112           0111  011GF 06614  0307   0011     0  0
```

Figure 3.—Sample tree records from the inventory of stand S248112 in the St. Joe National Forest.

records. Following is a description of what the variables are, how they should be coded, and how they are used in the Prognosis Model. Some variables may be omitted or sub sampled. In these cases, zeroes and blanks are treated as missing values.

Plot ID (*ITRE*).—Each stand inventory consists of 1 or more inventory plots. The term "plot" is used to describe a fixed area plot, a variable radius plot, or the combination of the two when used to measure separate components of the stand (see the discussion of DESIGN). A unique **numeric** code should be assigned to each plot within a stand, and the code should be recorded on each record for a tree sampled on the plot. The plot ID's are used to determine the number of plots in the stand when a plot count is not provided on the DESIGN record.

Number of trees represented by a record (*PROB*).—Trees on a plot that are similar (classed together) may be recorded on a single record. When this option is used, the number of trees in a class must be recorded (see fig. 3, records 3 and 27). If *PROB* is not recorded, the record is assumed to represent a single sample tree.

Tree history (*ITH*).—Only the codes 5, 6, 7, and 9 are significant to the Prognosis Model. These codes indicate types of tree records that are **not projected**. All other codes are assumed to represent live trees, and they are projected. The code 5 trees (record number 14 in fig. 3) are assumed to have died during the mortality observation period (see the discussion of GROWTH). These records are used to backdate stand density statistics to the beginning of the growth measurement period for the purpose of increment model calibration. The codes 6 and 7 represent trees that have been dead for longer periods of time and records with these codes are ignored (see fig. 3, record 5).

The code 9 is used to indicate a special type of record (that is, a planar intercept record in the Forest Service's Region 1 inventory system; USDA Forest Service 1978) and the code 9 records are also ignored.

Species (*ISP*).—Species is used in the Prognosis Model to index the various growth models and categorize summaries. The species recognized by the Prognosis Model and the default codes for these species are shown in table 4. The default codes may be replaced using the SPCODES records as discussed in the section on species codes. All tree records with unrecognizable codes are treated as mountain hemlock *(Tsuga mertensiana)*. The order in which the codes appear in table 4 (numeric codes) is the order in which species are subscripted within the Prognosis Model. Several keywords that relate to silviculture and growth model modification use species code in a parameter field. In these cases, the numeric species code must be used.

Table 4.—Tree species recognized by the Prognosis Model with Default coding conventions.

Common name	Scientific name	Default input code	Numeric code
Western white pine	*Pinus monticola*	WP	1
Western larch	*Larix occidentalis*	L	2
Douglas-fir	*Pseudotsuga menziesii*	DF	3
Grand fir	*Abies grandis*	GF	4
Western hemlock	*Tsuga heterophylla*	WH	5
Western redcedar	*Thuja plicata*	C	6
Lodgepole pine	*Pinus contorta*	LP	7
Engelmann spruce	*Picea engelmannii*	S	8
Subalpine fir	*Abies lasiocarpa*	AF	9
Ponderosa pine	*Pinus ponderosa*	PP	10
Mountain hemlock	*Tsuga mertensiana*		11

Tree diameter breast height *(DBH; **measured in inches)**.*—Most of the models which predict changes in tree attributes are dependent on *DBH*. Trees smaller than 4.5 feet in height should be assigned a small, but nonzero, diameter (for example 0.1 inch; see fig. 3, records 3, 15, and 27). This diameter will not be incremented unless projected height is greater than 4.5 feet. *DBH* must be recorded if the tree is to be projected; **records with blank or zero *DBH* values are ignored.**

Periodic diameter increment *(DG; **measured in inches).***—Periodic diameter increment data is used to calibrate the diameter increment model. If *DG* is measured on two or more sample trees of a species, the model for that species is calibrated. Diameter increment data may be entered into the Prognosis Model in two ways: (1) a past or future outside bark *DBH* measurement; or (2) a past or future inside bark diameter increment measurement. If the first method is used, the program will automatically convert *DG* to an inside bark increment prior to calibration.

We recommend subsampling for diameter increment, with the sample trees selected in proportion to *DBH* squared or *DBH* cubed (Stage 1960).

We also recommend using a 10-year period to measure growth because the diameter increment model is based on data for a 10-year period. The form of the diameter increment model was selected in part to enhance extrapolation to different period lengths. However, this capability should not be abused without evaluating the biases. In general, period lengths ranging from 5 to 15 years are safe. Both the method of growth measurement and the length of the period are entered on the GROWTH keyword record, which will be described shortly.

Tree height *(HT;* **measured in feet).**—Tree height is the second most important tree attribute that is projected. Height is used in the height increment and crown ratio calculations and in the volume formulae. Heights may be omitted from the tree records or they may be subsampled. If omitted, initial heights will be calculated using species-specific height-diameter relationships that are imbedded in the program. If height is subsampled, and four or more trees of a species have recorded heights and no apparent top damage, the parameters of the height-diameter equation will be estimated from the input data.

When the top of the tree is missing or dead (damage code 73 or 74; see the damage code description in this section), the variable *HT* should be used to record the actual live height of the tree. This is the height that will be projected and used in growth predictions. Trees with top damage are not included in the height-diameter curve parameter estimates.

Two additional variables are needed to approximate a taper curve so that volume loss due to top-kill can be estimated (Monserud 1980). These are the estimated height if the tree were not top-killed *(NORMHT)* and the height to point of top-kill *(THT). NORMHT* is initially computed from the height-diameter function and is adjusted each cycle by adding the predicted height increment.

Height to point of top-kill *(THT;* **measured in feet).**—When the top is dead or missing, the height to point of top-kill should be recorded (see fig. 3, records *6* and 22). *THT* serves as a permanent point of truncation for volume calculations and is not incremented.

When the damage code indicates a dead or missing top, and *THT* is not recorded, the height to the point of top-kill is assumed to be 80 percent of *NORMHT* (the tree height estimated from the height-diameter function). If *HT* is not recorded, it is set equal to *THT,* regardless of whether *THT* was recorded or computed. In any case, the heights are constrained such that

$$THT [HT [NORMHT.$$

We recommend recording both *HT* and *THT* for trees with visible top damage.

Periodic height increment *(HTG;* **measured in feet).**—Height increment is used to calibrate the small-tree height increment model in the same way that diameter increment is used to calibrate the diameter increment model. *HTG* may be subsampled, and trees selected should have a DBH that is less than 5 inches (see fig. 3, records 10, 12, 13, and 26). *HTG* is entered into the Prognosis Model either by recording an increment (future or past) or a height (future or past). If heights are recorded, *HTG* will be automatically converted to an increment prior to calibration.

We recommend a 5-year period for measuring height increment because this is the period length on which our models were based. For periods longer than 5 years, it becomes increasingly difficult to measure increment without destructively sampling trees or using permanent sample plots. Both the method by which increment is measured and the period length are specified on the GROWTH keyword record.

Crown ratio code *(ICR).*—The ratio of live crown length to total height is an important predictor of diameter increment. *ICR* is coded into 10 percent classes (1 = 0-10 percent, 2 = 11-20 percent,...,9 = > 80 percent). Within the program, *ICR* is converted to crown ratio *(CR)* by giving *CR* a value equal to the class midpoint. When *ICR* is missing, a value is computed using an imbedded equation. This equation is not calibrated from the input data.

Damage code *(IDCD).*—There are only two damage codes that are currently used by the Prognosis Model. If *IDCD* is equal to 73, the top is assumed to be dead; if *IDCD* is equal to 74 (see fig. 3, records 6 and 22), the top is assumed to be missing. These codes should be used in conjunction with actual and estimated tree heights as earlier described.

Tree value class code *(IMC).*—The tree value class is a factor in the formula which computes priority for removal if you specify thinnings. Four classes are allowed (codes 1,2,3,

and 8), and all other codes will be converted to 3. With all other factors held constant, code 3 trees will be removed prior to code 2 trees, and code 2 trees will be removed prior to code 1 trees.

Code 8 is used to include a null-record for a point that is nonstockable (see fig. 3, record 20). Once the nonstockable point has been tallied, the record is ignored. The nonstockable point tally is used to estimate the proportion of stand area associated with nonstockable openings. All stand statistics that are reported in the output are averaged across total stand area. The stand density statistics used for growth prediction, however, are averaged over only the stockable area.

Short-run prescription recommendation (*IPRSC*).—One of the Prognosis Model management options is the removal of trees marked for harvesting. A value of *IPRSC* less than or equal to 1 indicates a leave tree. Other values *(IPRSC* μ 2) indicate a tree marked for removal.

Example of tree records.—Figure 3 shows the sample tree records for the inventory of S248112. These records are organized in accordance with the default format (table 5). Table 5 also specifies the units in which data should be recorded and indicates the precision of the data to which the models were fitted.

Table 5.—Default format for tree records that are used in the Prognosis Model

Variable	Variable [1] name	Column(s)	Units	Implied decimal places [2]
Plot ID	*ITRE*	24-27	—	0
Tree count	*PROB*	31-32	trees	0
Tree history	*ITH*	33	—	0
Species	*ISP*	34-36	—	0
Diameter at breast height	*DBH*	37-39	inches	1
DBH increment	*DG*	40-41	inches	1
Live height	*HT*	45-47	feet	0
Height to topkill	*THT*	63-65	feet	0
Height increment	*HTG*	60-62	feet	1
Crown ratio code	*ICR*	48	—	0
Damage code	*IDCD*	52-53	—	0
Tree value class	*IMC*	54	—	0
Cut or leave	*IPRSC*	55	—	0

[1] Variable names are in accordance with standard FORTRAN conventions—*I,J,K,L,M*, and *N* are used to begin integer names; *ISP* is alphanumeric.
[2] For example, a *DBH* coded 115 indicates 11.5 inches. The number of decimal points indicates the precision of the data to which the models were fitted.

Reading the tree records.—Several options are available for entering tree records. Tree records are read when TREEDATA is encountered, or when PROCESS is encountered if no TREEDATA record has been previously found. The tree records are read from the dataset referenced by the number that is specified in parameter field 1 on the TREEDATA record:

TREEDATA   field 1:   Dataset reference number for tree record input file; default = 2.

The tree records can be treated like supplemental data records for the TREEDATA keyword. In this case, the dataset reference number (field 1) should be assigned the logical unit number for card input at your computer installation (logical unit 5 on most IBM systems) and a special record with *ITRE* equal to – 999 must be added to the end of the tree record file. Our example tree records could be inserted into the keyword record file as follows:

```
TREEDATA            5.0
              248112      0101      011LP      11510      0734      00111
              248112      0102      011WH      06523      0308      00111
                 .          .          .          .          .          .
                 .          .          .          .          .          .
                 .          .          .          .          .          .
              248112      0110      0111F      06614      0307      00111
                         –999
```

Another option is to treat the tree records as an independent file. This file can be stored on any medium (cards, disk, or tape) that your computer center supports. A job control statement must be created that assigns the dataset reference number indicated on the TREEDATA record to your file[4]. A programmer can help you create this job control statement for your computing environment.

The last tree record input option involves merging tree record files from different sources to form a single tree record file for projection. In this case, a TREEDATA record and a job control statement for each file are required. For example, to merge the example stand (as illustrated above) with two other stands, the keyword record file might look like:

```
TREEDATA            5.0
              248112      0101      011LP      11510      0734      00111
                 .          .          .          .          .          .
                 .          .          .          .          .          .
                 .          .          .          .          .          .
              248112      0110      011GF      06614      0307      00111
                         –999
TREEDATA           17.0
TREEDATA           18.0
```

In this example, the two additional stands are read from units 17 and 18, respectively. Separate job control statements for units 5, 17, and 18 are needed. In addition, data on the DESIGN and STDINFO keyword records must reflect the composite characteristics

---

[4] The data definition or DD statement in the IBM Job Control Language; the Assign file or @ASG and @USE statements in UNIVAC Job Control Language.

of the merged stand. Except for the values 2 and 5, dataset reference numbers that are less than 17 should not be used. Values that are less than 17 have been reserved for existing input and output files.

RECORD FORMAT   We have previously illustrated the default tree record format (fig. 3; table 5). It is likely, however, that your inventory records are formatted differently. Your records need not be modified prior to using the Prognosis Model. If the essential variables have been measured and recorded, the Prognosis Model input format can be altered using the TREEFMT record. This record must be inserted in the keyword record file **prior to** the TREEDATA record. The TREEFMT record does not use any parameter fields but requires two supplemental data records containing a FORTRAN execution-time format statement that describes your tree records. Both supplemental data records must immediately follow TREEFMT even though one may be blank. For example,

TREEFMT
(T24,I4,3X,F2.0,I1,A3,F3.1,F2.1,3X,F3.0,T63,F3.0,
T60,F3.1,T48,I1,3X,I2.2I1)

is the set of keyword records that specifies the default format.

SPECIES CODES   The tree records do not need to be modified when the species codes in the tree record file are different from the codes given in table 4. The way in which the Prognosis Model interprets species codes can be changed instead. This change is accomplished with the SPCODES record. The SPCODES record requires one parameter field to indicate the species for which the code is being replaced and is followed by a single supplemental record, containing the replacement code in columns one through four.

SPCODES   field 1:   Numeric species code (table 4) indicating the species for which the species code is to be replaced; if blank, replace all codes.

For example,

SPCODES   7.0
LPP

is the set of records needed to change the species code for lodgepole pine (the seventh species listed in table 4) to LPP.

When field 1 on the SPCODES record is blank, all species codes are replaced. The new codes are entered on the supplemental data record in the order that species occur in table 4 (western white pine in columns l-4, western larch in columns 5-8, . . ., mountain hemlock in columns 41-44).[5] If Forest Survey standard species codes[6] are used, the records needed to replace the species codes could be entered as follows:

SPCODES
119 073 202 017 263 242 108 093 019 122

---

[5] These codes are interpreted literally and blanks are not equivalent to zeroes. If all the tree records are ultimately classified as "other species" (i.e., mountain hemlock), an error has probably been made in the preparation of either the SPCODES or TREEFMT records.
[6] USDA Forest Service Handbook, 4809.11; HB-73 Tree Species.

In the above example, the spacing is important. Each code must be confined to a 4-column field, and the fields must be arranged consecutively on the supplemental record. Note also that each species can be represented by one and only one code within a tree record file.

INTERPRETING INCREMENT DATA

The final aspect we will consider with regard to the tree records is the interpretation of the periodic growth data. The projection always begins with the heights and diameters that were read as the variables *HT* and *DBH*. These variables should be measured at the same point in time. The Prognosis Model routinely assumes that *DBH* is a current outside bark diameter and that *DG* is a 10-year estimate of past inside bark diameter increment. Similarly, *HTG* is assumed to be current height and *HTG* is a 5-year estimate of past height increment. These interpretations can be altered with the GROWTH record. The GROWTH record is also used to define the length of the period over which current mortality (tree history code 5) was observed. The mortality observation period is assumed to be 5 years in length.

GROWTH   field1:   Measurement method code for diameter increment data; default = 0

            field 2:   Period length for diameter increment measurement; default = 10.

            field 3:   Measurement method code for height increment data; default = 0.

            field 4:   Period length for height increment measurement; default = 5

            field 5:   Period length for current mortality observation; default = 5.

As was described earlier, increment estimates can be either directly measured or computed as the difference between two successive diameter or height measurements. Furthermore, the values for *DBH* and *HT* can describe the tree at either the start or the end of the growth period. Consequently, there are four possible measurement method codes, which are coded in fields 1 and/or 3 as follows:

	The time that DBH or HT was measured	
Method	**End of growth measurement period**	**Start of growth measurement period**
Increment measured directly	Code = 0	Code = 2
Increment to be calculated by subtraction	Code = 1	Code = 3

When measurement methods 1 or 3 are used, the measurements recorded for *HTG* and/or *DG* should be actual heights or outside bark diameters.

Stand Management Options

Assuming that the stand inventory has been prepared for projection, you are now ready to assess the impact of various stand management strategies. In this section, the available thinning options will be described, and we will illustrate how to use these options to simulate silvicultural treatments.

Some of the thinning options allow selection of specific trees or classes of trees for removal. In other options, a removal priority is assigned on the basis of species, size (*DBH*), and tree value class (*IMC*). The highest priority trees are then removed until a stand density target (basal area or trees per acre) is achieved. When using the stand density target options, the types of trees removed can be controlled by adjusting the relative weights of the components of the removal priority formula.

GENERAL RULES

The process of thinning involves the removal of trees. However, when thinning is simulated within the Prognosis Model, the thinned tree records are not actually eliminated from the tree record file. Rather, the number of trees per acre represented by the thinned tree records is reduced.

Cutting Efficiency

The proportion of trees represented by a tree record that can be removed in any thinning, the cutting efficiency parameter, is initially set at 0.98. If, for example, a tree record representing 300 trees per acre was removed in a thinning, the tree record would then represent six trees per acre. The cutting efficiency parameter may be changed for any or all thinnings, but the value must fall between 0.01 and 0.99. The CUTEFF record is used to change the cutting efficiency parameter:

CUTEFF   field 1:   Proportion of the sample trees represented by a record that is eliminated if a tree is designated for removal in any thinning. The value of this parameter must fall between 0.01 and 0.99 or the keyword will be ignored; the default value is 0.98.

In addition, there is a cutting efficiency parameter on each thinning request keyword. If a value is supplied as part of a thinning request, it will only apply to that thinning request. If a value is not supplied with the thinning request, the cutting efficiency parameter associated with the CUTEFF record will be used.

Data Specification

All thinnings are scheduled by date, and the date used must fall within the range of dates defined by the TIMEINT, NUMCYCLE, and INVYEAR parameters. Thinning dates need not coincide with the beginning of a cycle, however.

Any number of thinnings may be scheduled during any one projection cycle. These thinnings will be simulated in order of date. Thinnings specified for the same date will be simulated in the order they occur in the input file. For purposes of computing growth and mortality, all thinnings are assumed to occur at the beginning of the cycle in which they are scheduled.

Specifying Minimum Acceptable Harvests

Thinnings can be constrained by specifying standards for minimum acceptable harvests. These standards may be expressed in terms of volume per acre (merchantable cubic feet or board feet) or basal area per acre (square feet). Minimum harvests are specified by cycle number. The accumulated removals across **all** thinnings in a cycle must exceed the standards for **all** of the units of measure, or none of the thinnings in

that cycle will be implemented. The minimum harvest standards are specified using the MINHARV record:

MINHARV field 1: The cycle in which minimum harvest standards will apply. If blank, the standards will be applied in all cycles.

       field 2: The minimum acceptable harvest volume in merchantable cubic feet per acre; default = 0.

       field 3: The minimum acceptable harvest volume in board feet per acre; default = 0.

       field 4: The minimum acceptable harvest in square feet of basal area per acre; default = 0.

MODIFYING VOLUME CALCULATIONS

Both the merchantable cubic foot volume and the board foot volume indirectly influence the frequency of thinning through the minimum harvest constraints. These volume predictions also directly influence any comparison of alternative management strategies. Therefore, we have included modifications of volume calculations as a part of the general discussion of management options.

The volume calculations may be modified in two ways. First, you may choose to vary the merchantability limits on the merchantable cubic foot volume equation. Merchantable cubic foot volume is derived from total cubic foot volume by using a Behre hyperbola to approximate bole form. You may specify stump height, minimum top diameter, and minimum *DBH* to be used in estimating merchantable cubic foot volume. These factors can be altered by cycle and by species with the VOLUME record:

VOLUME   field 1: Cycle number at which the merchantability limits are to take effect; default is beginning of the projection.

       field 2: Species number (see table 4) for the species that is to be effected by the merchantability limits; default is all species.

       field 3: Minimum merchantable *DBH* (inches). Trees with smaller *DBH* are not included in the merchantable volume calculation. If the number entered here is less than the top diameter (field 4), the value specified for minimum top diameter will be used for minimum *DBH* as well; default = 6.0 for lodgepole pine, 7.0 for all other species.

       field 4: The top minimum diameter (inches); default = 4.5.

       field 5: Stump height (feet); default = 1.0.

Note that the parameters on the VOLUME record do not affect the board foot volume predictions.

The other means of modifying volume predictions is by entering parameters for form and defect correction equations. Frequently, data are available which relate volume predictions to mill volume production on the basis of tree attributes. Region 1 of the Forest Service has

produced such equations for most of its National Forests and these equations are invariably polynomial expressions of tree *DBH*:

$$factor = b_0 + b_1 \exists DBH + b_2 \exists DBH^2 + b_3 \exists DBH^3 + b_4 \exists DBH^4 \tag{1}$$

where b_0 through b_4 are species dependent coefficients.

    Tree volume is then corrected for form and defect by multiplying *factor* times the predicted gross volume.

    Rather than incorporating parameters in the Prognosis Model for each species, for each National Forest, and for each merchantability standard, we have provided the facility to enter parameters. A form and defect correction can be implemented for any species and for either the merchantable cubic foot or the board foot volume predictions. The parameters of the equation are entered using the MCFDPOLY (for merchantable cubic feet) or BFFDPOLY (for board feet) records.

MCFDPOLY
or
BFFDPOLY   field 1:   Species number (see table 4) for which a form and defect correction factor equation is to be entered; if blank, the equation will be applied to all species.

               field 2:   Intercept term to be used in the form-defect correction factor equation (b_0 in eq. 1); default = 1.0.

               field 3:   Coefficient for the DBH term in the form-defect correction factor equation (b_1 in eq. 1); default = 0.0.

               field 4:   Coefficient for the DBH^2 term in the form-defect correction factor equation *(b_2 in eq. 1)*; default = 0.0

               field 5:   Coefficient for the DBH^3 term in the form-defect correction factor equation *(b_3 in eq. 1)*; default = 0.0.

               field 6:   Coefficient for the DBH^4 term in the form-defect correction factor equation *(b_4 in eq. 1)*; default = 0.0

    An alternative form for the form-defect correction equation is

$$\ln(V_s) = a_0 + a_1 \exists \ln(V_0) \tag{2}$$

where:

V_s = volume to some merchantability standard corrected for form and defect.

V_0 = uncorrected volume to the same merchantability standard.

a_0 and a_1 are species dependent coefficients.

Coefficients for the log-linear form-defect correction equation (eq. 2) can be supplied by the user. This equation may be used in addition to or instead of the polynomial formdefect correction equation. Coefficients are entered with the MCFDLN (for merchantable cubic volumes) and BFFDLN (for board foot volumes) records:

MCFDLN
or
BFFDLN   field 1:   Species number (see table 4) for which the log-linear form-defect corrections equation is to be entered; if blank, the equation will be applied to all species.

     field 2:   Intercept term for log-linear form-defect correction equation (parameter a_0 in eq. 2); default = 0.0.

     field 3:   Slope coefficient for log-linear form defect correction equation (parameter a_1 in eq. 2); default = 1.0.

REQUESTING REMOVAL OF SPECIFIC TREES OR CLASSES OF TREES

The first thinning options we will consider are the prescription and diameter limit thinnings. These options allow the removal of specific trees and trees that are greater than or less than a specified limiting value of *DBH*.

Prescription Thinning

The prescription thinning option uses the marking codes (*IPRSC*) that are input with the tree records. When a prescription thinning is requested, all trees with a value of *IPRSC* that is greater than or equal to two will be removed. For example, records number 3, 5, 6, 12, 13, 14, 15, 21, 22, 26, and 27 in figure 3 were marked for removal.

Only one set of marking codes can be entered with the tree records in any one projection. Multiple requests for the prescription thinning option may lead to numerical problems within the growth projection routines unless the cutting efficiency parameter is set to a small value (say 0.5).

Prescription thinning is requested with the THINPRSC record:

THINPRSC   field 1:   Year in which prescription thinning is requested; the default year is the starting date for the projection.

     field 2:   Cutting efficiency parameter to be used only with this thinning request. If blank, use the value specified on the CUTEFF record.

Diameter Limit Thinnings

The diameter limit thinning option can be used to remove segments of the *DBH* distribution without regard to species or tree value class. This option allows simulation of treatments such as cleaning and overwood removal (fig. 4). The diameter limit thinning option is requested with the THINDBH record:

THINDBH   field 1:   Year in which diameter limit thinning is requested; the default year is the starting date for the projection.

     field 2:   The smallest *DBH* in the segment of the diameter distribution that is to be **removed**. If blank, remove all trees that have a *DBH* that is less than the maximum *DBH* that is coded in field 3. If both field 2 and field 3 are blank, the request is ignored.

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field 3: The largest *DBH* in the segment of the diameter distribution that is to be **removed**. If blank, remove all trees that have a *DBH* that is greater than the minimum *DBH* that is coded in field 2. If both field 2 and field 3 are blank, the request is ignored.

field 4: Cutting efficiency parameter to be used only with this thinning request; if blank, use the value specified on the CUTEFF record.

```
IN THE YEAR 1981:
A.   REMOVE ALL TREES WITH DBH LESS THAN OR EQUAL TO 3 INCHES:
```

```
                                                          ─DBH
             3
        THINDBH      1981.0      ƀ      3.0      ƀ
```
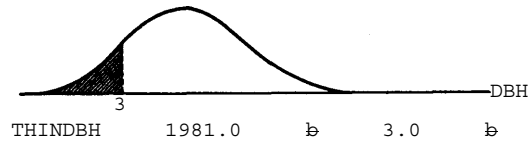
```
B.   REMOVE ALL TREES WITH DBH GREATER THAN OR EQUAL TO 20 INCHES:
```

```
                                                      DBH
                  20
        THINDBH      1981.0     20.0      ƀ      ƀ
```
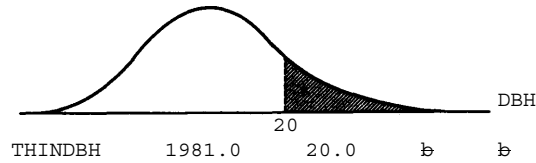
```
C.   REMOVE ALL TREES WITH DBH BETWEEN 3 AND 20 INCHES:
```

```
                                                  DBH
             3            20
        THINDBH      1981.0      3      20.0      ƀ
```
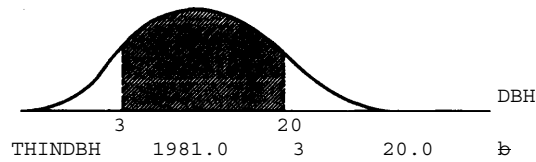
```
D.   LEAVE ONLY THOSE TREES THAT ARE BETWEEN 3 AND 20 INCHES:
```

```
                                             DBH
             3          20
                              THINDBH      1981.0      ƀ      3.0      ƀ
        THINDBH      1981.0     20.0     ƀ      ƀ
```
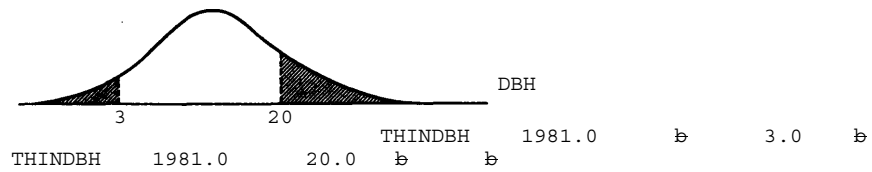
```
E.   LEAVE ONLY 50% OF THE TREES THAT ARE BETWEEN 20 AND 25 INCHES DBH:
```

```
                                       DBH
              20    25
        THINDBH                 1981.0      ƀ      20.0    ƀ
        THINDBH      1981.0     25.0    ƀ      ƀ
        THINDBH      1981.0     20.0    65.0   0.5
```
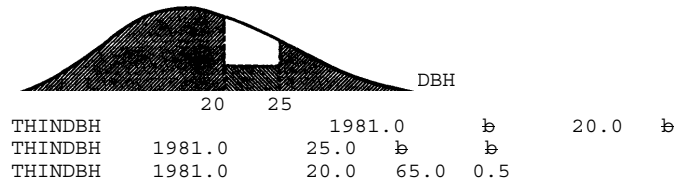
Figure 4.—Using the THINDBH record to remove specific segments
of the *DBH* distribution; five examples.

CONTROLLING STAND DENSITY

The remaining stand management options reflect a somewhat different management philosophy. With these options stand density may be managed while giving consideration to tree size, species, and value class in determining priority for removal. The thinning request keyword specifies whether basal area per acre or trees per acre will be controlled. It also indicates whether small trees (thinning from below) or large trees (thinning from above) will be favored for removal. Other keywords are needed to specify the role of species and tree condition in determining the actual removal priority.

Computing Removal Priority

Each tree is assigned a priority for removal (P) that is computed as

$$P = (S \cdot DBH) + SP + (T \cdot IMC) \tag{3}$$

where:

S = (–1) if thinning from below
(+1) if thinning from above

SP = User-specified species preference

IMC = input tree value class code

T = user-specified multiplier for the tree value class code.

The probability that a tree will be removed in a thinning is proportional to P. The tree with the largest P is removed first. Thereafter, trees are selected for removal, in descending order of P, until the residual stand density objective is achieved. By manipulating the values of SP and T and choosing an appropriate density control option, a thinning strategy can be designed to attain almost any silvicultural objective.

The default value of SP is zero for all species and the default value of T is 100. If these parameters are not altered by input, all tree value class 3 trees will be removed prior to removal of any class 1 or 2 trees, and all class 2 trees will be removed before any class 1 trees. Within a tree value class, the trees will be ordered by DBH.

The SPECPREF and TCONDMLT records can be used to modify the values of SP and T, respectively:

SPECPREF field 1: Date that the species preference code given on this record will take effect. If blank, it will be implemented at the start of the projection.

field 2: **Numeric** species code as given in table 4; the request is ignored if species code is invalid or missing.

field 3: Species preference code, SP. Any value may be used: negative values will decrease the probability of removal for a species; positive values will increase the probability of removal for a species; default = 0.

TCONDMLT   field 1:   Date that the tree condition class multiplier coded on this record will take effect. If blank, it will be implemented at the start of the projection.

field 2:   Tree condition class multiplier, *T*; default = 100.0.

The SPECPREF and TCONDMLT records are scheduled along with thinning requests. As we described earlier, scheduling is determined by date, and within date, by order of occurrence in the input file. Once the preference modifiers are set, they will remain in effect until replaced with new SPECPREF or TCONDMLT instructions.

Specifying Thinning Method and Target Density

The keywords used to specify a stand density target also indicate whether thinnings are to be from above or from below. These keywords are defined as follows:

(1) THINBTA—Thin from below to a trees-per-acre target.

(2) THINATA—Thin from above to a trees-per-acre target.

(3) THINBBA—Thin from below to a basal-area-per-acre target (square feet).

(4) THINABA—Thin from above to a basal-area-per-acre target (square feet).

With the exception of the unit of measure for the residual density, the same parameters must be entered on all of these keyword records:

THINBTA
THINATA
THINBBA
THINABA   field 1:   Year in which thinning is requested; if blank, schedule at start of projection.

field 2:   The desired residual stand density measured in the appropriate units. If a residual density is not specified, the thinning request will be ignored.

field 3:   The cutting efficiency parameter to be used only with this thinning request. If blank, use the value specified on the CUTEFF record.

Each tree record is considered for thinning only once per thinning request. If the cutting efficiency parameter is set at a relatively low level, it is possible that a thinning will be simulated without achieving the specified stand density target.

Automatic Stand Density Control

The last thinning option allows you to automatically maintain stand density within a specific range of trees per acre that is based on normal stocking. Normal stocking, in trees per acre (T_N), is predicted as a function of quadratic mean stand *DBH (QMD)*

$$T_N = \frac{1}{0.00004 \cdot (1 + QMD)^{1.588}} \tag{4}$$

The normal stocking function (fig. 5) was fit to data in Haig's (1932) yield tables but is intended only as a guide curve. The equation form is quite similar to Reineke's (1933) stand density index.

When automatic density control is used, the upper and lower limits of stand density (*MIN* and *MAX*) are defined as percentages of normal stocking. If, at the beginning of a cycle, the stand density is greater than *MAX* percent of normal, the number of trees in the stand will be reduced to *MIN* percent of normal by thinning from below. The removal priority as defined by SPECPREF and TCONDMLT (eq. 3) will determine the order of removal.

$$T_N = \frac{1}{0.00004 \ (1 + QMD)^{1.588}}$$
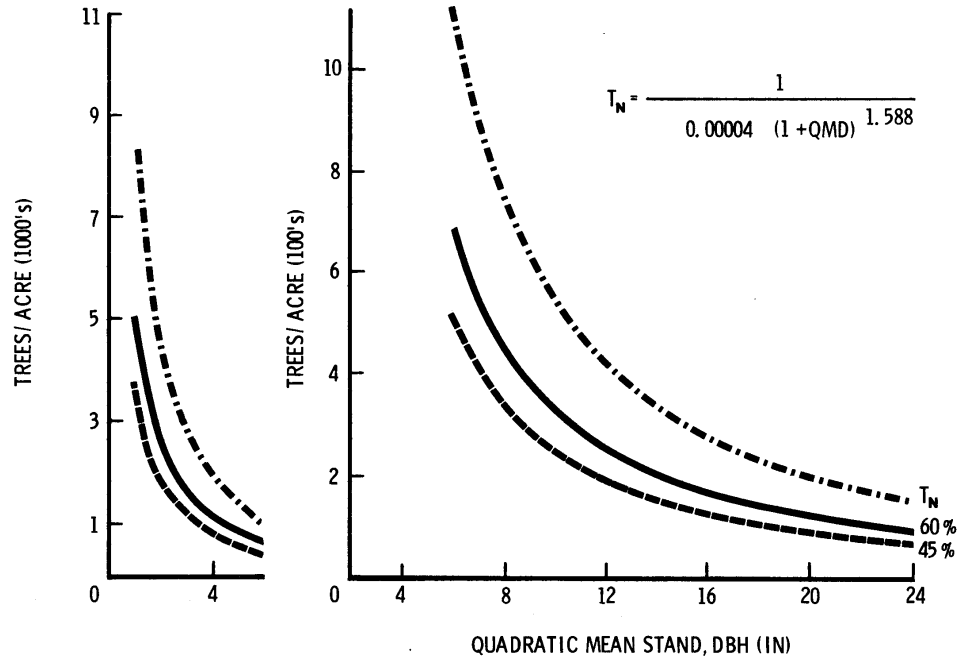
Figure 5.—Normal stocking density in trees per acre (T_N) as a function of quadratic mean stand *DBH* *(QMD)*. Based on Haig's (1932) yield tables for second-growth stands in the western white pine type.

Automatic density control may be started at the beginning of the projection or delayed for any number of years. Once initiated, automatic control will be implemented in each subsequent cycle for which there is no other thinning request.

Automatic density control is requested with the THINAUTO record:

THINAUTO   field 1:   The date that automatic density control is to start; default = start of projection.

             field 2:   The lower limit (*MIN*) of the range of normal stocking density that is to be maintained; default = 45 percent.

             field 3:   The upper limit (*MAX*) of the range of normal stocking density that is to be maintained; default = 60 percent.

             field 4:   The cutting efficiency parameter to be used with all removals invoked with this request. If blank, use the value specified on the CUTEFF record.

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A PRESCRIPTION FOR THE EXAMPLE STAND

We prepared some additional summaries of our example stand (table 6) and showed them to a certified silviculturist.[7] He prepared the following prescription:

(1) Implement the thinning indicated by the input tree marking codes (fig. 3) at age 60 (assumed to be 1980).
(2) At age 90, remove lodgepole pine and western larch. These species can be expected to be dominated by the Douglas-fir and grand fir in the future.
(3) At age 120, initiate a shelterwood regeneration treatment favoring the Douglas-fir and grand fir.
(4) Remove overwood at age 130 to release established regeneration.

To implement the first phase of the prescription, we need only use:

THINPRSC   1980.0

Table 6.—Additional summary data for stand S248112 [1]

Species	Trees per acre	Basal area per acre	Quadratic mean *DBH*	Average height[3]	Average 10-year *DBH* increment[3]
		Ft^2	Inches	Feet	Inches
Stand composition before thinning (1980) [2]					
LP	28.9	14.56	9.6	63.3	0.77
WH	15.8	3.64	6.5	23.0	2.30
L	40.5	14.56	8.1	67.8	.84
GF	163.5	18.20	4.5	19.1	1.30
DF	188.1	17.69	4.2	15.2	1.32
C	182.8	8.81	3.0	10.4	.85
All	619.6	77.46	4.8	20.7	1.13
----- Projected Prescription Removal (1980) -----					
LP	7.2	3.64	9.6	60.0	.50
L	10.4	3.64	8.0	63.0	.70
GF	81.8	0.0	0.1	3.0	—
DF	142.5	4.39	2.4	8.1	.90
C	136.4	1.53	1.4	5.0	.60
All	378.3	13.20	2.5	8.4	.64
-----Prescribed Residual Stand (1980)-----					
LP	21.7	10.92	9.6	65.3	1.06
WH	15.8	3.64	6.5	23.0	2.30
L	30.1	10.92	8.2	70.2	.89
GF	81.7	18.20	6.4	35.2	1.30
DF	45.6	13.30	7.3	37.4	1.46
C	46.4	7.28	5.4	26.3	1.00
All	241.3	64.26	7.0	37.8	1.27

[1]Location, St. Joe National Forest; habitat type, 570; elevation, 3400 ft; slope, 25 to 35 percent; aspect, north-west; age 57 years (1977 inventory).
[2]These statistics were based entirely on the inventory data used as input to the Prognosis Model.
[3]When variables are subsampled, the average includes only those trees for which the variable was measured.

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[7] Russelt. Graham, U.S. Department of Agriculture Forest Service, INT-RWU-1206; certified through USDA Forest Service, Region 1 CEFES program. What he actually told us was to leave the stand alone, as it was well stocked. Because the prescription would have made a poor example, we embellished a little.

The second phase of the prescription requires a little analysis. We can see from table 6 that, following the prescription thinning, there will be approximately 240 trees per acre, and 58 trees will be lodgepole pine and western larch (LP-L). The local rule-of-thumb predicts 0.5 percent mortality per year. This converts to about 14 percent mortality in 30 years; so, by age 90, we might expect 34 total trees to have died, of which 8 would be LP-L. This leaves us with approximately 207 trees, of which 50 are LP-L and 157 are of other species. The LP and L can be removed using:

SPECPREF	2010.0	2.0	999.0
SPECPREF	2010.0	7.0	9999.0
THINBTA	2010.0	157.0	

We considered the lodgepole pine to be less desirable and weighted it heavier to assure its removal.

To implement the third phase of the prescription, we need to define a shelterwood and then protect the Douglas-fir (species number 3) and grand fir (species number 4) from harvesting. A shelterwood is defined as a residual stand with about 35 trees per acre. Thus,

SPECPREF	2040.0	3.0	−999.0
SPECPREF	2040.0	4.0	−99.0
THINBTA	2040.0	35.0	

should produce the desired results. We have indicated a slight preference for keeping Douglas-fir over grand fir.

The final phase of the prescription requires no additional keywords unless a model has actually been used to predict the establishment of regeneration. In this case,

THINDBH	2050.0	5.0	b

will remove all trees with *DBH* greater than 5 inches, leaving the regenerated stand.

If we wished to project the development of the regenerated stand, we could use automatic density control to maintain stand density. In this example, we will initiate automatic density control after overwood removal and then reduce trees per acre to 50 percent of normal any time it exceeds 75 percent of normal:

THINAUTO	2060.0	50.0	75.0

INTERPRETING PROGNOSIS MODEL OUTPUT

When a projection begins, the keyword record file is processed and an activity schedule is prepared. The tree records are then checked for missing data and the growth models are calibrated based on the input increment data. The results of these activities are displayed in the first output table (fig. 6).

As events in the activity schedule are simulated, three additional output tables are prepared. The first of these is the stand composition table (fig. 7). Here, the distributions of important stand attributes are displayed relative to *DBH* and species. At each cycle endpoint, the per-acre distributions of trees and total cubic volume are described. In addition, total stand volume is displayed for two different utilization standards: cubic foot volume with user provided top diameter, minimum *DBH,* and stump height specifications; and Scribner board foot volume to an 8-inch top, assuming a l-foot stump and a 9-inch minimum *DBH.* Simulated removals are described with the same statistics and the distribution of trees in the residual stand is then given. Development of the stand is shown by the distributions of volume accretion and volume mortality, both measured in total cubic feet. Accretion is the growth on surviving trees.

The stand composition table is complemented by a table that features the development of individual trees within the stand. In this table (fig. 8), the attributes of six trees are displayed along with several statistics that describe the stand conditions in which the trees developed. The sample trees represent a cross section of the population of trees within the stand and the same trees are displayed each cycle. The statistics printed include species and tree value class, *DBH,* height, crown ratio, past periodic *DBH* increment, percentile in the basal area distribution, and trees per acre represented by the record. The stand is described with an age estimate, three density statistics (basal area, crown competition factor, and trees per acre), estimates of average *DBH,* and average dominant height. The stand statistics, excluding age, are repeated for the residual stand if a removal is simulated.

The last standard output table is a summary of stand development and management activity (fig. 9). This table repeats stand statistics from the previous tables in a concise yield table format with one line allotted to each date in the activity schedule.

Two optional tables can be selected by using the appropriate keyword records. The summary table (fig. 9) may be copied to a permanent storage device for subsequent machine processing (use the ECHOSUM record). In addition, a table that shows the attributes of all sample trees can be printed at each cycle endpoint (see the discussion of TREELIST). Output can also be generated to assist with program debugging. This special output is described in appendix A.

-------------------------------------- --

OPTIONS SELECTED BY INPUT

KEYWORD	PARAMETERS:

-------- --

STDIDENT
          STAND ID= S248112   HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL – NIG4 VERSION

COMMENT
          THE PRESCRIPTION CALLS FOR IMMEDIATE REMOVAL OF
          EXCESS TREES, A COMMERCIAL THINNING AT AGE 90
          TO REMOVE LODGEPOLE AND LARCH, A SHELTERWOOD
          REGENERATION TREATMENT AT AGE 120 FAVORING
          GRAND FIR AND DOUGLAS-FIR, AND AN OVERWOOD
          REMOVAL AT AGE 130.

END

TREELIST   CYCLE=1

DESIGN   BASAL AREA FACTOR= 40.0; INVERSE OF FIXED PLOT AREA= 300.0; BREAK DBH=   5.0
            SEE "OPTIONS SELECTED BY DEFAULT" FOR REMAINING DESIGN CARD PARAMETERS.

STDINFO   FOREST CODE=   18; HABITAT TYPE=570; AGE= 57; ASPECT CODE= 8.; SLOPE CODE= 3.
            ELEVATION(100'S FEET)= 34.0; SITE INDEX=   0.

INVYEAR   INVENTORY YEAR= 1977

NUMCYCLE   NUMBER OF CYCLES= 8

THINPRSC   DATE/CYCLE= 1980; PROPORTION OF SELECTED TREES REMOVED= 0.999

SPECPREF   DATE/CYCLE= 2010; SPECIES= 2.; THINNING SELECTION PRIORITY=   999.

SPECPREF   DATE/CYCLE= 2010; SPECIES= 7.; THINNING SELECTION PRIORITY= 9999.

THINBTA   DATE/CYCLE= 2010; RESIDUAL= 157.00; PROPORTION OF SELECTED TREES REMOVED= 0.980

SPECPREF   DATE/CYCLE= 2040; SPECIES= 3.; THINNING SELECTION PRIORITY= -999.

SPECPREF   DATE/CYCLE= 2040; SPECIES= 4.; THINNING SELECTION PRIORITY= -99.

THINBTA   DATE/CYCLE= 2040; RESIDUAL=   35.00; PROPORTION OF SELECTED TREES REMOVED= 0.980

TREEDATA   DATA SET REFERENCE NUMBER= 5

PROCESS   PROCESS THE STAND.

OPTIONS SELECTED BY DEFAULT

TREEFMT   (23X, I4,3X, F2.0,I1, A3, F3.1, F2.1,3X,F3.0,T63,F3.0   ,T60,F3.1,T48,   I1,3X, I2,
             2I1)

DESIGN   BASAL AREA FACTOR= 40.0; INVERSE OF FIXED PLOT AREA= 300.0; BREAK DBH=   5.0
            NUMBER OF PLOTS=   11; NON-STOCKABLE PLOTS=   1; STAND SAMPLING WEIGHT= 11.00000

ACTIVITY SCHEDULE

STAND ID= S248112   MANAGEMENT ID= NONE   HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL – NIG4 VERSION

```
CYCLE  DATE  EXTENSION  KEYWORD   DATE  PARAMETERS:
-----  ----  ---------  -------   ----  ----------------------------------------------------------------------

   1   1977
              BASE      THINPRSC  1980       1.00

   2   1987
   3   1997

   4   2007
              BASE      SPECPREF  2010       2.00     999.00
              BASE      SPECPREF  2010       7.00    9999.00
              BASE      THINBTA   2010     157.00       0.98

   5   2017
   6   2027

   7   2037
              BASE      SPECPREF  2040       3.00    -999.00
              BASE      SPECPREF  2040       4.00     -99.00
              BASE      THINBTA   2040      35.00       0.98

   8   2047
----------------------------------------------------------------------------------------------------------------

CALIBRATION STATISTICS:
```

	LP	DF	WH	L	GF	C
NUMBER OF RECORDS PER SPECIES	5	8	1	4	6	4
NUMBER OF RECORDS CODED AS RECENT MORTALITY	1	0	0	0	0	0
NUMBER OF RECORDS WITH MISSING HEIGHTS	1	0	0	0	0	0
NUMBER OF RECORDS WITH BROKEN OR DEAD TOPS	0	1	0	1	0	0
NUMBER OF RECORDS WITH MISSING CROWN RATIOS	0	0	0	0	0	0
NUMBER OF RECORDS AVAILABLE FOR SCALING THE DIAMETER INCREMENT MODEL	3	4	1	3	5	2
RATIO OF STANDARD ERRORS (INPUT DBH GROWTH DATA : MODEL)	0.84	0.74	1.00	0.42	0.87	0.72
WEIGHT GIVEN TO THE INPUT GROWTH DATA WHEN DBH GROWTH MODEL SCALE FACTORS WERE COMPUTED	1.00	1.00	0.00	1.00	1.00	1.00
INITIAL SCALE FACTORS FOR THE DBH INCREMENT MODEL	0.92	0.65	1.00	0.68	0.46	0.76
NUMBER OF RECORDS AVAILABLE FOR SCALING THE SMALL TREE HEIGHT INCREMENT MODEL	0	3	0	0	0	1
INITIAL SCALE FACTORS FOR THE SMALL TREE HEIGHT INCREMENT MODEL	1.00	0.76	1.00	1.00	1.00	1.00

Figure 6.—Input summary and calibration statistics table
from the Prognosis Model output.

STAND COMPOSITION

| | | | | PERCENTILE POINTS IN THE DISTRIBUTION OF STAND ATTRIBUTES BY DBH | | | | | TOTAL/ACRE OF STAND | DISTRIBUTION OF STAND ATTRIBUTES BY |
| | STAND | | | | | | | | | | SPECIES AND 3 USER-DEFINED SUBCLASSES |
YEAR	ATTRIBUTES	10	30	50	70	90	100		ATTRIBUTES	
				(DBH IN INCHES)						
1977	TREES	0.1	0.1	3.2	6.1	8.5	12.7	536.	TREES	27.% DF2, 15.% GF2, 15.% GF1, 10.% C2
	VOLUME:									
	TOTAL	5.8	8.0	9.4	10.0	11.5	12.7	1541.	CUFT	23.% LP1, 20.% GF1, 19.% DF1, 12.% L1
	MERCH	8.0	8.5	9.6	10.4	11.5	12.7	1075.	CUFT	31.% LP1, 23.% DF1, 14.% L1, 9.% LP2
	MERCH	9.5	9.6	10.4	11.5	12.7	12.7	2804.	BDFT	35.% LP1, 29.% DF1, 15.% LP2, 13.% GF1
	REMOVAL	0.1	0.1	0.1	1.2	3.2	10.4	296	TREES	48.% DF2, 28.% GF2, 18.% C2, 4.% L2
	VOLUME:									
	TOTAL	8.0	8.0	9.6	9.6	10.4	10.4	290.	CUFT	38.% LP2, 30.% L2, 29.% DF2, 3.% C2
	MERCH	8.0	8.0	9.6	9.6	10.4	10.4	250.	CUFT	40.% LP2, 31.% L2, 29.% DF2, 0.% ---
	MERCH	9.6	9.6	9.6	10.4	10.4	10.4	645.	BDFT	66.% LP2, 34.% DF2, 0.% ---, 0.% ---
	RESIDUAL	4.0	5.3	6.2	7.9	9.5	12.7	240.	TREES	33.% GF1, 19.% C1, 19.% DF1, 13.% L1
	ACCRETION	5.3	6.1	6.6	9.4	10.9	12.7	82.	CUFT/YR	34.% GF1, 20.% DF1, 14.% LP1, 11.% L1
	MORTALITY	5.8	6.5	8.4	9.5	11.5	12.7	8.	CUFT/YR	28.% GF1, 27.% LP1, 18.% DF1, 15.% L1
1987	TREES	5.5	6.8	8.0	9.3	11.3	15.5	223.	TREES	33.% GF1, 20.% C1, 19.% DF1, 13.% L1
	VOLUME:									
	TOTAL	6.8	8.7	9.5	11.3	13.3	15.5	1991.	CUFT	29.% GF1, 23.% LP1, 22.% DF1, 13.% L1
	MERCH	7.6	9.2	10.2	11.9	13.3	15.5	1627.	CUFT	26.% GF1, 26.% LP1, 22.% DF1, 14.% L1
	MERCH	9.3	10.3	11.3	12.4	13.6	15.5	4645.	BDFT	38.% LP1, 31.% DF1, 16.% GF1, 10.% L1
	ACCRETION	6.7	7.6	9.2	10.2	12.4	15.5	106.	CUFT/YR	39.% GF1, 19.% DF1, 11.% LP1, 11.% WH1
	MORTALITY	6.8	8.7	9.4	11.3	12.8	15.5	12.	CUFT/YR	30.% GF1, 21.% LP1, 18.% DF1, 13.% WH1
1997	TREES	7.0	8.3	9.5	10.8	13.2	18.2	209.	TREES	33.% GF1, 20.% C1, 19.% DF1, 13.% L1
	VOLUME:									
	TOTAL	6.8	8.7	9.5	11.3	13.3	15.5	1991.	CUFT	29.% GF1, 23.% LP1, 22.% DF1, 13.% L1
	MERCH	7.6	9.2	10.2	11.9	13.3	15.5	1627.	CUFT	26.% GF1, 26.% LP1, 22.% DF1, 14.% L1
	MERCH	9.3	10.3	11.3	12.4	13.6	15.5	4645.	BDFT	38.% LP1, 31.% DF1, 16.% GF1, 10.% L1
	ACCRETION	6.7	7.6	9.2	10.2	12.4	15.5	106.	CUFT/YR	39.% GF1, 19.% DF1, 11.% LP1, 11.% WH1
	MORTALITY	6.8	8.7	9.4	11.3	12.8	15.5	12.	CUFT/YR	30.% GF1, 21.% LP1, 18.% DF1, 13.% WH1
2007	TREES	7.7	9.6	10.8	11.8	14.8	19.3	196.	TREES	33.% GF1, 20.% C1, 19.% DF1, 13.% L1
	VOLUME:									
	TOTAL	9.2	10.8	11.9	14.5	16.3	19.3	3887.	CUFT	34.% GF1, 21.% DF1, 16.% LP1, 10.% L1
	MERCH	9.3	11.0	12.0	14.7	16.4	19.3	3606.	CUFT	35.% GF1, 20.% DF1, 17.% LP1, 10.% L1
	MERCH	10.4	11.6	12.4	14.8	16.9	19.3	14518.	BDFT	35.% GF1, 20.% DF1, 18.% LP1, 10.% WH1
	REMOVAL	10.0	10.5	11.0	11.5	13.5	15.5	39	TREES	55.% L1, 45.% LP1, 0.% L2, 0.% LP2
	VOLUME:									
	TOTAL	10.0	10.7	11.5	12.8	14.7	15.5	945.	CUFT	66.% LP1, 34.% L1, 0.% LP2, 0.% L2
	MERCH	10.0	10.7	11.5	12.8	14.7	15.5	895.	CUFT	66.% LP1, 34.% L1, 0.% LP2, 0.% L2
	MERCH	10.0	10.7	11.5	13.1	14.9	15.5	3765.	BDFT	70.% LP1, 30.% L1, 0.% LP2, 0.% L2
	RESIDUAL	7.6	9.2	10.8	11.9	15.2	19.3	157.	TREES	41.% GF1, 25.% C1, 24.% DF1, 7.% WH1

```
        ACCRETION    9.2  10.4  11.7  13.7  16.8  19.3     128. CUFT/YR   55.% GF1,  16.% DF1,  14.% WH1,  13.% C1
        MORTALITY    9.2  11.6  12.7  15.3  16.9  19.3      19. CUFT/YR   44.% GF1,  23.% WH1,  22.% DF1,   8.% C1


2017  TREES          8.5  10.9  12.7  13.6  16.8  22.4     148. TREES     41.% GF1,  26.% C1,   24.% DF1,   6.% WH1
      VOLUME:
        TOTAL       10.4  12.8  13.8  15.8  18.4  22.4    4032. CUFT      49.% GF1,  24.% DF1,  13.% C1,   12.% WH1
        MERCH       10.7  12.6  14.0  16.3  18.4  22.4    3829. CUFT      49.% GF1,  24.% DF1,  12.% WH1,  12.% C1
        MERCH       11.5  12.9  14.1  16.5  18.9  22.4   16871. BDFT      52.% GF1,  22.% DF1,  14.% WH1,   9.% C1


        ACCRETION   10.4  12.7  13.1  14.3  17.8  22.4     136. CUFT/YR   55.% GF1,  17.% C1,   16.% DF1,  10.% WH1
        MORTALITY   11.3  12.9  14.2  17.3  19.9  22.4      26. CUFT/YR   46.% GF1,  24.% WH1,  20.% DF1,   8.% C1


2027  TREES          9.5  11.2  14.1  15.7  18.2  23.9     139. TREES     41.% GF1,  26.% C1,   24.% DF1,   6.% WH1
      VOLUME:
        TOTAL       11.2  14.2  15.7  17.3  20.2  23.9    5126. CUFT      50.% GF1,  22.% DF1,  14.% C1,   11.% WH1
        MERCH       11.2  14.2  15.7  17.4  20.2  23.9    4914. CUFT      51.% GF1,  22.% DF1,  14.% WH1,  11.% WH1
        MERCH       11.9  14.3  15.7  17.5  20.4  23.9   23122. BDFT      53.% GF1,  21.% DF1,  12.% WH1,  11.% C1


        ACCRETION   11.7  14.3  15.6  17.3  20.0  23.9     157. CUFT/YR   53.% GF1,  18.% C1,   14.% WH1,  13.% DF1
        MORTALITY   11.9  14.4  16.2  18.2  21.3  23.9      34. CUFT/YR   49.% GF1,  21.% WH1,  19.% DF1,   9.% C1


2037  TREES         10.0  12.1  15.1  17.7  19.4  26.0     131. TREES     41.% GF1,  27.% C1,   25.% DF1,   5.% WH1
      VOLUME:
        TOTAL       12.1  15.5  17.7  18.9  22.4  26.0    6351. CUFT      51.% GF1,  20.% DF1,  15.% C1,   11.% WH1
        MERCH       12.2  15.5  17.7  18.9  22.4  26.0    6127. CUFT      52.% GF1,  20.% DF1,  15.% C1,   11.% WH1
        MERCH       12.6  15.8  17.8  19.1  22.4  26.0   29948. BDFT      54.% GF1,  19.% DF1,  13.% WH1,  13 % C1


        REMOVAL      10.4  13.3  15.3  17.8  19.1  26.0      96  TREES     54.% GF1,  36.% C1,    7.% WH1,   3.% L1
      VOLUME:
        TOTAL       12.5  15.6  17.6  18.4  22.4  26.0    4846. CUFT      63.% GF1,  20.% C1,   15.% WH1,   2.% L1
        MERCH       12.5  15.7  17.6  18.4  22.4  26.0    4676. CUFT      64.% GF1,  19.% C1,   15.% WH1,   2.% L1
        MERCH       13.3  15.7  17.7  18.7  22.4  26.0   23273. BDFT      65.% GF1,  17.% WH1,  16.% C1,    2.% L1


        RESIDUAL      8.0  10.0  11.6  16.5  19.9  26.0      35. TREES     92.% DF1,   5.% GF1,   2.% C1,    0.% WH1


        ACCRETION   10.0  12.6  16.5  19.2  22.9  26.0      33. CUFT/YR   83.% DF1,  13.% GF1,   2.% C1,    1.% WH1
        MORTALITY   10.4  15.5  18.9  20.4  23.2  26.0       7. CUFT/YR   80.% DF1,  16.% GF1,   2.% WH1,   1.% C1


2047  TREES          8.4  11.7  12.6  17.5  21.2  27.5      33. TREES     92.% DF1,   5.% GF1,   2.% C1,    0.% WH1
      VOLUME:
        TOTAL       11.7  16.0  19.5  20.9  24.3  27.5    1760. CUFT      85.% DF1,  12.% GF1,   1.% C1,    1.% WH1
        MERCH       11.8  16.0  19.5  20.9  24.6  27.5    1703. CUFT      85.% DF1,  13.% GF1,   1.% C1,    1.% WH1
        MERCH       12.6  17.3  20.1  21.2  24.7  27.5    8034. BDFT      83.% DF1,  14.% GF1,   1.% C1,    1 % WH1


        ACCRETION    8.4  12.8  17.5  20.2  24.0  27.5      51. CUFT/YR   84.% DF1,  13.% GF1,   2.% C1,    1.% WH1
        MORTALITY   12.0  16.8  20.0  21.2  24.7  27.5       9. CUFT/YR   80.% DF1,  16.% GF1,   2.% WH1,   1.% C1


2057  TREES         10.5  12.8  14.1  20.3  23.6  29.6      32. TREES     92.% DF1,   5.% GF1,   2.% C1,    0.% WH1
      VOLUME:
        TOTAL       21.8  18.0  21.1  23.3  26.9  29.6    2183. CUFT      85.% DF1,  12.% GF1,   2.% C1,    1.% WH1
        MERCH       12.8  18.0  21.1  23.3  26.9  29.6    2123. CUFT      85.% DF1,  13.% GF1,   2.% C1,    1.% WH1
        MERCH       13.5  18.1  21.1  23.3  26.9  29.6   10684. BDFT      84.% DF1,  13.% GF1,   1.% C1,    1 % WH1
```

Figure 7.—Stand composition table from the Prognosis Model output.

		ATTRIBUTES OF SELECTED SAMPLE TREES							ADDITIONAL STAND ATTRIBUTES				
YEAR	INITIAL TREES/A %TILE	SPECIES	DBH (INCHES)	HEIGHT (FEET)	LIVE CROWN RATIO	PAST DBH GROWTH (INCHES)	BASAL AREA %TILE	TREES PER ACRE	STAND AGE	QUADRATIC MEAN DBH (INCHES)	TREES PER ACRE	BASAL AREA (SQFT/A)	HEIGHT OF DOMINANTS (FEET)	CROWN COMP FACTOR

YEAR	INITIAL TREES/A %TILE	SPECIES	DBH (INCHES)	HEIGHT (FEET)	LIVE CROWN RATIO	PAST DBH GROWTH (INCHES)	BASAL AREA %TILE	TREES PER ACRE	STAND AGE	QUADRATIC MEAN DBH (INCHES)	TREES PER ACRE	BASAL AREA (SQFT/A)	HEIGHT OF DOMINANTS (FEET)	CROWN COMP FACTOR
1977						(10 YRS)								
	10	GF2	0.10	3.00	65	0.0	0.0	81.82						
	30	DF2	0.10	2.00	55	0.0	0.0	81.82						
	50	C2	3.20	17.00	45	0.60	3.0	27.27						
	70	GF1	6.10	38.00	75	1.20	24.8	17.92						
	90	LP1	8.50	62.54	25	0.0	62.4	9.23						
	100	DF1	12.70	67.00	35	1.60	100.0	4.13						
									57	5.1	536.	77.	63.0	99.8
								RESIDUAL:		7.0	240.	64.	64.3	83.8
1987						(10 YRS)								
	10	GF2	0.63	8.69	65	0.49	0.0	0.07						
	30	DF2	0.65	7.39	55	0.48	0.0	0.07						
	50	C2	4.83	23.68	45	1.55	0.5	0.03						
	70	GF1	7.65	49.76	75	1.42	28.7	16.58						
	90	LP1	9.32	69.22	23	0.80	55.2	8.68						
	100	DF1	13.98	75.40	33	1.11	98.6	3.95						
									67	8.6	223.	89.	70.6	112.1
1997						(10 YRS)								
	10	GF2	2.21	16.08	65	1.44	0.0	0.07						
	30	DF2	2.49	14.99	55	1.59	0.0	0.07						
	50	C2	6.28	30.11	46	1.37	0.8	0.02						
	70	GF1	9.25	61.12	73	1.47	27.7	15.47						
	90	LP1	10.07	75.50	19	0.73	43.7	8.21						
	100	DF1	15.27	83.35	30	1.12	95.1	3.76						
									77	10.1	209.	115.	76.6	139.0
2007						(10 YRS)								
	10	GF2	4.39	24.33	68	1.99	0.0	0.06						
	30	DF2	4.73	23.95	57	1.95	0.0	0.06						
	50	C2	8.48	37.08	53	2.10	7.2	0.02						
	70	GF1	11.82	73.65	74	2.35	53.0	14.52						
	90	LP1	10.68	81.20	16	0.59	30.6	7.75						
	100	DF1	17.68	92.68	29	2.09	97.0	3.57						
									87	11.3	196.	136.	81.6	157.6
								RESIDUAL:		11.2	157.	108.	81.4	130.9
2017						(10 YRS)								
	10	GF2	6.58	34.21	70	2.01	0.0	0.06						
	30	DF2	7.05	35.65	62	2.01	0.1	0.06						
	50	C2	9.64	43.52	55	1.10	10.3	0.02						
	70	GF1	14.08	85.13	75	2.07	60.4	13.63						
	90	LP1	11.17	86.34	15	0.47	16.4	0.15						
	100	DF1	18.39	98.24	28	0.62	91.4	3.38						
									97	12.8	148.	132.	88.4	151.3
2027						(10 YRS)								
	10	GF2	7.32	42.89	72	0.67	0.1	0.05						
	30	DF2	9.28	47.66	72	1.93	3.1	0.05						
	50	C2	11.09	50.46	55	1.37	12.4	0.02						
	70	GF1	15.70	94.88	73	1.49	55.6	12.78						
	90	LP1	11.78	91.72	14	0.59	15.7	0.14						
	100	DF1	18.83	102.81	26	0.39	87.3	3.20						
									107	14.2	139.	152.	91.1	169.4
2037						(10 YRS)								
	10	GF2	9.31	53.72	77	1.82	1.9	0.05						
	30	DF2	10.33	56.82	71	0.91	4.3	0.05						
	50	C2	12.59	57.48	55	1.43	16.7	0.02						
	70	GF1	17.86	105.17	72	1.97	59.0	11.95						
	90	LP1	12.25	96.53	13	0.46	13.9	0.13						
	100	DF1	19.33	107.41	24	0.43	78.9	3.02						
									117	15.5	131.	172.	99.3	189.1
								RESIDUAL:		14.4	35.	40.	112.7	40.4

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2047   (10 YRS)

          10   GF2   10.18   63.09   88   0.80   6.0   0.00
          30   DF2   13.14   69.02   87   2.43   24.3   0.05
          50   C2   14.01   64.28   58   1.35   24.7   0.00
          70   GF1   18.86   112.56   82   0.91   49.9   0.22
          90   LP1   13.60   103.19   20   1.31   24.5   0.00
         100   DF1   20.86   113.92   32   1.33   75.7   2.87
                                                                          127   15.6   33.   44.   118.5   43.4

2057   (10 YRS)

          10   GF2   10.99   71.34   88   0.74   7.5   0.00
          30   DF2   16.42   80.52   88   2.85   30.0   0.05
          50   C2   16.38   72.27   58   2.25   30.0   0.00
          70   GF1   22.14   123.29   84   3.01   67.2   0.21
          90   LP1   14.53   108.75   20   0.90   26.1   0.00
         100   DF1   23.27   121.03   32   2.09   75.3   2.73
                                                                          137   17.3   32.   52.   125.6   49.0

Figure 8—Tree and stand attributes table from the Prognosis Model output.

                              STAND GROWTH PROGNOSIS SYSTEM   VERSION 4.0 -- INLAND EMPIRE

                                        SUMMARY STATISTICS

            VOLUME PER ACRE   REMOVALS PER ACRE   AVE   GROWTH
        ----------------------   -----------------   BA/   DOM ------------- STAND   IDENTIFIERS
        TREES TOTAL MERCH MERCH   TREES TOTAL MERCH MERCH ACRE   HT PRD ACC MOR SAMPLE -------------
YEAR AGE /ACRE CU FT CU FT BD FT /ACRE CU FT CU FT BD FT SQFT CCF YRS CUFT /YR WEIGHT STAND MGMT
---- --- ----- ----- ----- ----- ----- ----- ----- ----- ---- --- --- ---- -- ------   ------- -----
1977 57   536 1541 1075 2804   296   290   250   645   64   84 64   10   82 8   11 S248112 NONE
1987 67   223 1991 1627 4645   0   0   0   0   89 112 71   10 106 12   11 S248112 NONE
1997 77   209 2934 2648 9128   0   0   0   0   115 139 77   10 114 18   11 S248112 NONE
2007 87   196 3887 3606 14518   39   945   895 3765   131   81 81   10 128 19   11 S248112 NONE
2017 97   148 4032 3829 16871   0   0   0   0   132 151 88   10 136 26   11 S248112 NONE
2027 107   139 5126 4914 23122   0   0   0   0   152 169 91   10 157 34   11 S248112 NONE
2037 117   131 6351 6127 29948   96 4846 4676 23273   40   40 113   10   33 7   11 S248112 NONE
2047 127   33 1760 1703 8034   0   0   0   0   44   43 119   10   51 9   11 S248112 NONE
2057 137   32 2183 2123 10684   0   0   0   0   52   49 126   0   0 0   11 S248112 NONE

                                        ACTIVITY SUMMARY

STAND ID= S248112   MANAGEMENT ID= NONE   HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL – NIG4 VERSION

CYCLE DATE EXTENSION KEYWORD   DATE ACTIVITY DISPOSITION PARAMETERS:
----- ---- --------- -------- ---- -------------------- --

   1   1977
              BASE   THINPRSC 1980 DONE IN 1977   1.00

   2   1987
   3   1997

   4   2007
              BASE   SPECPREF 2010 DONE IN 2007   2.00   999.00
              BASE   SPECPREF 2010 DONE IN 2007   7.00   9999.00
              BASE   THINBTA   2010 DONE IN 2007   157.00   0.98

   5   2017
   6   2027

   7   2037
              BASE   SPECPREF 2040 DONE IN 2037   3.00   -999.00
              BASE   SPECPREF 2040 DONE IN 2037   4.00   -99.00
              BASE   THINBTA   2040 DONE IN 2037   35.00   0.98

   8   2047

Figure 9.—Summary table from the Prognosis Model output.

The Input Summary Table

PROGRAM OPTIONS

The table displaying the options selected, the activity schedule, and the calibration statistics (fig. 6) is printed to verify that the projection is based on the intended silvicultural and ecological assumptions. These data facilitate recordkeeping and problem determination.

The keyword records are printed as they are processed. The descriptions of parameters and supplemental data are quite terse. The discussion of keyword records contained elsewhere in this manual will help resolve ambiguities.

Within this segment of the table, you may find messages such as:

SPSO3 WARNING: FOREST CODE INDICATES THAT THE GEOGRAPHIC LOCATION IS OUTSIDE THE RANGE OF THE MODEL.

These messages are intended to bring attention to potential problems with input data. Even though the messages may indicate doubt, we usually assume that you know what you are doing; the projection is continued unless program capacities have been exceeded. The possible warning messages are collected in appendix C along with explanatory details and suggested user responses.

Several keyword records will be specifically printed if they are omitted from the input file. These records contain data that are particularly useful for debugging but may not be easily remembered. They include:

(1) the tree record format (TREEFMT),
(2) the sampling design parameters (DESIGN), and
(3) the stand description data (STDINFO).

These data are printed immediately following the input keyword records, beneath the heading "OPTIONS SELECTED BY DEFAULT" (for example, TREEFMT and DESIGN in fig. 6).

The input keyword records are always displayed in the order that they are processed. Usually this order is unimportant. However, if a TREEDATA record is used and the species codes or the tree record format differ from the default specifications, the SPCODES and/or TREEFMT records must precede the TREEDATA record in the input file. Failure to meet this requirement will result in a variety of errors.

ACTIVITY SCHEDULE

The activity schedule follows the lists of options selected. The management activities that were specified by keyword input are arranged in the order that they will be simulated. The dates on the activity schedule are calculated from the inventory year, as entered on the INVYEAR record, and the intervals specified on the TIMEINT record. These dates represent projection cycle endpoints (in fig. 6, cycle 1 is the period 1977-87; cycle 2 is the period 1987-97, etc.).

CALIBRATION STATISTICS

After the keyword input is interpreted, the tree records are scanned for missing height and crown ratio observations. Then, factors that scale growth predictions to match the input growth data are computed. These activities are reported in the calibration statistics section of the input summary table (fig. 6).

The total number of tree records excludes records that were rejected because *DBH* was not recorded. It also excludes records of those trees that died before the start of the mortality observation period (tree history codes 6 and 7). The count includes the trees that died

during the mortality observation period (tree history code 5). These recent mortality records are used to compute the stand density estimates that are used in scaling models. The number of recent mortality records is given immediately below the total tree record count (fig. 6). These records will be removed from the tree record file before the stand is projected. If either of these counts appears to be inaccurate, the tree history codes, species codes, and tree record format should be checked.

The Prognosis Model will accept records with omitted height or crown ratio observations. However, these data must be estimated before the stand can be projected. Heights are predicted from *DBH* and species. If four or more records for a species have measured heights, the parameters of the equation used for that species will be fitted to the input data. However, records with measured heights but dead or broken tops are not used. The total number of records less the number of records with missing heights and broken or dead tops gives the number of records available for calibrating the height-*DBH* relationship for a species.

The omitted crown ratio observations are estimated using a variety of stand and tree characteristics (see section titled Missing Data). Variation is introduced by drawing random errors from a Normal distribution. We strongly recommend that crown ratios for all sample trees be measured and recorded. If crown ratios and/or heights were recorded, and the output indicates they are missing, the tree record format is probably in error.

The remaining entries in the calibration statistics table refer to the process of computing growth model scale factors. If increment data are provided with the tree records, the diameter increment model and the small tree height increment model will be scaled to reflect local deviations from the regional growth trends represented in the models. In order to compute scale factors for either increment model, for any species, there must be two or more increment observations. Diameter increment observations are accepted only from trees that were 3 inches *DBH* or larger at the **start** of the growth measurement period. Height increment observations are accepted only from trees that were less than 5 inches *DBH* at the **end** of the period. The number of records that is reported as available for scaling a model includes only those records that have measured increments and meet the above size restrictions.

The height increment scale factor is used as a direct multiplier of predicted height increment. However, the diameter increment scale factor is used as a multiplier of change in squared diameter *(DDS)* and is, in effect, a multiplier of basal area increment. The rate of conversion of *DDS* to diameter increment is dependent on the magnitude of tree *DBH*.

The scale factors for both models should normally fall between 0.5 and 2.0. We have assumed that the model estimate of basal area increment derived from our extensive data base is the best available predictor of long-term growth performance. As the stand is projected through time, we move the basal area increment scale factors toward 1.0. The effect of this transition is to gradually replace sample-based estimates of increment with the model-based estimates (see appendix A).

The remaining entries in the calibration statistics table are by-products of the diameter increment scaling process. They indicate how the distribution of the growth sample compares to the distribution of our data base. The distribution variances are compared using the ratio of the standard deviation of the residuals for the growth sample to the model standard error. If the values of this ratio consistently exceed 1.0, you should carefully examine your growth measurement techniques, including the methods used to delineate stands. We assume that stands are uniform with regard to slope, aspect, elevation, and habitat type. If this assumption is stretched too far, the variance in the growth sample residuals will be exaggerated.

The final table entry is the weight given to the diameter increment sample during scaling. This weight is part of an empirical Bayes estimation process (Krutchkoff 1972) that is complex and will not be explained here. The interpretation of the weight, however, is quite simple. Values in the vicinity of zero imply that the models were not adjusted while values close

Stand Composition   One line in the stand composition table is allotted to the description of each reported stand attribute at each cycle endpoint. The description consists of a terse label, the per-acre total for the attribute, the distribution of the attribute by *DBH* class, and the distribution of the attribute by species and tree value class. The per-acre total is located near the center of the table and separates the distribution by *DBH* (located to the left of the total) from the distribution by species and tree value class (fig. 7).

The attributes summarized in the stand composition table include trees per acre, volume per acre for three merchantability standards, and annual per-acre accretion and mortality (total stem cubic feet). The merchantability standards used to compute volumes include:

(1) Total stem cubic feet;
(2) Merchantable stem cubic feet; merchantability limits are provided by the user (default values are 1-foot stump height, 4.5-inch minimum top diameter, and 6-inch minimum *DBH* for lodgepole pine, 7-inch minimum *DBH* for other species).
(3) Merchantable stem Scribner board feet, assuming a 1-foot stump height, a 9-inch minimum *DBH*, and an 8-inch minimum top diameter.

The trees per acre and the volume per acre are reported at the beginning of the projection. These are repeated, along with accretion and mortality statistics, at the completion of each projection cycle. If there are any thinnings in a cycle, the number of trees per acre and the volume per acre removed as well as the number of trees per acre in the residual stand are reported.

By compromising traditional format, we are able to capture the essence of a stand or stock table in a single line of output. The compromise consists of defining the classes in the table as fixed percentages of the total for the attribute. Thus, the smallest class is defined as the interval between zero and the *DBH* such that 10 percent of the attribute is in trees that are the same size or smaller (0.1 in the 1977 TREES distribution, see fig. 7). This value is referred to as the 10th percentile point in the distribution of the attribute by *DBH.* We also identify the 30th, 50th, 70th, 90th, and 100th percentile points in the distributions of each of the attributes. The intervals between these percentile points define five additional classes. By abandoning fixed *DBH* classes, we are able to summarize a long-term projection in a compact table, with little loss of detail (fig. 10).

The remaining information in the stand composition table concerns the distribution of each attribute by species and tree value class. Tree value class is entered with the tree record and remains unchanged throughout the projection. This variable has a value of 1, 2, or 3 and influences the tree removal priority when the stand is thinned (see section titled Computing Removal Priority). We compute the percentage of each attribute that is distributed to each possible combination of species and tree value (there are 33 combinations). We then print the percentages for the four largest combinations.

Experience has shown that, although the stand composition table is detailed and compact, the format is somewhat formidable to the inexperienced user. We have prepared several illustrations that will help you visualize the distributions represented in the table. It is relatively easy to construct histograms that illustrate the distributions of attributes by *DBH* (fig. 11,12, 13). The area of the rectangle representing a *DBH* class is equal to the quantity of the attribute associated with the class—either 10 or 20 percent of the total. The width of the rectangle (horizontal axis*)* is equal to the *DBH* interval between percentile points. For example, in the year 2007 in our sample output (see fig. 7), there are 196 trees per acre. Ten percent of these (19.6 trees per acre) are less than or equal to 7.7 inches *DBH.* Thus, the area of the rectangle representing the smallest *DBH* class is 19.6, the width is 7.7, and the height (vertical axis) is 2.55 (19.6 + 7.7).
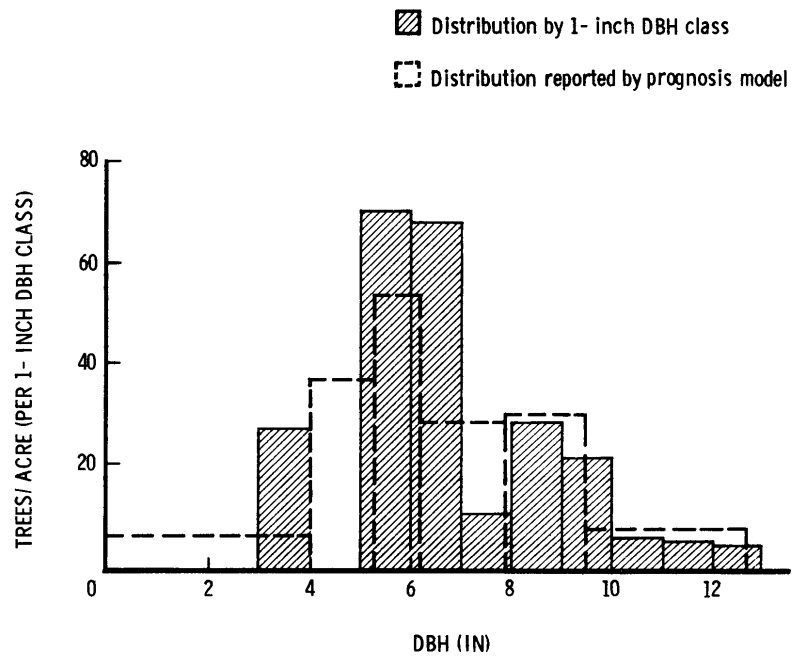
Figure 10.—The distribution of trees by *DBH*. The histogram outlined with dashes was developed from the percentile points reported by the Prognosis Model. The shaded histogram shows how the same sample of tree records is distributed by 1-inch *DBH* classes.
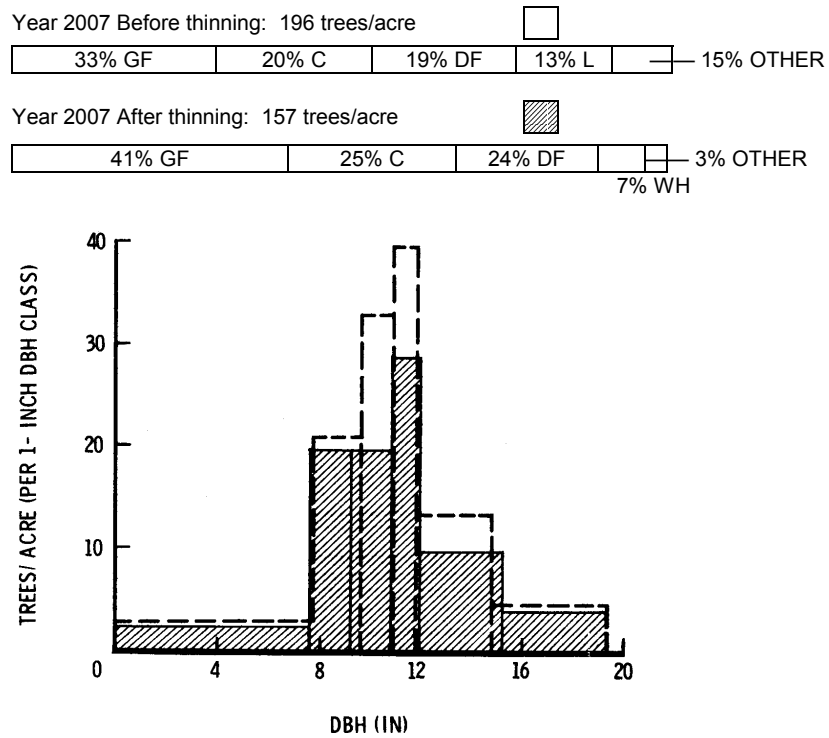
Year 2007 Before thinning: 196 trees/acre

| 33% GF | 20% C | 19% DF | 13% L | — 15% OTHER |

Year 2007 After thinning: 157 trees/acre

| 41% GF | 25% C | 24% DF | — 3% OTHER |

7% WH

Figure 11.—Examples of before- and after-thinning distributions of trees per acre by species and by *DBH*.

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Year 2008 Before thinning: 3387 ft³/acre ☐

| 34% GF | 21% DF | 16% LP | 10% L | —— 19% OTHER |

Year 2007 Removal: 945 ft³/acre ▨
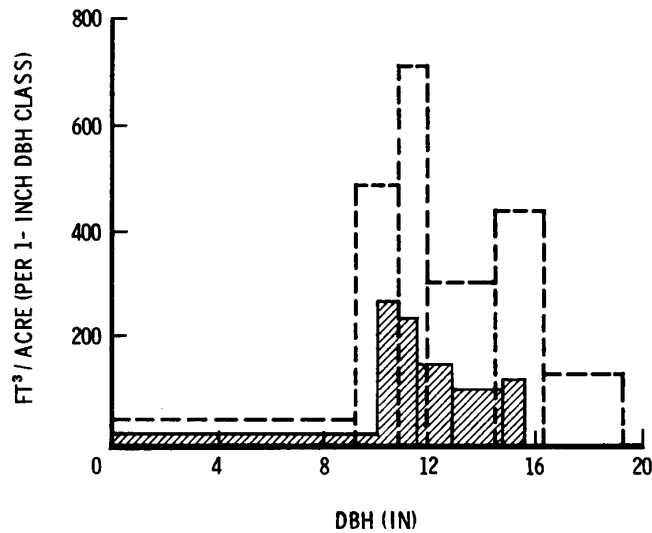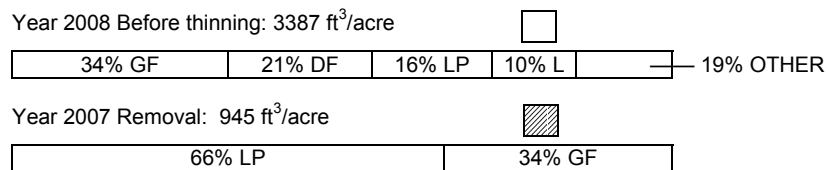
| 66% LP | 34% GF |

Figure 12.—Examples of distributions of total cubic volume by species and *DBH* showing the before-thinning distribution and the distribution of the removed material.
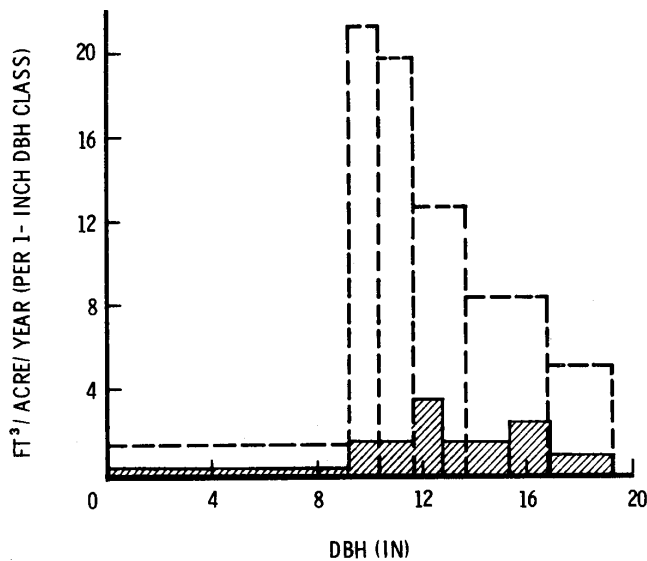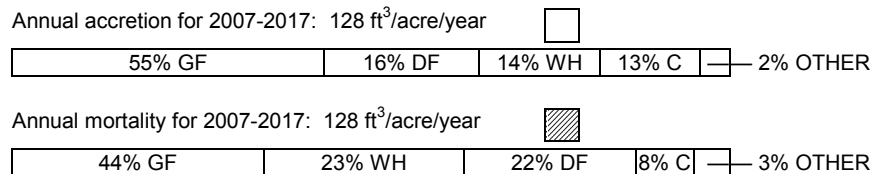
Annual accretion for 2007-2017: 128 ft³/acre/year ☐

| 55% GF | 16% DF | 14% WH | 13% C | —— 2% OTHER |

Annual mortality for 2007-2017: 128 ft³/acre/year ▨

| 44% GF | 23% WH | 22% DF | 8% C | —— 3% OTHER |

Figure 13.—Examples of distributions of accretion and mortality by species and by *DBH*.

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These distributions can also be arrayed by cycle to illustrate changes in the various attributes over time (fig. 14, 15). Plotting changes in the percentile points of the distributions over time will give a snapshot of how management actions influence stand composition (fig. 16,17). Finally, with a little arithmetic, it is possible to estimate average volume by species and plot the trend over time (fig. 18).
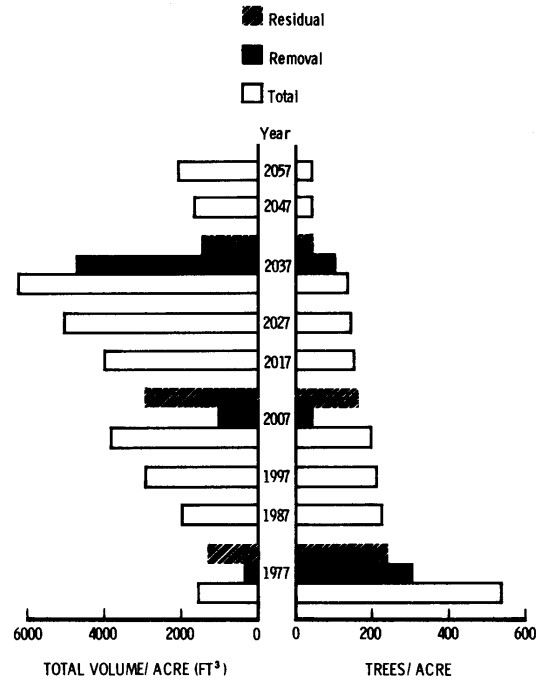

Figure 14.—Changes in total cubic volume
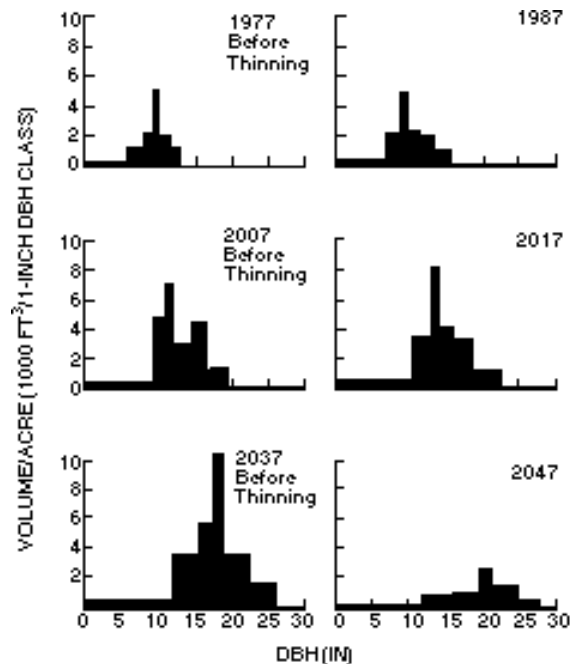and trees per acre over time.

Figure 15.—Changes in the distribution of
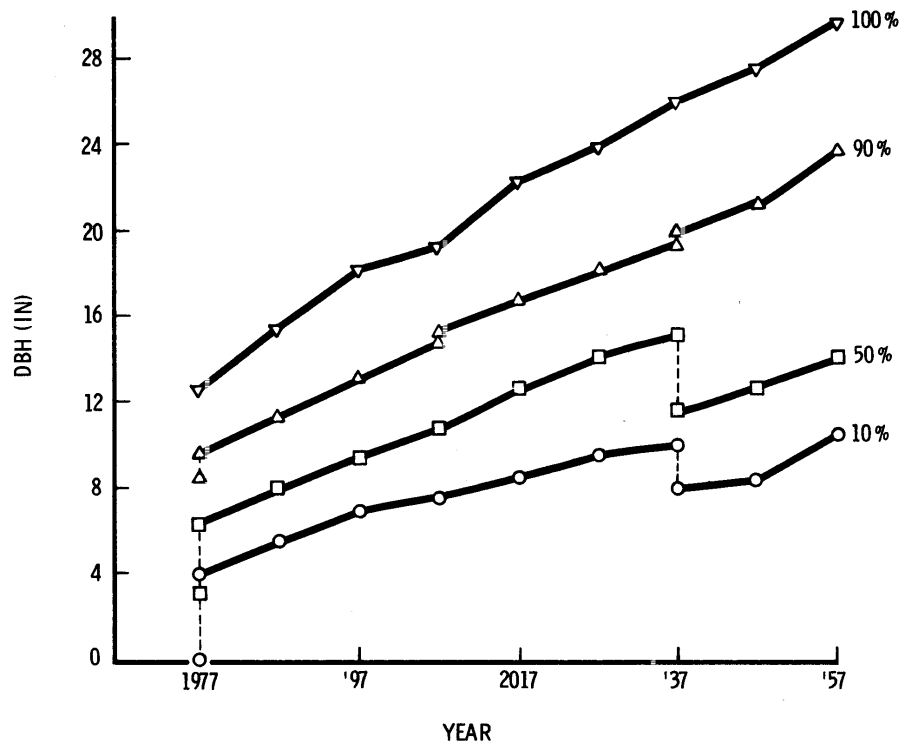total cubic volume per acre by *DBH*
through time.

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Figure 16.—Changes in the percentile points of the distribution of trees per acre by DBH through time. Discontinuities indicate thinning.
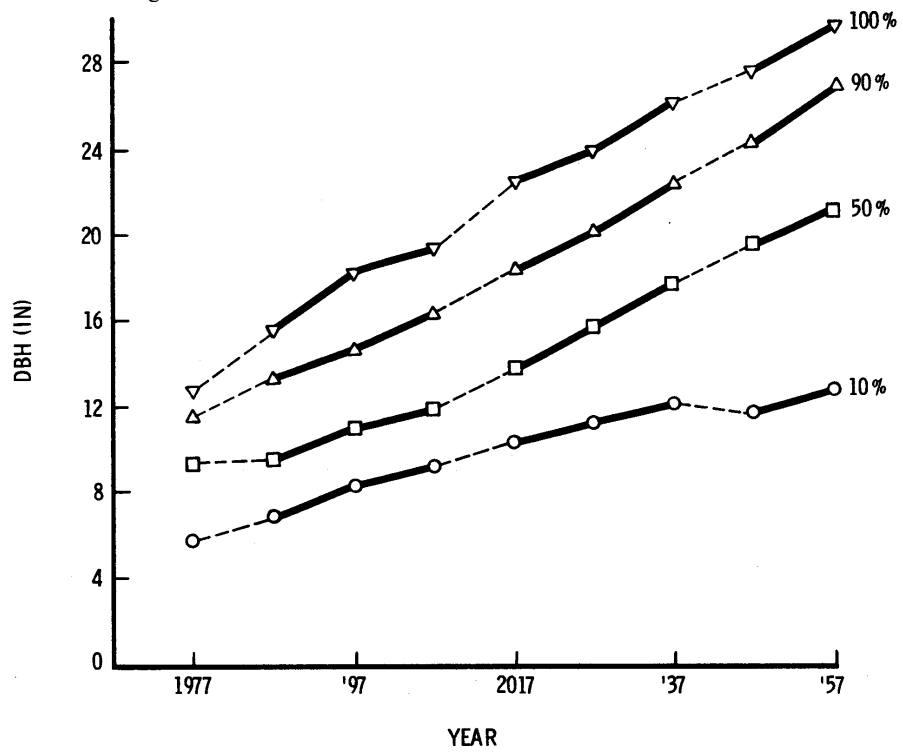

Figure 17.—Changes in the percentile points of the distribution of total cubic volume by DBH, over time. Dashed segments represent growth periods immediately following thinning.
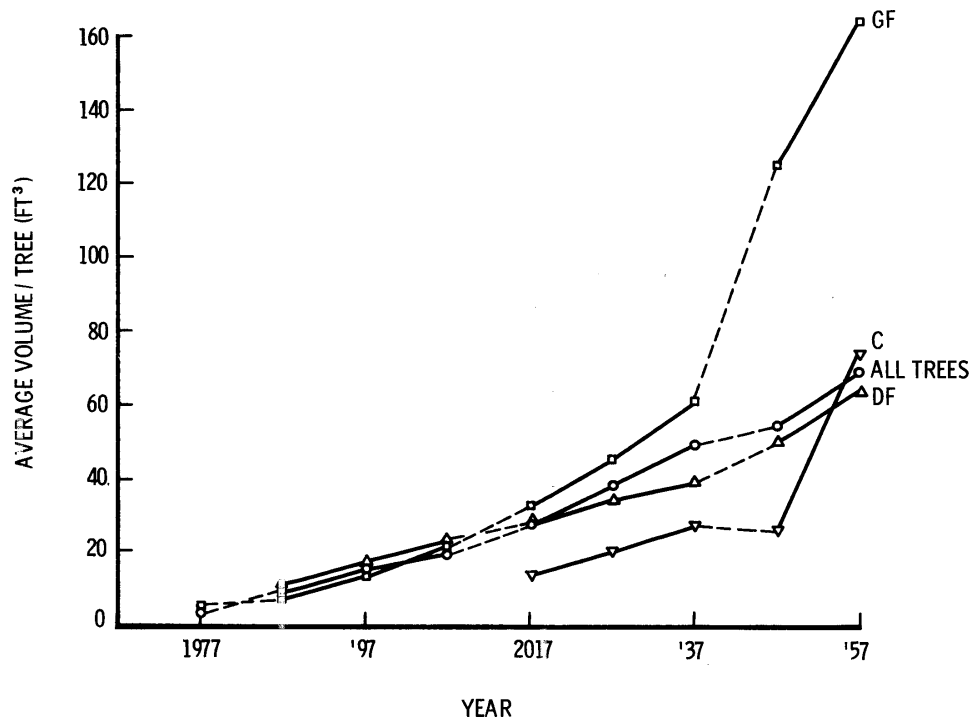
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Figure 18.—Change in average volume per tree by species through time. Dashed segments indicate growth periods immediately following thinning.

Tree and Stand Attributes

The stand composition table portrays the development of the stand over time. The growth of individual trees, and the stand conditions that influence tree growth are recorded in the tree and stand attributes table (fig. 8).

The trees that are selected for display correspond to the *DBH's* recorded for the percentile points in the initial trees-per-acre distribution (the percentile points in the 1977 TREES distribution, compare fig. 7 and 8). These trees reflect a cross section of the stand and are followed throughout the projection. The initial percentile values are maintained to identify the trees. Beyond the initial report, however, these percentile values do not reflect the actual percentile position of the trees in the stand.

At the beginning of the projection, and at the end of each cycle, the following attributes are displayed for the selected trees:

Σ   Species and tree value class.

Σ   Current *DBH* outside bark.

Σ   Current height.

Σ   Live crown ration (expressed as a percent of total height.)

Σ   Inside bark *DBH* increment for the preceding projection cycle.

Σ   Percentile in the stand basal area distribution.

Σ   Number of trees per acre represented by the record.

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The stand attributes reported are stand age, stand density, and average tree size. Density is indicated by trees per acre, basal area per acre, and crown competition factor. Average tree size is reported as quadratic mean *DBH* (the *DBH* of the tree of average basal area) and the average height of dominants. The average height of dominants is computed by averaging the heights of all trees in the upper 30th percentile of the stand basal area distribution. When the stand is thinned at the start of a cycle, stand attributes are repeated to reflect the impact of thinning.

The information presented in the tree and stand attributes table gives additional insight into the course of stand development (fig. 19). It also reflects how a cross section of trees in the stand responds to changes in stand structure (fig. 20).
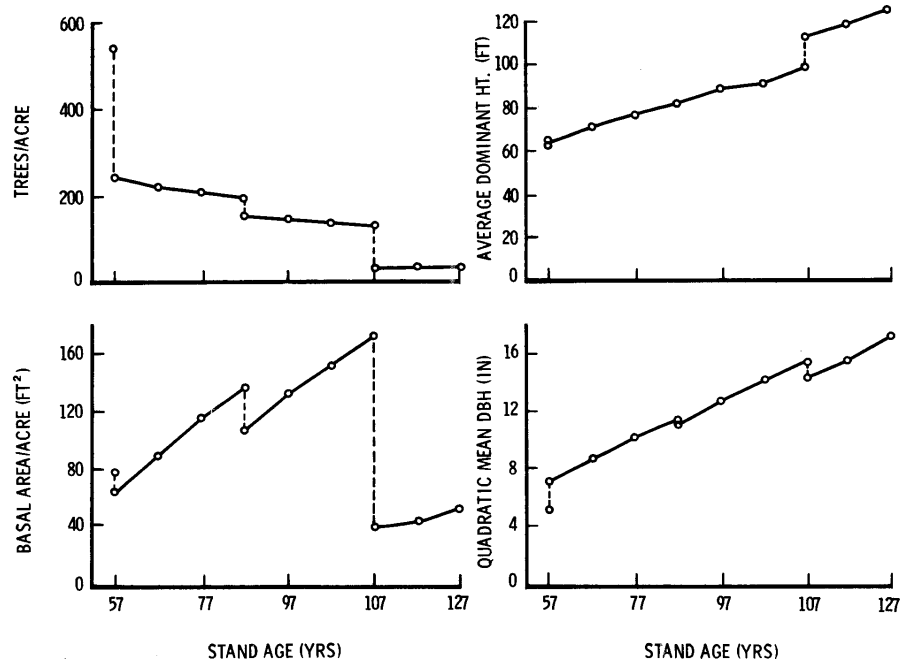

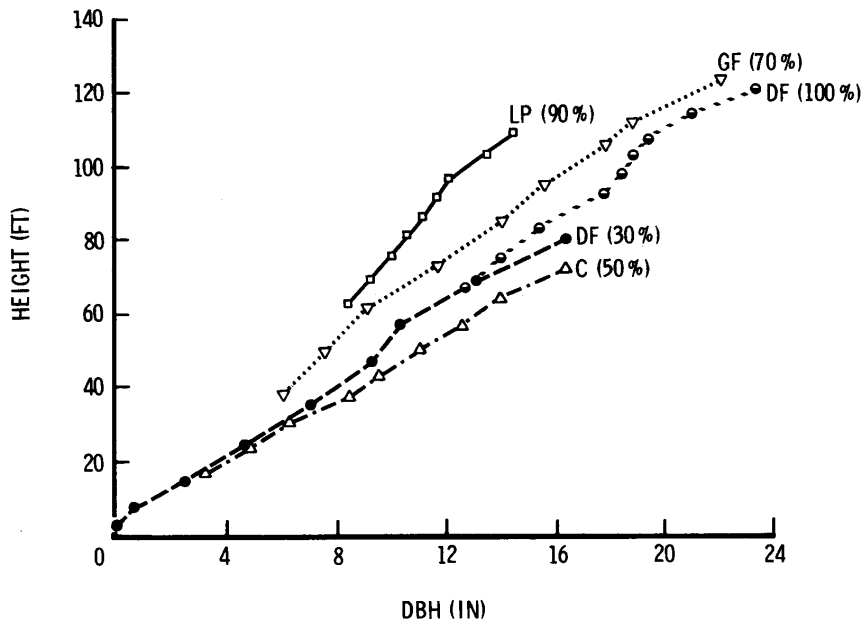Figure 19.—Changes in stand attributes over time. Discontinuities indicate thinning.

Figure 20.—Tree height versus *DBH* for four different species through time. The percentage values indicate the initial percentile of the tree in the distribution of trees per acre by *DBH*.

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The Summary Table

Many of the stand attributes are repeated, in concise format, in the summary table (fig. 9). A single line in the table summarizes stand conditions at each cycle endpoint. This output was initially intended to reproduce yield data for subsequent machine processing. As a result, there are three fields in each record in which the program inserts user-supplied labels for the output: the sample weight, a stand identification, and a management identifier consisting of a four-character label (see section titled ENTERING STAND AND TREE DATA). In addition, the summary table reports per-acre trees and volume before thinning (to three merchantability standards), per-acre trees and volume removed, basal area per acre after thinning, crown competition factor (*CCF*), average dominant height, and growth period length, accretion, and mortality (the last two in total cubic feet per acre per year).

Additional Output and Keywords

Several additional outputs may be specifically requested. The first is a complete list of all tree records (fig. 21) that can be generated in any or all cycles with the TREELIST record. The tree list reports all of the tree attributes given in the tree and stand attributes table. In addition, it gives past periodic height increment, total cubic foot volume, board foot volume (corrected for form and defect), normal height, and truncated height. These last two variables reflect the status of trees with dead or missing tops and have a value of zero for trees without top damage. To generate this list use:

TREELIST   field 1:   The cycle in which a complete list of trees is to be printed. The list is printed at the end of the cycle and the records are updated to include growth for the period. If blank, a tree list will be generated at the beginning of the projection and at the end of each cycle. This option usually generates a lot of extra output.

```
COMPLETE   TREE LIST -   STAND: S248112
TREE SPE   TREES PER   CURRENT   DIAMETER CURRENT    HEIGHT    CROWN BASAL AREA TREE   TOTAL CU NET BOARD NORMAL TRUNCATED
NUM  CODE    ACRE     DIAMETER INCREMENT  HEIGHT  INCREMENT  RATIO  PERCENTILE CLASS   FT VOL.  FT VOL.   HEIGHT HEIGHT
---- ----  ---------- -------- --------- ------- --------- ----- ---------- ----- ---------- --------- ------ ---------
  34   2    2.4990     9.53     1.389    88.80    13.802    26    63.015     1      14.85     50.66      0        0
   4   2    5.9977     8.68     0.668    86.77    11.775    23    40.990     1      12.04      0.0       0        0
  35   2    1.4994     8.27     0.315    85.19    10.193    23    33.454     1      10.72      0.0       0        0
  36   2    0.0024     9.62     1.377    76.62    13.620    24    63.017     2      13.54     49.70    8618     5600
   5   2    0.0059     8.78     0.661    74.53    11.528    23    40.993     2      11.11      0.0     8409     5600
  37   2    0.0015     8.37     0.312    72.90     9.898    23    35.778     2       9.97      0.0     8246     5600
  40   2    2.2154    10.21     1.543    13.36     8.363     5    67.067     1       2.56      0.0       0        0
   7   2    5.3170     9.27     0.744    11.90     6.899     5    52.462     1       1.88      0.0       0        0
  41   2    1.3293     8.81     0.351    10.75     5.754     5    41.624     1       1.54      0.0       0        0
  46   2    2.3227    10.23     1.726    79.23    14.320    45    68.551     1      15.25     52.84      0        0
  10   2    5.5745     9.18     0.837    76.93    11.925    43    47.512     1      11.94     34.89      0        0
  47   2    1.3936     8.67     0.396    75.11    10.113    43    37.226     1      10.38      0.0       0        0
  30   3    0.0184     0.97     0.754     7.39     5.392    55     0.000     2       0.04      0.0       0        0
   2   3    0.0442     0.65     0.479     7.39     5.392    55     0.000     2       0.02      0.0       0        0
  31   3    0.0110     0.44     0.299     7.39     5.392    55     0.000     2       0.02      0.0       0        0
  44   3    6.2943     6.72     2.358    33.59    13.589    24    10.388     1       3.47      0.0       0        0
   9   3   15.1063     5.34     1.161    32.78    12.775    19     3.133     1       2.28      0.0       0        0
  45   3    3.7766     4.63     0.547    32.11    12.115    20     0.498     1       1.76      0.0       0        0
  48   3    0.0062     4.94     3.238    21.50    10.495    60     0.501     2       1.31      0.0       0        0
  11   3    0.0148     3.31     1.829    21.50    10.495    54     0.002     2       0.68      0.0       0        0
  49   3    0.0037     2.32     0.975    21.50    10.495    55     0.001     2       0.39      0.0       0        0
  50   3    0.0062     5.65     3.247    24.20    11.203    53     3.825     2       1.85      0.0       0        0
  12   3    0.0149     3.92     1.747    24.20    11.203    44     0.003     2       1.00      0.0       0        0
  51   3    0.0037     2.92     0.885    24.20    11.203    45     0.001     2       0.63      0.0       0        0
  56   3    1.5938    12.80     2.424    77.30    12.300    35    92.318     1      25.51    101.61      0        0
  15   3    3.8250    11.32     1.142    74.42     9.424    33    79.265     1      19.59     70.27      0        0
  57   3    0.9563    10.60     0.523    72.18     7.176    33    71.938     1      16.86     56.05      0        0
  60   3    0.9869    15.45     2.388    77.99    10.992    34   100.000     1      36.59    161.51      0        0
  17   3    2.3684    13.98     1.110    75.40     8.396    33    98.560     1      29.33    122.48      0        0
  61   3    0.5921    13.28     0.504    73.39     6.389    33    92.956     1      25.96    104.52      0        0
  64   3    0.0015    13.59     2.768    67.73    12.732    44    94.241     2      24.19    102.65    6906     4900
  19   3    0.0035    11.91     1.312    64.77     9.771    43    79.908     2      18.37     68.75    6610     4900
  65   3    0.0009    11.09     0.602    62.44     7.444    43    76.270     2      15.70     53.40    6377     4900
  70   3    1.7986    12.16     2.391    73.20    13.195    35    85.158     1      21.98     83.18      0        0
  22   3    4.3167    10.70     1.129    70.47    10.473    34    74.959     1      16.75     55.64      0        0
  71   3    1.0792    10.00     0.518    68.34     8.339    33    64.305     1      14.35     43.17      0        0
  38   4    4.0137     8.59     2.185    50.57    12.573    47    37.587     1       8.73      0.0       0        0
   6   4    9.6329     7.36     1.063    49.22    11.222    44    21.339     1       6.24      0.0       0        0
  39   4    2.4082     6.75     0.502    48.15    10.150    43    11.053     1       5.13      0.0       0        0
  52   4    0.0184     0.95     0.780     8.69     5.692    65     0.000     2       0.02      0.0       0        0
  13   4    0.0442     0.63     0.488     8.69     5.692    65     0.000     2       0.01      0.0       0        0
  53   4    0.0110     0.42     0.297     8.69     5.692    65     0.000     2       0.00      0.0       0        0
  54   4    5.4708     8.34     2.779    39.00    11.999    69    35.778     1       6.34      0.0       0        0
  14   4   13.1300     6.81     1.379    37.95    10.946    64    14.776     1       4.11      0.0       0        0
  55   4    3.2825     6.02     0.659    37.10    10.096    63     4.552     1       3.15      0.0       0        0
  58   4    4.1446     9.23     2.861    51.18    13.181    79    49.668     1      10.19     22.21      0        0
  16   4    9.9469     7.65     1.417    49.76    11.759    75    28.690     1       6.81      0.0       0        0
  59   4    2.4867     6.84     0.677    48.61    10.612    74    15.487     1       5.32      0.0       0        0
  68   4    1.3188    13.60     2.470    77.50    12.500    66    95.731     1      33.54    151.20      0        0
  21   4    3.1651    12.20     1.186    74.64     9.639    65    88.034     1      25.98    109.42      0        0
  69   4    0.7913    11.51     0.555    72.39     7.395    64    79.905     1      22.43     89.81      0        0
  80   4    3.5481     9.46     2.621    42.25    12.249    68    61.628     1       8.86     14.80      0        0
  27   4    8.5154     8.01     1.288    40.73    10.728    64    32.828     1       6.11      0.0       0        0
  81   4    2.1289     7.27     0.611    39.51     9.510    63    18.149     1       4.88      0.0       0        0
  32   5    3.4419    11.95     5.087    42.82    12.825    80    82.910     1      13.39     36.22      0        0
   3   5    8.2607     9.40     2.707    41.36    11.364    77    59.686     1       8.00      6.63      0        0
```

Figure 21.—Example of complete tree list output from the Prognosis Model.

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The second optional output is a copy of the summary table routed without headings to a supplemental output unit. This unit can be referenced to a tape or disk drive, producing a machine readable copy of the yield table resulting from the projection. The copy of the summary table is requested with the ECHOSUM record:

ECHOSUM   field 1:   Dataset reference number for output of summary table copy; default = 4

When using the ECHOSUM option to produce a machine readable copy of the summary table, a four-character label can be added (see fig. 9, identifiers) to assist subsequent processing. The label is entered with the MGMTID record (see section titled Identifying the Stand).

Finally, explanatory text may be added to the output to aid in interpretation. To enter this text, the COMMENT and END records are needed. These keywords define the beginning and end of a set of text that will be reproduced, verbatim, in the input summary table. There are no restrictions on the number or format of records used to input comments except that the first three columns cannot contain the word "END" if the fourth column is blank. **Note**: if END is omitted from the keyword file, subsequent keyword records will be treated as part of the COMMENT packet, and the projection likely will fail.

For example, a description of silvicultural objectives could be added to the output for the simulation of our example prescription:

```
COMMENT
  THE PRESCRIPTION CALLS FOR IMMEDIATE REMOVAL OF
  EXCESS TREES, A COMMERCIAL THINNING AT AGE 90
  TO REMOVE LODGEPLE AND LARCH, A SHELTERWOOD
  REGENERATION TREATMENT AT AGE 120 FAVORING
  GRAND FIR AND DOUGLAS-FIR, AND AN OVERWOOD
  REMOVAL AT AGE 130.
END
```

INSIDE THE PROGRAM

Information presented in previous sections of this manual will enable you to prepare input for a Prognosis Model projection and interpret the resulting output. The Prognosis Model is, however, more than a computer program. It is a set of mathematical models that represent tree and stand development. A basic understanding of these models is essential to effective program use. For this reason, we have included the following "guided tour" through the various equations and operations that lead to each stand projection.

Getting Started

The initial phase of our tour considers the beginning of the projection. We first read and interpret any user instructions and all inventory records. These processes were described in the previous sections, and we will assume for now that they have been successfully completed. Before the actual projection can begin, however, several housekeeping chores must be performed.

BACKDATING INPUT DIAMETERS

The Prognosis Model uses a forward-projection technique. The predictions of growth are dependent on the tree and stand conditions at the start of the growth period. When current diameter breast height *(DBH)* and past periodic increment (*DG*) are entered, diameters must be backdated before growth models are calibrated. In the model, *DBH* is assumed to

be measured outside bark while increment is assumed to be measured inside bark. In order to backdate diameters properly, an adjustment is made to correct for bark growth (Monserud 1979). The adjustment is of the form

$$DBH_0 = DBH - k \ni DG$$

where DBH_0 is the diameter outside bark at the start of the growth period and k is a species-specific bark growth adjustment factor (table 7).

Stand density statistics are compiled using tree diameters and, therefore, all diameters must be backdated even though increments are not measured on all trees. In order to backdate trees without measured diameter increments, we compute the basal area ratio:

$$BAR = \frac{DBH_0^2}{DBH^2}$$

for all trees with measured increments. The values of BAR are averaged by species, and the average ratios are applied to trees with missing increments

$$DBH_0 = \sqrt{BAR \cdot DBH^2}$$

When none of the trees for a species have measured increments, BAR is assumed to be equal to 1.0.

STAND DENSITY STATISTICS

Three stand density descriptors are used by the Prognosis Model. These descriptors are basal area per acre, crown competition factor (CCF) and the basal area percentile distribution. Before density statistics can be computed, the number of trees per acre *(PROB)* associated with each tree record must be determined. *PROB* is a function of tree DBH and the sampling design parameters (see section titled Describing the Stand). For fixed area plots,

$$PROB = \frac{1}{N \cdot A}$$

For variable radius plots,

$$PROB = \frac{BAF}{0.005454 \cdot N \cdot DBH^2}$$

where

N = number of sample plots in the stand
A = area of a sample plot (acre)
BAF = basal area factor for horizontal angle gauge (ft^2/acre/tree)

Figure 7.—Bark growth adjustment factors and sources. These factors are used to predict total increment (bark and wood) given only the wood increment.

Species	Adjustment factor	Source
Western white pine	1.037	Finch (1948)
Western larch	1.175	Finch (1948)
Douglas-fir	1.153	Monserud (1979)
Grand fir	1.093	Finch (1948)
Western hemlock	1.071	Finch (1948)
Western redcedar	1.053	Finch (1948)
Lodgepole pine	1.032	Finch (1948)
Engelmann spruce	1.047	Spada (1960)
Subalpine fir	1.063	Finch (1948)
Ponderosa pine	1.128	Johnson (1956)[1]
Mountain hemlock	1.053[2]	

[1] Johnson gave one factor based on 123 trees with *DBH* less than 9.5 inches (1.245) and a second factor (1.121) based on 1,951 trees with *DBH* greater than 8.5 inches. The rate we use is the weighted average of these numbers.
[2] No data were available for mountain hemlock. The rate for western redcedar is used.

When the density statistics are backdated, the *PROBs* for recent mortality records (tree history code 5) are multiplied by the ratio of diameter increment measurement period length to mortality observation period length. Periodic growth of recent mortality records is assumed to be zero. These records will be culled from the tree record file when program initialization is completed.

To compute basal area per acre, we simply sum the product of trees per acre and tree basal area across all tree records.

Crown competition factor (Krajicek and others 1961) is a relative measurement of stand density that is also based on tree diameters. Tree values of *CCF* estimate the percentage of an acre that would be covered by the tree's crown if the tree were open grown. Stand *CCF* is the summation of individual tree (CCF_t) values. A value of 100 theoretically indicates that tree crowns will just touch in an unthinned, evenly spaced stand. CCF_t is estimated from tree diameter as follows:

$$CCF_t = \begin{cases} PROB \cdot \left(a_0 + a_1 \cdot DBH + a_2 \cdot DBH^2\right) & \text{for } DBH \geq 10 \text{ in.} \\ \\ PROB \cdot b_0 DBH^{b_1} & \text{for } DBH < 10 \text{ in.} \end{cases} \tag{5}$$

where
$a_0, a_1, a_2, b_0, b_1,$ are species-dependent constants (table 8).

Table 8.—Coefficients for computing the contribution of each tree record to the stand estimate of crown competition factor from tree diameter (DBH) (see eq. 5)

| | Model coefficients | | | | |
| | DBH < 10 inches | | DBH μ 10 inches | | |
Species	b_0	b_1	a_0	a_1	a_2
Western white pine	0.00988	1.6667	0.03	0.0167	0.00230
Western larch	.00724	1.8182	.02	.0148	.00338
Douglas-fir	.01730	1.5571	.11	.0333	.00259
Grand fir	.01525	1.7333	.04	.0270	.00405
Western hemlock	.01111	1.7250	.03	.0215	.00363
Western redcedar	.00892	1.7800	.03	.0238	.00490
Lodgepole pine	.00919	1.7600	.02	.0168	.00325
Engelmann spruce	.00788	1.7360	.03	.0173	.00259
Subalpine fir	.01140	1.7560	.03	.0216	.00405
Ponderosa pine	.00781	1.7680	.03	.0180	.00281
Mountain hemlock	.01111	1.7250	.03	.0215	.00363

The basal area percentile distribution is a measure of the relative size of the trees in the stand (Stage 1973b) and, to some extent, it indicates the competitive status of each tree. The basal area percentile rank of a tree (*PCT*) is the percentage of total stand basal area represented by that tree and all trees that are the same size or smaller. The largest tree in the stand has a *PCT* of 100 and successively smaller trees have successively smaller rankings. All trees must have *PCT* greater than zero (*PCT* is listed for six of the trees in S248112 in figure 8—the tree and stand attributes output table).

MISSING DATA

We indicated earlier that tree heights and crown ratios could be subsampled. When tree heights are missing, a height-diameter function is used to estimate the missing values (fig. 22):

$$HT = \exp[C_0 + C_1 \cdot 1/(DBH+1)] + 4.5 \tag{6}$$

where C_0 and C_1 are species-dependent constants (table 9). When there are four or more tree records for a species with measured heights and undamaged tops, the coefficients for the height-diameter model for that species are estimated from the input data. Four trees are an adequate sample only if the trees are undamaged and they represent the entire range of *DBH* in the stand.
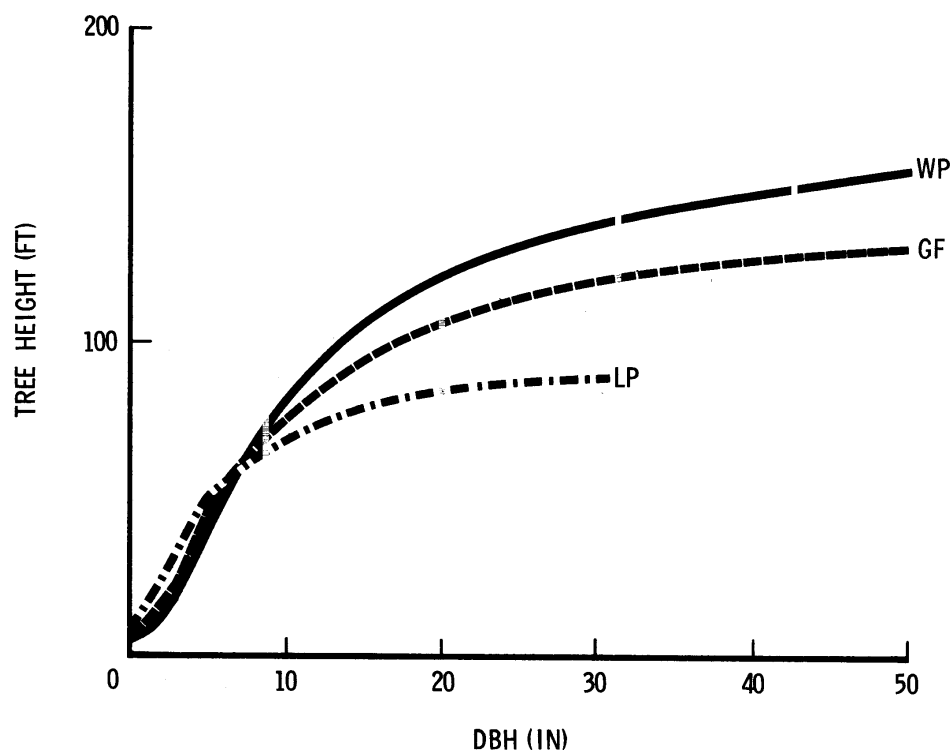
Figure 22.—Height as predicted from *DBH* with the default height-diameter equations in the Prognosis Model. The three species represented are western white pine (WP), grand fir (GF), and lodgepole pine (LP).

Table 9.—Coefficients for the default height-diameter model (see eq. 6)

Species	C_0	C_1
Western white pine	5.19988	-9.26718
Western larch	4.97407	-6.78347
Douglas-fir	4.81519	-7.29306
Grand fir	5.00233	-8.19365
Western hemlock	4.97331	-8.19730
Western redcedar	4.89564	-8.39057
Lodgepole pine	4.62171	-5.32481
Engelmann spruce	4.92190	-8.30289
Subalpine fir	4.76537	-7.61062
Ponderosa pine	4.92880	-9.32795
Mountain hemlock	4.77951	-9.31743

The missing crown ratios are estimated as a function of habitat type, *DBH, HT, PCT, CCF,* and species. This model is part of the algorithm we use to predict change in crown ratio and will be specified in detail when the prediction of change in crown ratio is discussed. The crown ratio model predicts an expected value. When using the model to supply missing data, a random deviate is added to the prediction. This deviate is drawn from a Normal distribution with a mean of zero and a variance of 159. This distribution approximates the distribution of residuals about the fitted model.

CALCULATION OF MODEL SCALE FACTORS TO REPRESENT INCREMENT DATA

When periodic increment data is provided to the Prognosis Model, the imbedded increment models will be adjusted to reflect local conditions. Both the diameter increment model and the small-tree height increment model may be calibrated. In both cases, the calibration factor is a multiplier that is a weighted average between the median ratio of observed to predicted values and 1.0. The weight is dependent on how closely the variation in the residuals for the stand being calibrated matches the variation in the residuals for the overall model (Stage 1973b, 1981). In a later section, we will elaborate on the calculation and use of correction factors.

Predicting Periodic Increment

When calibration is completed, stand density statistics are updated to correspond to the beginning of the first projection period. Then, the Prognosis Model prepares the input summary table (fig. 6) and the entries in other tables (figs. 7,8,9) that summarize initial conditions. Next, all scheduled thinnings are simulated and stand density statistics are again modified to reflect removals. Finally, we begin the process of projecting stand development.

Stand development is simulated by predicting increments in the dimensions of the trees that comprise the stand. The first and most important prediction is diameter increment.

DIAMETER INCREMENT PREDICTION

All facets of predicted tree development are dependent in part on diameter or diameter increment. The behavior of the Prognosis Model as a whole is, therefore, strongly influenced by the behavior of the diameter increment model and the subsequent use of *DBH* and diameter increment in the prediction of other tree attributes. Consequently, we will spend some time examining the diameter increment model and important interactions with other variables.

Specifying the Model

Actually, we do not predict diameter increment. Rather, we derive diameter increment from predicted periodic (10-year) change in squared inside-bark diameter (*dds*) (Stage 1973b; Cole and Stage 1972):

$$dds = (dib + DG)^2 - dib^2$$
$$= 2 \cdot dib \cdot DG + DG^2$$

where:

DG = periodic increment in inside bark diameter (10-year)

dib = inside bark diameter at the beginning of the growth period
$= (1/k) \cdot DBH$ where k is a species dependent bark adjustment factor is given in table 7.

From the above:
$$DG = \sqrt{dib^2 + dds} - dib \tag{7}$$

As we are primarily interested in diameter increment, we will not belabor this transformation beyond a brief explanation. The choice of dependent variable is a matter of statistical convenience: the trend in ln(*dds*) relative to ln(*DBH*) is linear and the residuals on this scale have a nearly homogeneous variance. These conclusions are based on about 45,000 data points[8] and are consistent across all species represented in the Inland Empire version.

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[8] The diameter increment data used to develop this model were extracted from the inventories (1971-75) for the National Forests listed in table 2.

The diameter increment model is specified as follows:

$$\ln(dds) = HAB + LOC$$
$$+ b_1 \cdot \cos(ASP) \cdot SL + b_2 \cdot \sin(ASP) \cdot SL + b_3 \cdot SL + b_4 \cdot SL^2$$
$$+ b_5 \cdot EL + b_6 \cdot EL^2 + b_7 \cdot (CCF/100)$$
$$+ b_8 \cdot \ln(DBH) + b_9 \cdot CR + b_{10} \cdot CR^2 + b_{11} \cdot (BAL/100)$$
$$+ b_{12} \cdot DBH^2 \tag{8}$$

where:

HAB = a constant term (intercept) that is dependent on habitat type (tables 10 and 11).
LOC = a constant term (intercept) that is dependent on location (tables 10 and 12).
ASP = stand aspect (degrees).
SL = stand slope ratio (percent/100).
EL = stand elevation (in hundreds of feet).
CCF = stand crown competition factor.
CR = ratio of crown length to total tree height.
BAL = total basal area per acre in trees that are larger than the subject tree (the tree for which a prediction is being made).
b_1 through b_{12} = regression coefficients that are dependent on species (see table 10); b_{12} is dependent on location as well (table 13).

Table 10.—Coefficients of the diameter increment model by species (see eq. 8)

Variables (classes)		Species[1]										
		WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
HABITAT CLASS INTERCEPTS (HAB)[2]	1	0.52413	0.09942	-0.14504	-0.29300	-0.04936	-.05206	0.12576	-1.00547	-1.22567	0.51095	-1.85096
	2	.21955	.16062	-.08077	-.18647		.11324	.43686	-.94485	-.98325	.18432	-1.70123
	3	.39811	.24828	-.01849	-.52237		-.13744	.49842	-.74478	-.81103	.37804	
	4		.20583	-.45104	-.33345			.36061	-1.43486	-1.07653	-.01902	
	5		.45896	-.21060				.18277	-1.29358	-1.50160	.28779	
	6		-.00942					.30146	-1.10471	-1.39603		
LOCATION CLASS INTERCEPTS (LOC)[3]	1	.15050	.28070	.55791	.45526	.10409	.48022	.44873	.27427	.39372	.27234	.11650
	2	.25383	.15733	.32382	.25827	.50090	.19002	.21252	.07059	.11026	.62851	.47050
	3	.0	.09762	.20639	-.21506	.0	.30175	.13555	-.14313	-.16460	.42701	.0
	4		.43740	.67618	.18436		.0	.0	.0	-.03889	.0	
	5		.0	.0	.58661							
	6				.0							
COS(ASP)∃SL	(b₁)	-.02384	-.18391	-.05446	-.04167	.10295	-.06283	.00419	-.12416	-.11696	-.10666	.18760
SIN(ASP)∃SL	(b₂)	.04285	.03467	.06653	-.00710	.11043	.00762	.13073	-.05792	-.06235	.00945	.12718
SL	(b₃)	-.30352	.19829	.67627	.78498	.15025	.29811	.47800	.73989	.33983	-.00322	.09233
SL²	(b₄)	.0	-.59316	-1.11525	-1.19852	.0	-.19797	-.62155	-.97938	-.67813	-.50149	.0
(EL)	(b₅)	.04126	.02672	.02187	.02059	.03200	.01269	-.00111	.06282	.06542	.03067	.08298
(EL)²	(b₆)	-.000578	-.000342	-.000341	-.000260	-.000473	-.000280	-.000096	-.000711	-.000700	-.000416	-.000926
CCF/100	(b₇)	-.10407	-.10269	-.08163	-.10040	.0	-.12506	-.12417	-.10708	-.04203	-.15025	-.13803
ln (DBH)	(b₈)	.84748	.76815	.87807	1.04715	.85462	1.00184	.98853	.94147	.98464	.78570	1.01045
CR	(b₉)	1.13594	1.51862	2.10953	2.00814	1.84253	1.76810	1.89451	1.50962	.53338	1.07122	1.29276
CR²	(b₁₀)	.0	-.38137	-.66989	-.80903	-.49184	-.42293	-.42759	-.22132	.86079	.34044	.0
(BAL/100)	(b₁₁)	-.37061	-.41332	-.40192	-.25244	-.34693	-.12036	-.24188	-.24366	-.22331	-.47261	-.25349
DBH² CLASSES (b₁₂)[4]	1	-.000618	-.000495	-.000615	-.000562	-.000468	-.000176	-.001523	-.000364	-.000696	-.000475	-.000586
	2	-.000224	-.000583	-.000724	-.000650	-.000356	-.000126	-.002498	-.000506	-.000982	-.000590	-.000381
	3		-.000788	-.000839	-.000384	-.000593	-.000154	-.002061	-.000667	-.000459	-.000259	
	4			-.000933	-.000867	-.000874		-.001182	-.000254			

[1]Species are defined in table 4.
[2]Habitat classes are defined in table 11.
[3]Location classes are defined in table 12.
[4]DBH squared classes are defined in table 13.

Table 11.—Classification of habitat effects by species among habitat types for the diameter increment model (see equation 8)

Habitat code[2]	Habitat effects by species[1]										
	WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
130	3	6	5	4	1	3	6	6	6	1	2
170	3	6	5	4	1	3	6	6	6	1	2
250	3	6	5	4	1	3	6	6	6	3	2
260	3	6	5	4	1	3	6	6	6	5	2
280	3	6	5	4	1	3	1	6	6	5	2
290	3	6	5	4	1	3	2	6	6	5	2
310	3	6	5	4	1	3	3	6	6	5	2
320	3	6	1	4	1	3	6	6	6	5	2
330	3	6	5	4	1	3	6	6	6	4	2
420	3	1	5	4	1	3	6	6	6	5	2
470	3	1	5	4	1	3	6	6	6	5	2
510	3	2	1	4	1	3	2	1	6	1	2
520	1	1	2	1	1	3	2	1	1	1	2
530	1	3	3	4	1	1	4	2	2	1	2
550	1	3	3	4	1	2	4	3	3	1	2
570	1	4	3	4	1	3	4	2	4	3	2
610	1	3	3	4	1	2	4	3	3	1	2
620	1	2	3	4	1	3	4	1	1	3	2
640	3	6	5	4	1	3	5	6	6	5	2
660	3	2	4	4	1	3	5	4	6	5	2
670	2	1	2	2	1	3	4	6	6	5	1
680	2	1	2	3	1	3	5	2	6	5	2
690	3	1	5	3	1	3	6	6	6	5	2
710	3	6	5	2	1	3	6	6	6	5	2
720	3	6	5	4	1	3	6	6	6	5	2
730	3	5	5	4	1	3	5	2	1	5	2
830	3	6	4	4	1	3	5	5	5	5	2
850	3	6	4	4	1	3	6	6	6	5	2
999[3]	3	6	5	4	1	3	6	6	6	5	2

[1] Species codes are defined in table 4.
[2] Habitat codes are defined in table 3.
[3] Types grouped with 999 were included in the overall mean for the species.

Table 12.—Classification of location effects by species among National Forests for the diameter increment model (see equation 8)

National Forest	Location effects by species[1]										
	WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
Bitterroot	3	1	5	6	3	4	4	4	5	1	3
Clearwater	1	1	1	1	3	1	1	1	1	2	1
Coeur d'Alene	3	2	2	2	1	1	1	1	2	2	1
Colville	3	3	3	2	3	2	2	2	2	1	3
Flathead	3	3	3	3	3	2	4	3	3	4	3
Kaniksu	3	2	2	2	3	3	3	4	3	3	3
Kootenai	3	5	3	4	3	4	3	4	4	1	3
Lolo	3	5	5	6	3	2	4	4	5	4	1
Nezperce	3	4	1	2	3	1	2	1	2	3	3
St. Joe	2	1	4	5	2	1	2	1	1	2	2

[1] Species codes are defined in table 4.

Table 13.—Classification of diameter-squared effects by species among National Forests for the diameter increment model (see equation 8)

National Forest	DBH squared effects by species[1]										
	WP	**L**	**DF**	**GF**	**WH**	**C**	**LP**	**S**	**AF**	**PP**	**MH**
Bitterroot	1	1	1	1	1	1	1	1	1	1	1
Clearwater	2	2	2	1	1	2	2	2	2	2	1
Coeur d'Alene	2	2	2	2	2	1	2	1	3	2	1
Colville	2	2	2	2	3	3	1	1	2	2	1
Flathead	1	2	3	3	1	1	1	1	3	3	1
Kaniksu	2	2	1	3	1	1	2	3	3	3	1
Kootenai	1	1	4	4	1	2	3	2	2	2	1
Lolo	1	2	1	1	1	1	1	1	1	1	2
Nezperce	1	2	1	3	1	2	4	4	3	1	1
St. Joe	2	3	4	1	4	1	1	1	2	2	2

[1] Species codes are defined in table 4.

An Example

At this point, we will demonstrate the evaluation of the diameter increment model. For an example, we will use the 19th tree record from stand S248112 (fig. 3). This tree is a Douglas-fir with a 12.7-inch DBH and a crown ratio of about 35 percent. It is the largest live tree sampled in the stand.

As previously noted, stand S248112 is located in the St. Joe National Forest on a *Tsuga heterophylla/Clintonia uniflorum* habitat type (code 570) at an elevation of about 3,400 feet. The aspect is northwesterly with about a 30 percent slope. Following a light thinning in 1977, the stand supports 64 square feet of basal area per acre and has a *CCF* of 83.8 (fig. 6,8).

For Douglas-fir, habitat type 570 is part of habitat class 3 (table 11) and the St. Joe National Forest is in location class 4 (table 12). These classes are assigned constants of -0.01849 and 0.67618, respectively (see table 10). The entire model is evaluated as follows:

— Habitat

-0.018

— Location

0.676

— Slope and aspect

$$= b_1 \cdot SL \cdot \cos(ASP) + b_2 \cdot SL \cdot \sin(ASP) + b_3 \cdot SL + b_4 \cdot SL^2$$

$$= (-0.05446) \cdot (0.3) \cdot \cos(315°) + (0.06653) \cdot (0.3) \cdot \sin(315°)$$

$$+ (0.067627) \cdot (0.3) + (-1.11525) \cdot (0.03) \cdot (0.03)$$

$$= 0.077$$

— Elevation

$$= b_5 \cdot EL + b_6 \cdot EL^2$$

$$= (0.02187) \cdot 34 - (0.000341) \cdot (34)^2$$

$$= 0.349$$

— *CCF*

$$= b_7 \cdot (CCF / 100)$$

$$= (-0.08163 \cdot 0.838)$$

$$= -0.068$$

— *DBH* (from table 13, the St. Joe National Forest uses the fourth *DBH* squared coefficient for Douglas-fir)

$$= b_8 \cdot \ln(DBH) + b_{12} \cdot DBH^2$$

$$= (0.87807) \cdot \ln(12.7) - (0.000933) \cdot (12.7)^2$$

$$= 2.081$$

— Crown ratio

$$= b_9 \cdot CR + b_{10} \cdot CR^2$$

$$= (2.10953) \cdot (.035) - (0.66989) \cdot (0.35)^2$$

$$= 0.656$$

— Basal area in larger trees

$$= b_{11} \cdot BAL$$

$$= (-0.40192) \cdot (0) \text{ (this is the largest tree in the stand)}$$

$$= 0.0$$

Predicted ln(*dds*) is equal to 3.753 which is the sum of the above effects. Therefore,

$$dds = e^{3.753} = 42.65$$

Now to calculate diameter increment, we need the bark ratio for Douglas-fir (table 7) and equation 7:

$$DG = \sqrt{dib^2 + dds} - dib$$

$$= \sqrt{(DBH/k)^2 + dds} - (DBH/k)$$

$$= \sqrt{\left(\frac{12.7}{1.153}\right)^2 + 42.65} - \left(\frac{12.7}{1.153}\right)$$

$$= 1.79 \text{ inches}$$

The computed *DG* differs significantly from the increment reported in figure 8 (1.11 inches). The difference is attributable to two factors:

(1) In the example projection, the predicted growth was scaled (scale factor = 0.65; see figure 6) to reflect input increment data. We have neglected this step.
(2) Also in the example projection, the predicted growth was modified, through record tripling, to introduce some variation.

When the scale factor is applied,

$$dds = (42.65) \exists (0.65)$$
$$= 27.72$$

and the prediction of *DG* is reduced to 1.19 inches.

The effect of record tripling is not as easily traced. The record tripling procedure generates three records (triples) from each original record. The trees-per-acre represented in the original record are partitioned by arbitrarily assigning 25 percent to one triple (fast-growing trees), 15 percent to another triple (slow-growing trees), and 60 percent to the final triple (average-growing trees) (Stage 1973b). Each triple is then assigned an increment based on the distribution of errors about predicted increments. These errors are assumed to be distributed Normally (on the logarithmic scale), with a mean of zero and a variance equal to the weighted average of the mean squared errors from the regression model and from the input increment data (appendix A). The slow-growing trees are assigned an increment cor-

responding to the 7.5th percentile point in the distribution of errors (this is the median of the lower 15 percent). Increments assigned to the average and fast-growing trees correspond to the 45th and the 87.5th percentile points in the error distribution, respectively. The weighted average increment prediction for the three triples is equal to the original prediction. The increments displayed in the stand and tree attributes table (fig. 8), however, are always from the middle triple and are always slightly less than the original predicted value. In the case of our example,

$$dds = 25.53,$$

resulting in a *DG* equal to 1.11 inches. Note, however, that the ratio of the *dds* associated with the 45th percentile point to the original *dds* prediction (in our example this ratio is 0.921) varies by species and by the distribution of the input increment data.

Behavior of Predicted Diameter Increment Relative to *DBH*

The value of *dds* is directly proportional to basal area increment. The shape of the *dds* curve relative to *DBH* is unimodal with a maximum at or beyond 20 inches *DBH*. The *DBH* at culmination of *dds* varies by species but is considerably larger than the *DBH* at culmination of diameter increment (fig. 23).

When scale factors are used to adjust for local variation in growth, the value of *dds* is directly multiplied so that there is no shift in the *DBH* at culmination of *dds*. However, as the value of the scale factor increases, the value of *DBH* corresponding to the culmination of *DG* also increases (fig. 24).
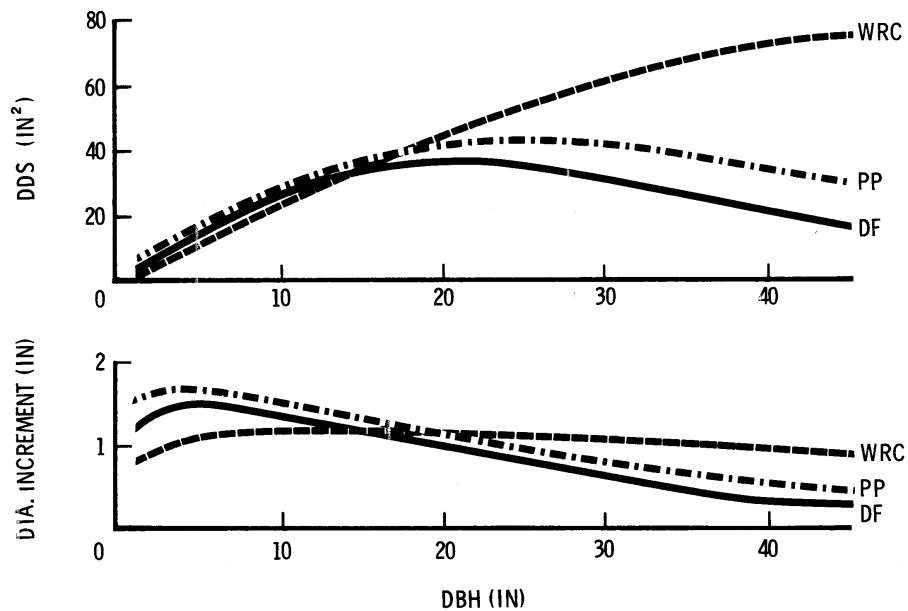
Figure 23.—Diameter increment and *dds* (see equations 7 and 8) predicted for three species assuming a *Thuja plicata/Pachistima myrsinites* habitat type on the St. Joe National Forest. The slope is assumed to be level at 3,800 feet elevation. The trees depicted are dominants in medium density stands (basal area = 150 ft^2/acre). The species are western redcedar (WRC), ponderosa pine (PP) and Douglas-fir (DF).
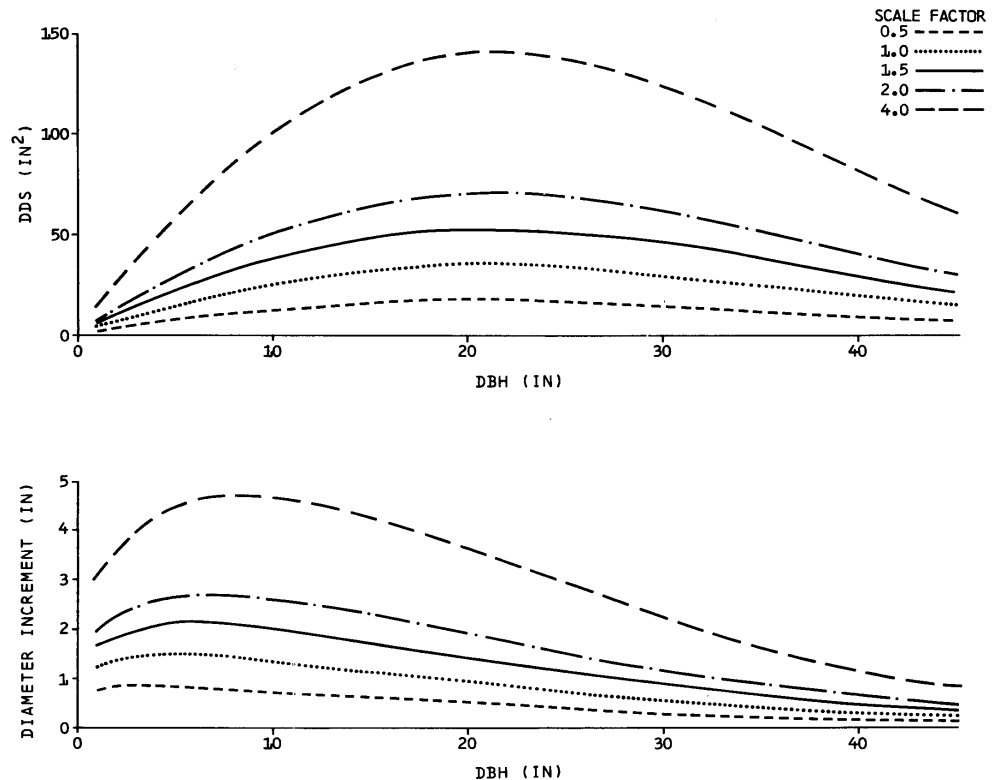
Figure 24.—The effect of scaling on the predictions of *dds* (see equations 7 and 8) and diameter increment. The species is Douglas-fir with other stand conditions as specified for figure 23. Note that the maximum of the diameter increment curve shifts to the right as the scale factor increases. The maximum of the *dds* curve remains at about 20 inches *DBH* regardless of scale factor.

The Influence of Site Factors

Site factors are included in the model in two general ways. The effects of habitat type and location are readily observed but difficult to quantify. These effects are included in the model by varying intercepts. Slope, aspect, and elevation are treated as continuous variables.

The location intercepts were developed by first estimating coefficients for each National Forest. National Forests that had statistically similar coefficients were then grouped into location classes. This procedure was repeated to group habitat types into habitat classes, at which time the integrity of the location classes was reexamined.[9] As a result, when you move from one National Forest or habitat type to another, there is a discrete shift in the increment function (fig. 25).

We use a modification of Stage's (1976) transformation to incorporate aspect and slope as a continuous circular effect. The modification is the addition of a slope-squared term that allows optimum growth to occur at other than infinite or level slopes. The optimal aspect varies by species but, with the exception of the two hemlock species and lodgepole pine, is within 60 degrees of due south (fig. 26 and 27). Most species prefer moderate slopes. Moderate slopes tend to be well drained with adequate soil, and the growing season is longer on the warmer southern exposures.

Elevation is also transformed so that an optimum is possible. That optimum normally occurs at an elevation that is in the middle of the range of species occurrence in northern Idaho (fig. 28). Although the optimal level of most predictor variables is within the range of species occurrence, the effects are independently estimated, and there is no guarantee that

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[9] Habitat and location constants were estimated using the dummy variable technique. Statistical similarity implies that none of the estimated coefficients that are grouped into a class differs from any other at the 50 percent level of significance.

there exists a site at which all predictor variables are at their optimum level. For example, optimum growth of western redcedar is expected on a south aspect, 90 percent slope at an elevation of 2300 feet in a cedar/devil's club (code = 550) habitat type in the Nezperce or Clearwater National Forests. This combination of site factors would be difficult, if not impossible to find.
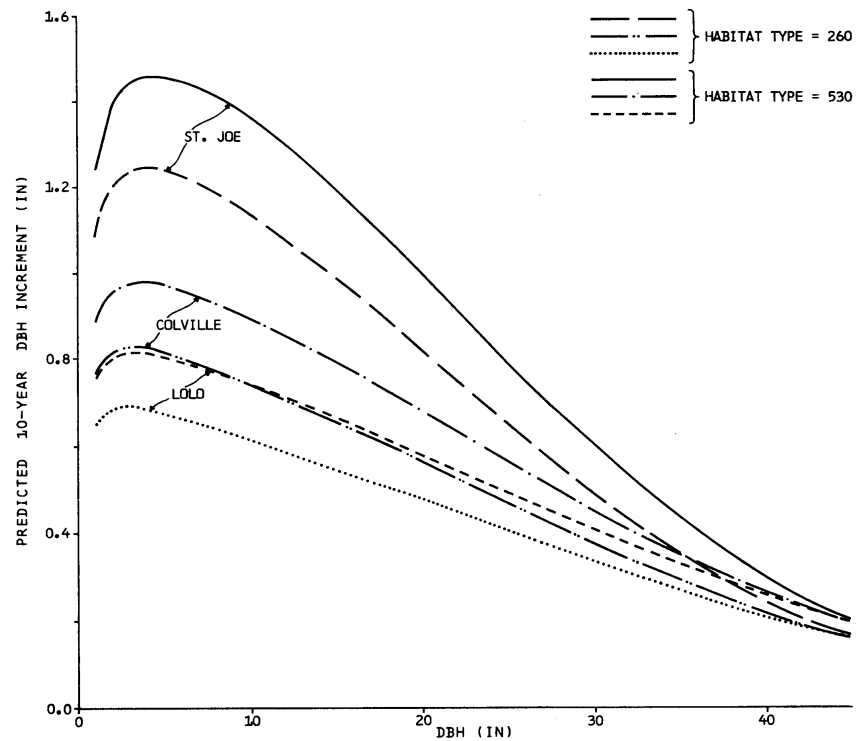

Figure 25.—The effect of habitat type and location on the prediction of diameter increment. The species shown is Douglas-fir; other conditions are as represented in figure 23.
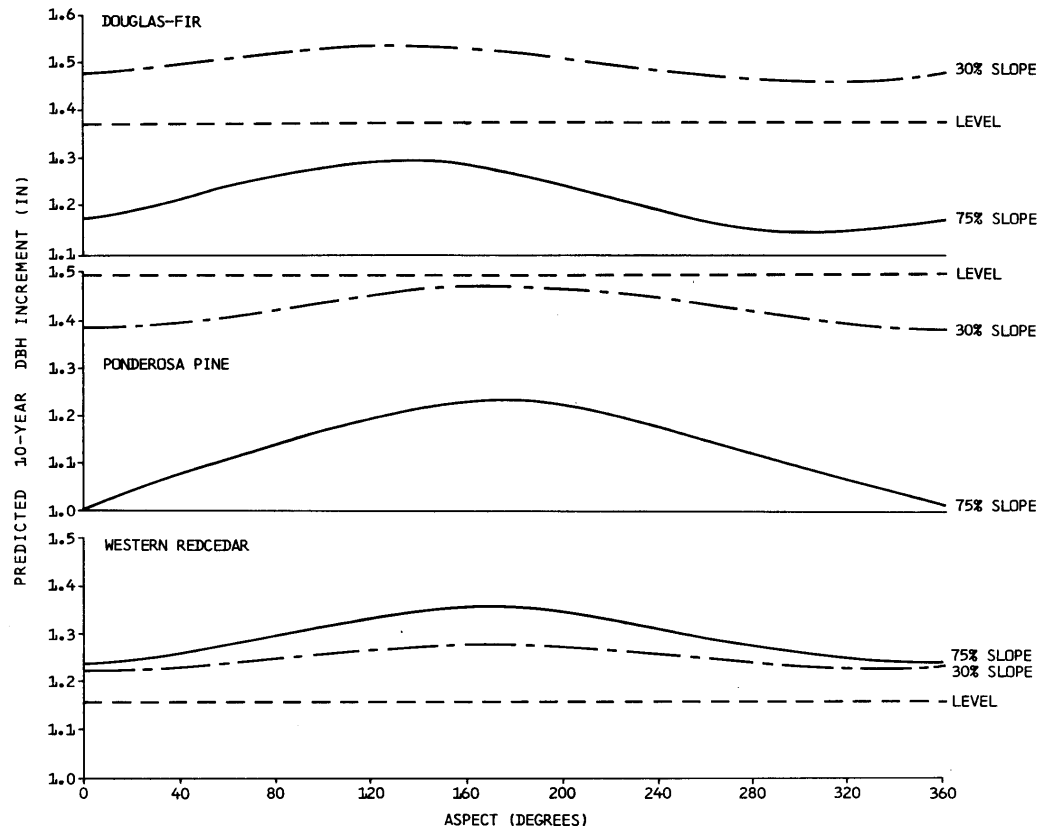
Figure 26.—The effect of aspect on diameter increment predictions for three different slopes. The species and site conditions are as specified in figure 23.
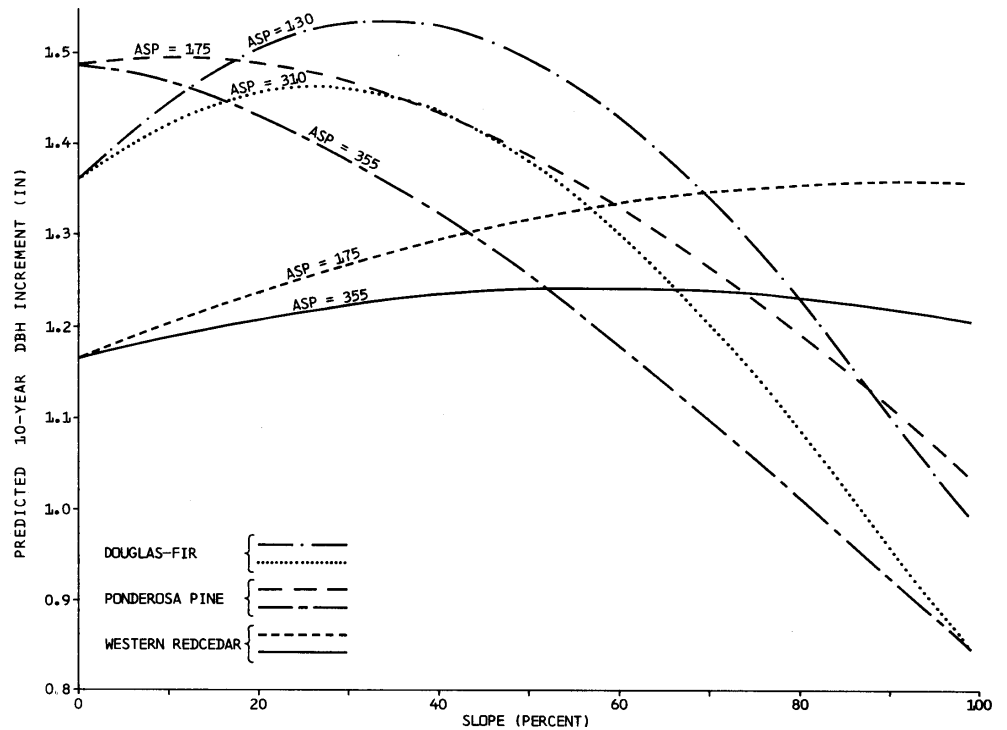
Figure 27.—The effect of slope on diameter increment predictions for two different aspects. Species and site conditions are as specified in figure 23.
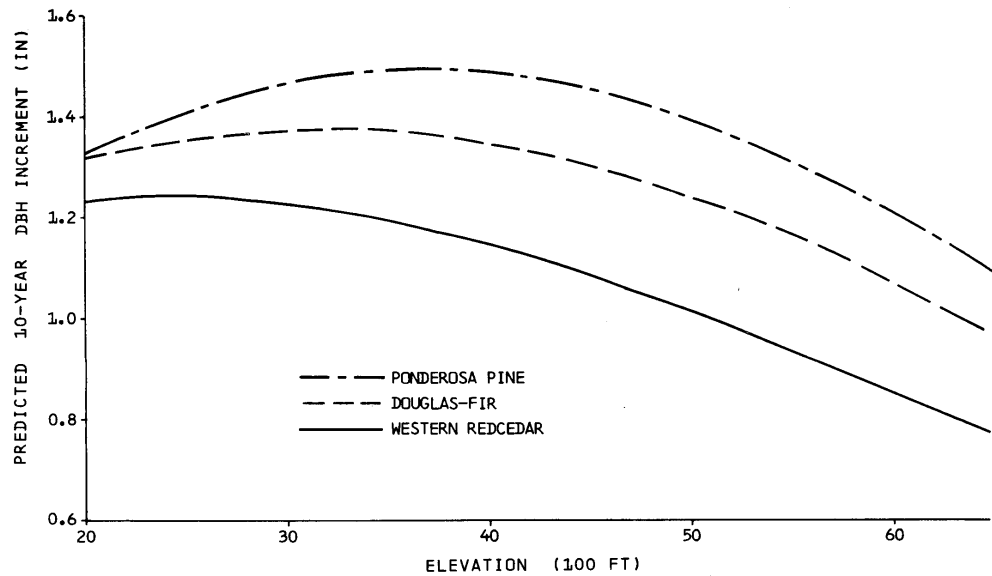
Figure 28.—The effect of elevation on diameter increment predictions. Three species (Douglas-fir, ponderosa pine, and western redcedar) are shown. Site conditions are as specified in figure 23.

Stand and Tree Characteristics that Can Be Managed

So far, we have described the features of the model over which we have no control. Through management, we can adjust stand density and the distribution of trees among size classes, and we can influence the development of crowns. Trees with large crowns and trees in dominant crown positions will grow more rapidly than subordinate trees with smaller crowns. As stand density increases, the growth rates of all trees will be suppressed (fig. 29). If we thin a stand by removing the smaller stems, the diameter increment of the residual stems will increase in proportion to the reduction in stand density. Over the long run, the residual trees will have larger crowns, which will enhance future development. If we remove the larger trees, the residual trees will respond with yet faster growth rates because we have improved their position in the canopy.

To this point, we have examined the growth model in two- or three-dimensional space. This viewpoint has made it easy to see the influence of a given variable on tree growth. However, this simplistic view can be misleading. The northern Idaho forest stand is a complex of species and size classes. Within this complex, any change in one of the variables used to predict growth will usually be associated with changes in one or more of the other predictor variables. We earlier displayed the relationship between *DBH* and diameter increment with all other variables held constant (fig. 23). If we reexamine this relationship in a stand whose development is simulated through time, each tree exhibits the classical unimodal increment curve (Assman 1970). However, some important differences result from the interactions of crown class, crown length, and stand density (fig. 30).

Within a stand, at any point in time, the largest diameter increment attained by any tree of a given species is likely to be attained by the largest tree of the species. The growth rate of a suppressed tree culminates at a smaller *DBH,* than does the growth rate of a dominant tree. In a relatively even-aged stand, however, culmination of all trees of a species will occur at about the same time. As a result, at any time, the relationship between diameter increment and *DBH* is monotonic or sigmoid increasing, with slope depending on stand density. Through time, this relationship flattens and its maximum decreases (fig. 31).
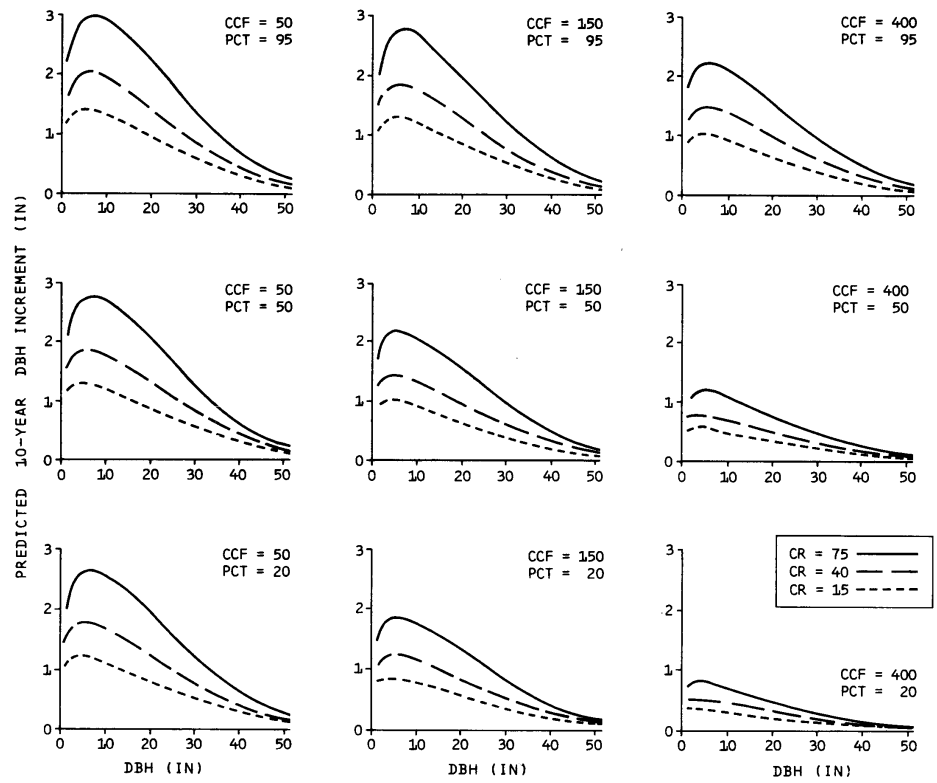
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Figure 29.—The effects of dominance, crown ratio, and stand density on diameter increment predictions. Largest increments are attained by dominant trees with large crowns in open stands. As crowns shorten, as density increases, and as the tree is subordinated, the diameter increment predictions decrease.
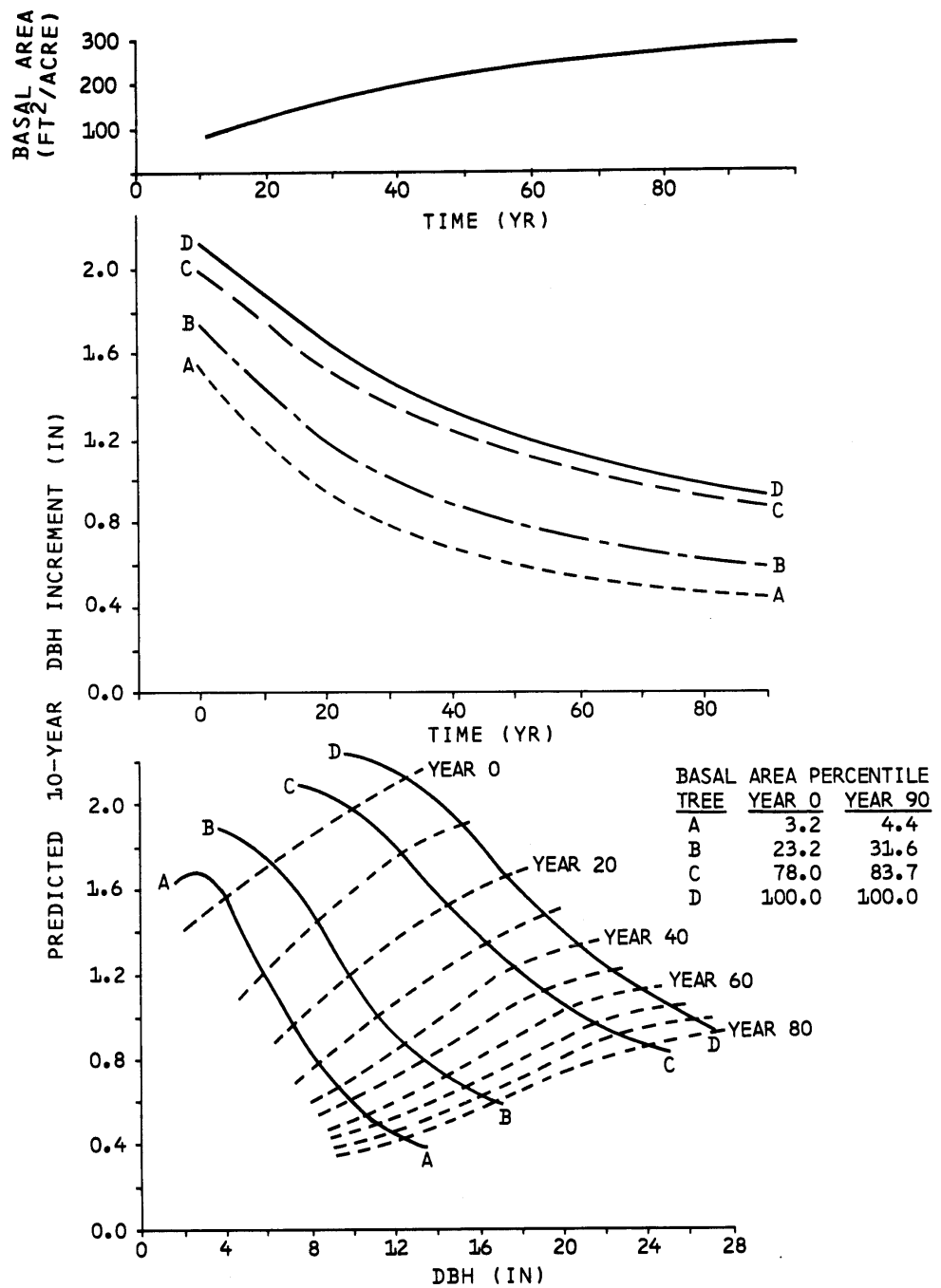
Figure 30.—Simulated development of four Douglas-fir trees through time. The larger trees always attain larger increments, although increments appear to converge over time. The *DBH* associated with the maximum in the diameter increment curve is shifted to the right for the larger trees.
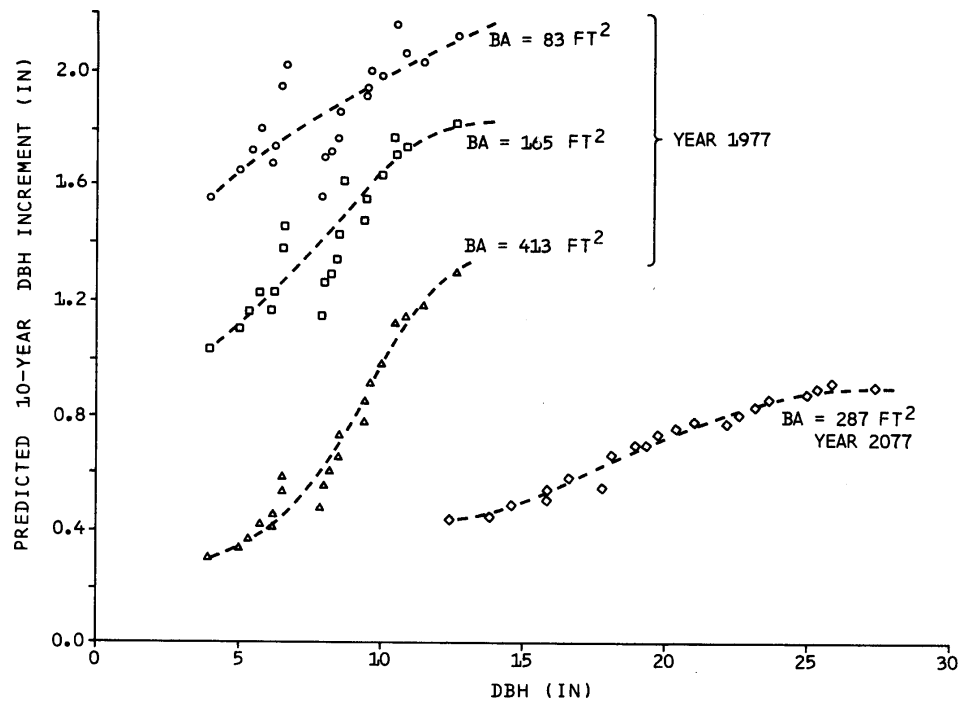
Figure 31.—Simulated increments versus *DBH* for all the trees in a stand. The three curves labeled 1977 show that density effects are felt most severely by the smaller trees in the stand. The curve labeled 2077 represents the predictions for the period 2467–2077 in the continuation of the projection for the stand that was least dense in 1977 (*BA* = 83 sq.ft.). These illustrations were prepared by using a single set of tree records and changing the number of plots assumed to be in the inventory. Initial crown ratios were computed by the program to reflect the influence of density.

THE HEIGHT INCREMENT MODEL

Formulation

Stage (1975) developed a periodic height increment model based on the differential of the allometric relationship between height (*HT*) and diameter *(DBH)*. Periodic (10-year) height increment (*HTG$_1$*) is predicted as a function of *HT, DBH,* 10-year *DBH* increment (*DG),* species, and habitat type.

A series of modifications has been implemented in the basic model. Problems with over-mature trees have been lessened to a great extent by addition of an *HT^2* term to Stage's basic model. This term forces height increment to slow down in very tall trees even though diameter increment may still be quite substantial. In the modified form, coefficients of the *DG* and *HT^2* terms are dependent on habitat type and coefficients of the *DBH* term are dependent on species:

$$\ln(HTG_1) = HAB + SPP + b_1 \cdot \ln(HT) + b_2 \cdot \ln(DBH) + b_3 \cdot \ln(DG)$$
$$+ b_4 \cdot HT^2 \tag{9}$$

where:

   HAB = habitat dependent intercept

   SPP = species dependent intercept

   b_1 through b_4 = regression slope coefficients (table 14); b$_2$ is species
            dependent, b_3 and b_4 are habitat dependent.

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Table 14.—Coefficients for the large tree height increment model (see equation 9)

Variable[1]

In (*HT*)   0.23315

	Species[2]									
	WP	L	DF	GF	WH	C	LP	S	AF	PP
SPP	−0.5345	0.1433	0.1641	−0.6458	−0.6959	−0.9941	−0.6004	0.2089	−0.5478	0.7316
In (*DBH*)	−.04935	−.3889	−.4574	−.0977	−.1555	−.1219	−.2454	−.5720	−.1997	−.5657

	Habitat Class[3]							
	1	2	3	4	5	6	7	8
HAB	1.72222	1.74090	2.03035	1.19728	1.81759	2.14781	1.76998	2.21104
In(*DG*)	1.02372	.34003	.62144	.85493	.75756	.46238	.49643	.37042
HT^2(x 10^{-5})	−3.81	−4.46	−13.36	−3.72	−2.61	−5.20	−1.61	−3.63

[1] Definition of variables:
  HT = Current height (feet)
  DBH = Current diameter at breast height (inches)
  DG = Predicted 10-year DBH increment (inches)
  SPP = Species dependent intercept
  HAB = Habitat dependent intercept

[2] No data were available for mountain hemlock; coefficients for cedar (C) are used for mountain hemlock predictions. Species codes are given in table 4.

[3] Definition of habitat classes:

Class	Codes included in class (see table 3)
1	250, 260, 280, 290, 310, 320, 330
2	690, 710, 720
3	130, 170, 660, 730, 830, 850, 999
4	420, 470,
5	510, 620, 640, 670, 680
6	520
7	530
8	540, 550, 570, 610

In Stage's height increment model, many of the effects related to site characteristics and stand conditions are indirectly represented in the diameter increment term. For trees with less than 3 inches *DBH,* it is difficult to sample for periodic diameter increment. There may be less than 10 years' growth at breast height, and removal of an increment core could severely damage the tree. For very large trees, height increment measurement requires expensive stem analysis techniques; for small trees of most coniferous species, height increments for periods of up to 5 years can be obtained easily by counting whorls and measuring internodes.

Consequently, we developed an independent model to predict periodic (5-year) height increment (HTG_2) for small trees. This model has explicit site and stand density variables and no diameter increment term:

$$\ln(HTG_2) = LOC + HAB + SPP + b_1 \cdot \ln(HT) + b_2 \cdot CCF$$
$$+ b_3 \cdot SL \cdot \cos(ASP) + b_4 \cdot SL \cdot \sin(ASP) + b_5 \cdot SL \qquad (10)$$

where:

  LOC = Location dependent intercept (defined by National Forest boundaries)
  HAB = Habitat type dependent intercept
  SPP = Species dependent intercept
  CCF = Crown competition factor
  ASP = Stand aspect
  SL = Stand slope (percent/100)
  b_1 through b_5 = regression slope coefficients; b_1 and b_2 are dependent on species
      (table 15).

Table 15.—Coefficients for the small tree height increment model (see equation 10)

Variable[1]										
cos(*ASP*) ∃ *SL*	0.22157									
sin(*ASP*) ∃ *SL*	− .12432									
SL	− .10987									

	Species[2]									
	WP	L	DF	GF	WH	C	LP	S	AF	PP
SPP	1.4700	1.6204	1.4932	0.9981	1.0202	0.8953	1.2336	1.0964	1.0667	1.7311
ln (*HT*)	.4214	.2716	.3907	.3487	.3417	.2354	.5843	.2827	.3740	.4485
CCF	−.00591	−.00654	−.00591	−.00391	−.00391	−.00391	−.00654	−.00391	−.00391	−.00654

	Habitat class[3]		
	1	2	3
HAB	−0.0941	0.0	−0.2146

	Location class[4]		
	1	2	3
LOC	0.0	−0.0480	−0.2785

[1] Definition of variables:
  ASP = Stand aspect
  SL = Stand slope ratio (percent/100)
  SPP = Species dependent intercept
  HT = current tree height (feet)
  CCF = Stand crown competition factor
  HAB = Habitat dependent intercept
  LOC = Location dependent intercept
[2] Species codes are given in table 4. No data were available for mountain hemlock; coefficients for cedar (C) are used for mountain hemlock predictions.

[3] Definition of habitat classes:

Class	Codes included in class (see table 3)
1	530
2	550, 570, 610
3	all others

[4] Definition of location classes:

Class	National Forests included
1	Clearwater, Nezperce
2	St. Joe, Coeur d'Alene
3	all others

With two independent models to predict the same attribute, we were unable to find a suitable tree size for transition between models. Regardless of the diameter chosen as a switching point, a discontinuity in the response surface existed. This problem was resolved by using a simple switching function. For trees with *DBH* less than 2 inches (1 inch for lodgepole pine), the height increment prediction is based entirely on the small tree model; for trees with *DBH* greater than 10 inches (5 inches for lodgepole pine), the prediction is based entirely on the large tree model. If *DBH* is between 2 and 10 inches (1 and 5 inches for lodgepole pine), the large tree prediction (HTG_1) is given weight of *HWT*, and the small tree prediction (HTG_2) is given a weight of (1-*HWT*) where

$$HWT = \begin{cases} (DBH - 1)/4 & \text{for lodgepole pine} \\ (DBH - 2)/8 & \text{for all other species} \end{cases}$$

hence,

$$HTG = HWT \cdot HTG_1 + (1 - HWT) \cdot HTG_2 \cdot (10/5)$$

Because the small tree height increments can be measured with relative ease, we have included a calibration procedure for the small tree height increment model that is analogous to the procedure used in the large tree *DBH* increment model. The median residual between observed and predicted height increments is computed on the logarithmic scale and incorporated in the prediction equation as an additional intercept term.

Behavior

Examining the composite behavior of the model (fig. 32) reveals that the height increment curve increases rapidly to a maximum at 3 to 5 inches *DBH* and then gradually decreases, much in the fashion of the classical increment curve (Assman 1970). The effect of increasing density is to suppress height increment—directly through the *CCF* term in the small tree model, indirectly through the *DG* term in the large tree model (fig. 33).

In an undisturbed even-aged stand, the height and diameter increment models work together to produce increasingly flattened height-diameter curves over time (fig. 34).
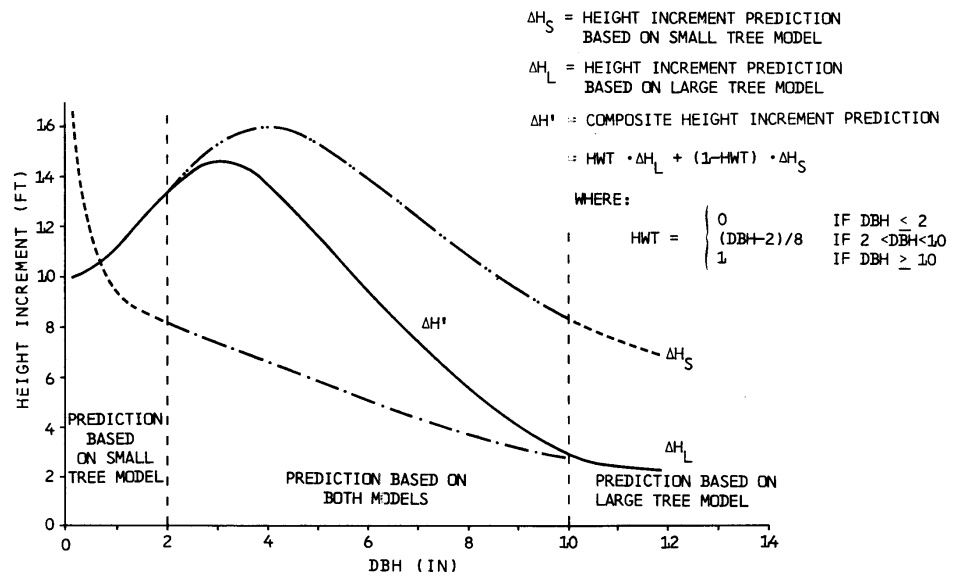
Figure 32.—Composite periodic height prediction based on two independent models; species is Douglas-fir.

TREE	TIME	DBH (IN)	HT (FT)
A	40	0.1	4.7
	160	11.8	74.0
D	0	0.1	4.7
	160	27.5	100.0
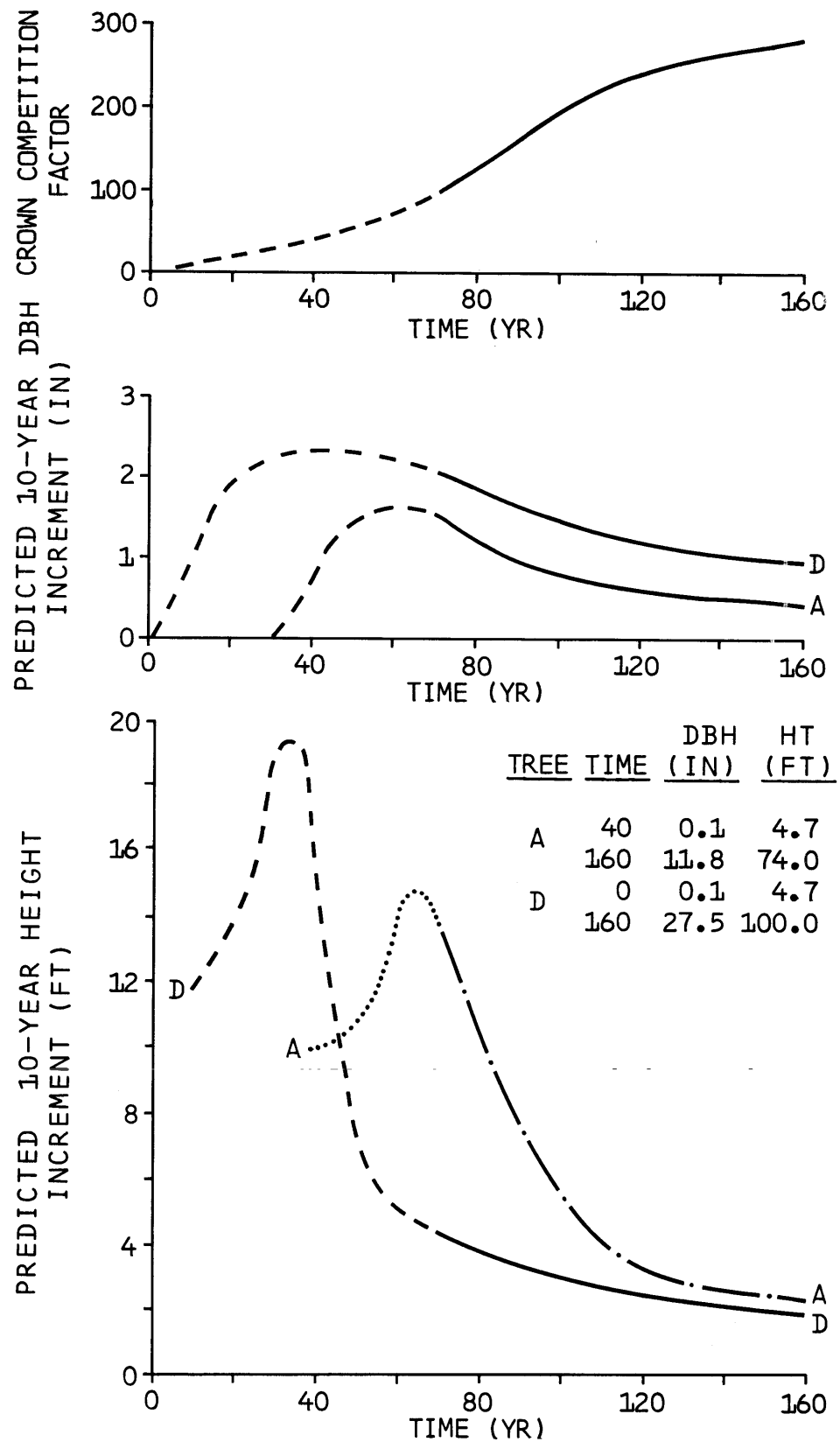
Figure 33.—Simulated increment predictions over time showing stand density and the corresponding height and diameter increments of a dominant (D) and an intermediate (A) Douglas-fir.
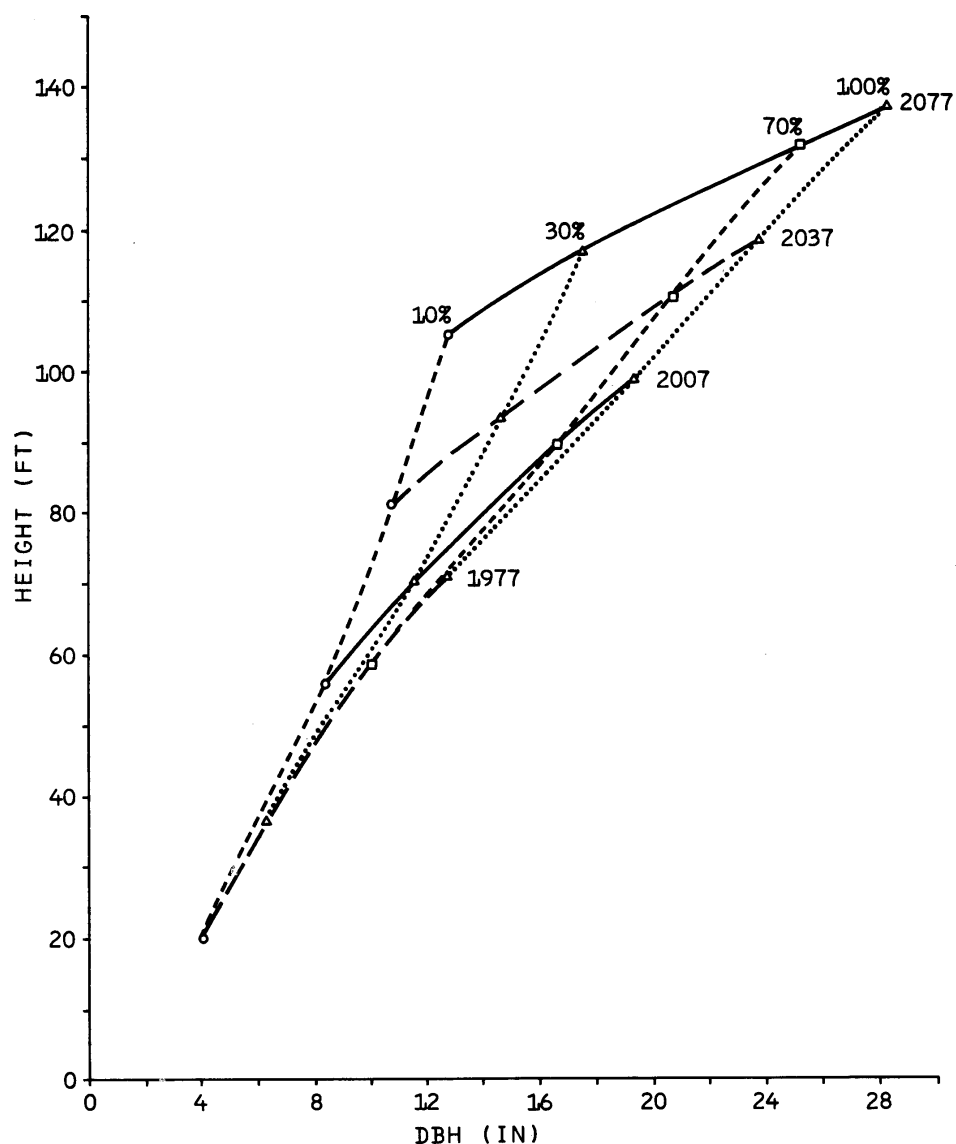
Figure 34.—Changes in the stand height-diameter over time;
species is Douglas-fir. Percentages indicate approximate percentile
points in the trees per acre distribution.

PREDICITNG MORTALITY RATES

The Prognosis Model mortality predictions are intended to reflect background or normal mortality rates. The predictions are dependent on species, *DBH*, quadratic mean stand diameter, habitat type, trees per acre, and stand basal area. Three models are involved in the prediction. They are related with an intricate set of weighting functions so that overall rate prediction is continuous with respect to all of the predictor variables.

The Diameter-Based Individual Tree Model

Hamilton and Edwards (1976) developed a method for predicting individual tree mortality rate as a function of tree *DBH*. This method was subsequently used to develop a species-specific mortality model that is applicable to forests in the Inland Empire. Parameter estimates were derived from analysis of the USDA Forest Service Region 1 timber management inventory along with data from a mortality survey that utilized

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large-scale aerial photography.[10] This diameter-based model (eq. 11) is the first step in our mortality rate calculation procedure.

$$R_d = \frac{1}{1 + e^{\left(b_0 + b_1 \cdot DBH + b_2 \cdot DBH^2\right)}}$$
(11)

where:

R_d = diameter-based individual tree annual mortality rate,
and b_1, b_2, and b_3 = species-specific coefficients (table 16).

Table 16.—Coefficients for the diameter-based mortality rate equation used in the Prognosis Model (see equation 11)

Species	b_0	b_1	b_2
Western white pine	5.45676	−0.01182	0.0
Western larch	5.26043	−.00971	.0
Douglas-fir	5.55086	−.01291	.0
Grand fir	5.16774	−.00777	.0
Western hemlock	4.28773	.0	.0
Western redcedar	6.06747	−0.0865	.0
Lodgepole pine[1]	3.87794	.30780	−.01740
Engelmann spruce	6.41265	−.01273	.0
Subalpine fir	5.88697	−.03338	.0
Ponderosa pine	5.58766	−.00525	.0
Mountain hemlock	7.47709	−.03952	.0

[1] The coefficients for lodgepole pine are based on Lee's (1971) model for predicting average stand mortality rate as a function of mean stand *DBH*.

For many conditions, the diameter-based model yields acceptable results. The usual predictions of 0.3 to 0.7 percent mortality per year are within the range of expectations.

The diameter-based model, however, is insensitive to stand density. In situations where we would expect accelerated mortality due to suppression and competition, the diameterbased rates are too low. When stands are well- or overstocked, and mortality rates are predicted only with the diameter-based model, projected volume and basal area estimates substantially exceed normal yield table estimates. As a consequence, we developed two theoretical models to represent the effects of density on individual tree mortality rates. These models predict mortality rates that reflect approach to normality and approach to maximum basal area.

Approach to Normality

The first density-dependent model is based on the concept of approach to normality. It was developed using data from the yield tables for second-growth stands in the western white pine type (Haig 1932).

Normal stocking density in trees per acre (T,) is computed from quadratic mean stand *DBH (QMD):*

$$T_n = 25000 \cdot \left[QMD - (-1) \right]^{-1.5881}$$
(12)

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[10] Hamilton, D.A., Jr. 1981. Personal communication. Data and analysis on file at the Intermountain Forest and Range Experiment Station's Moscow Forestry Sciences Laboratory, Idaho.

Equation 12 is a hyperbola with a vertical asymptote at QMD equal to (-1). It is a restatement of the guide curve for the THINAUTO option (eq. 4 and fig. 5).

When current quadratic mean stand DBH and periodic change in quadratic mean stand DBH (G_p) are known, the normal stocking model can be used to estimate a normal periodic mortality rate (r_p):

$$r_p = \frac{T_{n0} - T_{n1}}{T_{n0}}$$

where:

T_{n0} = normal stocking estimate based on current quadratic mean stand DBH
$= 25000 \; \exists \; (QMD + 1)^{-1.5881}$

and T_{n1} = normal stocking estimate based on current quadratic mean stand DBH at the end of the period
$= 25000 \; \exists \; [(QMD + G_p) + 1]^{-1.5881}$

Applying this rate in a stand that was not normally stocked would not, however, cause stand density to approach normality.

To effect an approach to normality, we translate the guide curve (eq. 12) such that it passes through the point (QMD, S_0) where S_0 represents current stocking density in stems per acre. The equation is translated by adding a quantity Δ to the vertical asymptote,

$$S_0 = 25000 \; \exists \; [QMD - (\Delta - 1)]^{-1.5881}$$

such that Δ is the difference between QMD and the diameter (D_n) that is associated with the value S_0 on the normal stocking curve (fig. 35).

$$D_n = e^{\left[\frac{\ln(25000) - \ln(S_0)}{1.5881} \right]} - 1$$
$$\text{and} \;\; \Delta = QMD - D_n$$

With this modified equation and an estimate of 10-year change in QMD (G_{10}), we predict the number of stems per acre 10 years hence (S_{10})

$$S_{10} = 25000 \; \exists \; [(QMD + G_{10}) - (\Delta - 1)]^{-1.5881}$$

Then,

$$R_n = 1 - \left[1 - \frac{(S_0 - S_{10})}{S_0} \right]^{0.1}$$

where R_n is the estimated annual mortality rate based on approach to normality. When R_n is less than R_d, it is set equal to R_d.
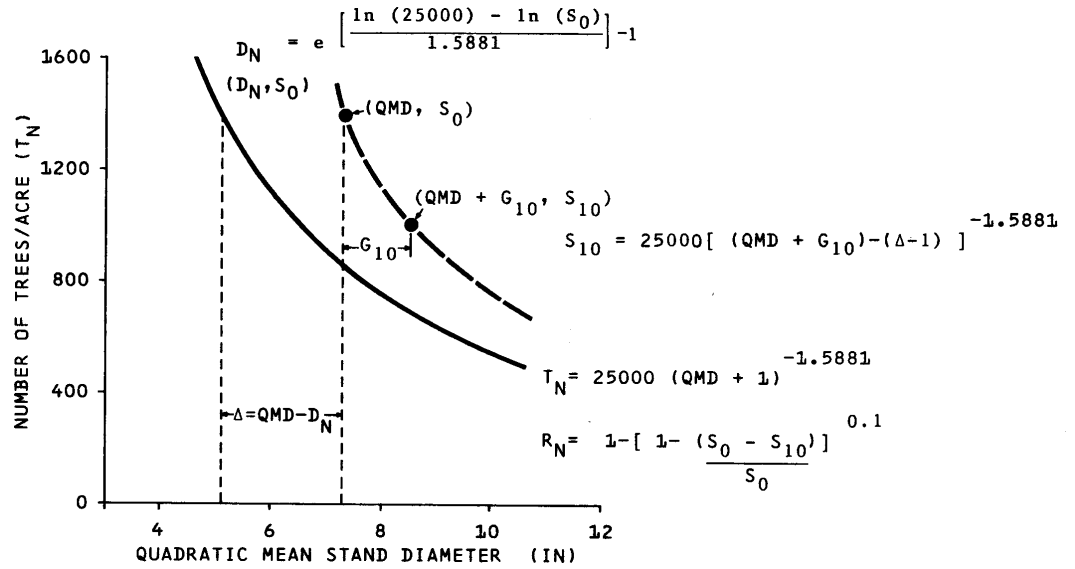
$$D_N = e^{\left[\frac{\ln(25000) - \ln(S_0)}{1.5881}\right]} - 1$$

$$S_{10} = 25000[(QMD + G_{10}) - (\Delta - 1)]^{-1.5881}$$

$$T_N = 25000(QMD + 1)^{-1.5881}$$

$$R_N = 1 - \left[1 - \frac{(S_0 - S_{10})}{S_0}\right]^{0.1}$$

Figure 35.—Calculation of the annual "approach to normality" mortality rate (R_N). Inputs to the model are current stand quadratic mean *DBH* (*QMD*), current number of stems per acre (S_0), and an estimate of the 10-year change in *QMD* (G_{10}). The curve T_N represents normal stocking. By shifting the vertical asymptote an amount Δ, the curve is translated such that it passes through the point (*QMD*, S_0) The modified equation is solved for number of stems per acre 10 years hence (S_{10}). The values of S_0 and S_{10} are then used to compute R_N.

Approach to Maximum Basal Area

The second density-dependent mortality rate estimate is based on the assumption that there is a maximum basal area that a site can sustain and that this maximum varies by site quality. Data from the Region 1 timber management inventory and summaries from Pfister and others (1977) were used to define maximum attainable basal area (*BAMAX*) by habitat type (table 17). The rate estimate is designed to absorb an increasing proportion of gross stand basal area increment (*BAI*) as *BA* approaches *BAMAX*. If *BA* is exactly equal to *BAMAX*, the rate estimate will be such that *BAI* is equal to zero. As with the approach to normality procedure, estimation of the number of stems per acre 10 years hence (SB_{10}) is an intermediate step in the rate calculation.

$$SB_{10} = \frac{BA + \left(1 - \frac{BA}{BAMAX}\right) \cdot BAI}{TB_{10}}$$

where

TB_{10} = average basal area per tree 10 years hence
$= 0.005454154 \cdot (QMD + G_{10})^2$

Then,

$$R_b = 1 - \left\{1 - \left[\frac{(S_0 - SB_{10})}{S_0}\right]\right\}^{0.1}$$

where

R_b = the annual approach to maximum basal area mortality rate.

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Table 17.—Values used for BAMAX in the Inland Empire version of the Prognosis Model.

Habitat code	BAMAX	Habitat code	BAMAX
	Ft²/acre		Ft²/acre
130	140	550	500
170	220	570	390
250	250	610	390
260	310	620	440
280	240	640	180
290	270	660	290
310	310	670	400
320	310	680	350
330	200	690	390
420	310	710	260
470	290	730	220
510	330	830	220
520	380	850	160
530	440	999	300

At this point, we make an adjustment to reflect the increased probability of death that is normally associated with advanced age. In an even-aged stand, the larger trees are normally the more vigorous trees and would be expected to have a greater chance of survival than trees in a competitively less advantageous position. Stands in the Inland Empire, however, are predominantly composed of multiple age classes, and in sawtimber stands, the largest trees are approaching overmaturity. Our adjustment has no effect when *QMD* is less than 10 inches or when the *DBH* of the subject tree is less than *QMD*. When *DBH's* are in the range normally associated with managed stands, the effect of the adjustment is limited. For example, when *QMD* is equal 15 inches, the mortality rate for a tree with *DBH* equal to 30 inches is approximately 1.06 times the rate for a tree with *DBH* less than or equal to *QMD*. When *QMD* is equal to 30 inches, however, a situation that would normally indicate an old stand, the mortality rate for a tree with *DBH* equal to 60 inches would be twice the rate for a tree with *DBH* less than or equal to *QMD*. The adjustment is a multiplier (*COSMIC*) that is applied to the rate R_b

$$R_{bc} = COSMIC \; \exists \; R_b$$

where

$$COSMIC = \frac{1 + \frac{Z \cdot DBH}{QMD}}{1 + Z}$$

$$Z = \begin{cases} 0 & \text{when } (QMD \le 10) \text{ or } (DBH \le QMD) \\ \dfrac{(QMD - 10)^2}{400} & \text{when } (QMD > 10) \text{ and } (DBH > QMD) \end{cases}$$

and R_{bc} = the adjusted approach to maximum basal area mortality rate.

**Combining the Mortality
Rate Estimates**

The weight given to each rate estimate in the development of a combined annual mortality rate estimate for a tree (R_t) depends on stand basal area and tree *DBH*. When stand basal area is greater than *BAMAX*, the rates R_d and R_n are ignored and R_{bc} is inflated by the ratio of *BA* to *BAMAX*:

$$R_t = R_{bc} \cdot \left(\frac{BA}{BAMAX} \right)$$

for (BA μ $BAMAX$).

When stand basal area is less than *BAMAX* but tree *DBH* is greater than or equal to 10 inches, the approach to normality rate (R_n) is ignored and the combined rate is computed as follows:

$$R_t = R_{bc} \cdot \frac{BA}{BAMAX} + R_d \cdot \left(1 - \frac{BA}{BAMAX} \right)$$

for ($BA < BAMAX$) and (DBH μ 10).

When the tree *DBH* is less than *BAMAX*, all three rate estimates are used to predict R_t:

$$R_t = R_{bc} \cdot \frac{BA}{BAMAX} + \left(1 - \frac{BA}{BAMAX} \right) \left[R_d \cdot \frac{DBH}{10} + R_n \cdot \left(1 - \frac{DBH}{10} \right) \right]$$

for ($BA < BAMAX$) and ($DBH < 10$).

Finally, the annual rate prediction is converted to a survival rate and compounded to estimate periodic rate (R_p) for a *p*-year period

$$R_p = 1 - (1 - R_t)^p$$

Model Behavior

When there are a relatively large number of small trees in the stand, the predicted mortality rates for small trees are relatively high. The mortality rates predicted for large trees are unaffected by the number of trees in the stand. As stand basal area increases, however, mortality rates for all trees increase (fig. 36).

On the stand level, the effect of increasing density on mortality rates can be observed by comparing accretion and net total cubic foot volume increment (fig. 37). With all other factors held constant (including time), accretion continues to increase, even at very high levels of stand basal area. As stand basal area approaches *BAMAX,* however, net volume increment rapidly approaches zero.
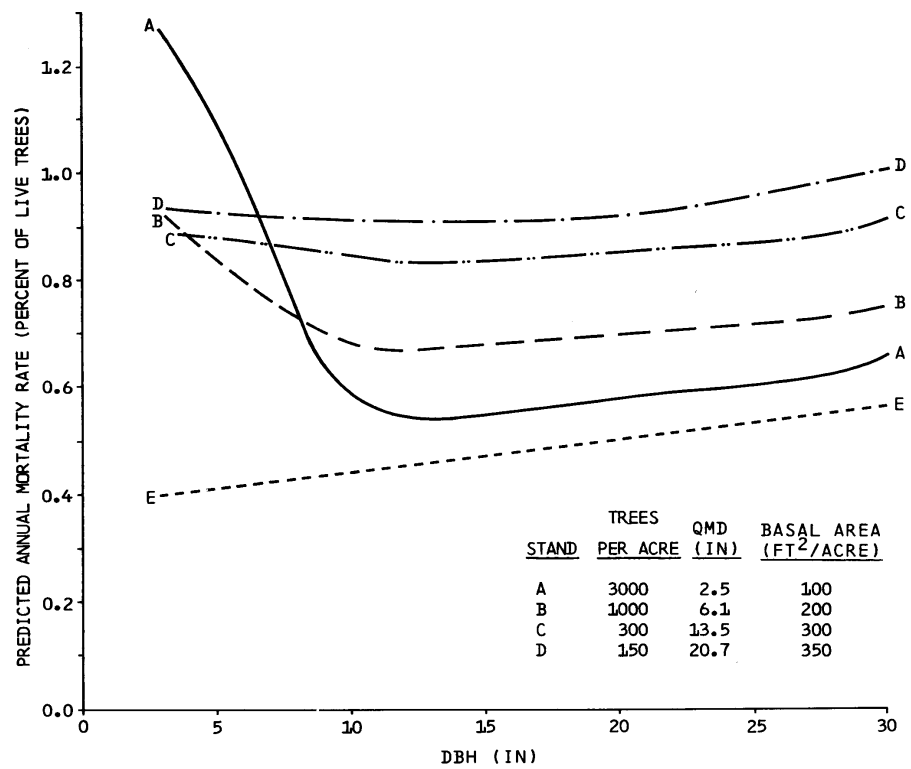
Figure 36.—Individual tree mortality rates for trees of different *DBH*. Curves A, B, C, and D reflect different assumptions about stand density. Curve E is the rate predicted on the basis of *DBH* alone (equation 11).
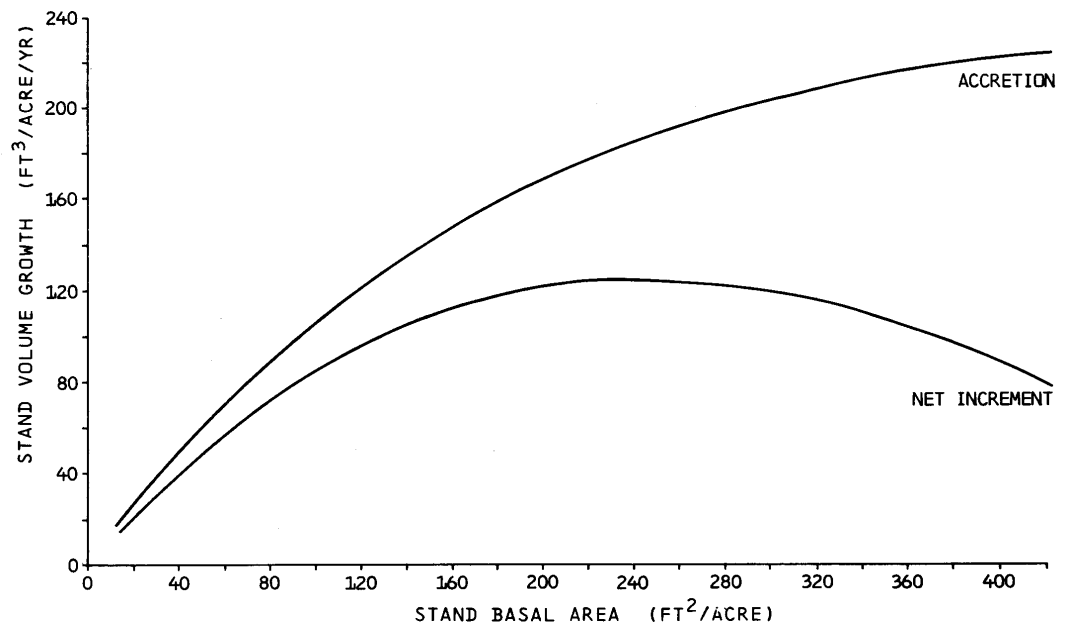
STAND	TREES PER ACRE	QMD (IN)	BASAL AREA (FT^2/ACRE)
A	3000	2.5	100
B	1000	6.1	200
C	300	13.5	300
D	150	20.7	350

Figure 37.—The effect of stand density on stand growth rates, all other factors held constant.

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CHANGE IN CROWN RATIO

Formulation

The ratio of live crown length to total tree height is a good indicator of tree vigor. As such, it is an important predictor of periodic increment even though it has substantial shortcomings.

Crown ratio changes slowly with time, but it does change. However, very limited data describing the rate of change are available. The dearth of data can be attributed in part to the difficulty of objective crown ratio measurement. Limbs are not systematically distributed on the bole, and it is difficult to pinpoint a base of live crown that is physiologically meaningful. As a result, crown ratio measurements and predictions are subjective, imprecise, and prone to error. Nevertheless, we feel that the utility of crown ratio as a predictor substantially outweighs the difficulties associated with its measurement.

The model used to predict change in crown ratio was developed by Hatch (1980). The model predicts crown ratio as a function of species, habitat type, stand basal area (BA), crown competition factor (CCF), tree DBH, tree height (HT), and the tree's percentile in the stand basal area distribution (PCT):

$$
\begin{aligned}
\ln(CR) = {} & HAB + b_1 \cdot BA + b_2 \cdot BA^2 + b_3 \cdot \ln(BA) + b_4 \cdot CCF + b_5 \cdot CCF^2 \\
& + b_6 \cdot \ln(CCF) + b_7 \cdot DBH + b_8 \cdot DBH^2 + b_9 \cdot \ln(DBH) \\
& + b_{10} \cdot HT + b_{11} \cdot HT^2 + b_{12} \cdot \ln(HT) + b_{13} \cdot PCT \\
& + b_{14} \cdot \ln(PCT) \qquad\qquad\qquad\qquad\qquad\qquad\qquad (13)
\end{aligned}
$$

where:

HAB = intercept term that depends on species and habitat type (tables 18 and 19)

b_1 through b_{14} = species dependent regression coefficients (table 18).

Table 18.—Coefficients for the crown ratio equation (see eq. 13)

Variable[1]	Class	WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
						Species[2]						
Habitat Class Intercepts[3]	1	0.8884	0.06533	0.8643	−0.2304	−0.2413	−1.6053	−0.3785	0.05351	0.09453	−0.9436	0.4649
	2	.7309	.03441	.7271	−.5421		−1.7128	−.4142	−.05031	−.07740	−.8654	.3211
	3	.9347	.2307	.9840	−.4343			−.3984	.1075	.07113	−.8849	.1970
	4	.9888	.1661	.8127	−.3759			−.2987	−.1872	.2039	−.9067	.2295
	5	.9945	−.1253	.8874	−.4129			−.3810	.01729	.06176	−.8783	.3383
	6	1.1126	−.05018	.7055	−.4879			−.4087	.03667	.1513	−1.0103	.3450
	7	1.0263	.1100	.7708	−.2674			−.3577	.01885	.09086	−1.0268	
	8		.08113	.7849	−.1941			−.2994	.09102	.1580	−1.0050	
	9		.1782	.8038				−.2486	.1371	.09229	−1.0301	
	10		.03919	.8742				−.2863	.08368	.01551		
	11		.2107	.8232				−.1968	.1230			
	12			.8415				−.4931	−.02365			
	13			.9759				−.2675				
	14							−.5625				
BA		.0	−.00204	.0	−0.00183	.0	.0	.0	−.00203	−.00190	−.00216	−.00264
BA^2(x10⁻⁶)		.0	.0	.0	.0	−1.902	.0	.0	.0	.0	.0	.0
$\ln(BA)$		−.34566	.0	.0	.0	.0	.17479	.0	.0	.0	.0	.0
CCF		.0	.0	.0	.0	.0	−.00183	.0	.0	.0	.0	.0
CCF^2(x10⁻⁶)		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.12
$\ln(CCF)$		.0	.0	−.15334	.0	.0	.0	−.18555	.0	.0	.0	.0
DBH		.03882	.0	.0	.0	.03027	−.00560	.0	.0	.0	.0	.0
DBH^2		−.00070	.0	.0	.0	−.00055	.0	.0	.0	.0	.0	.0
$\ln(DBH)$		.0	.30066	.33840	.24293	.0	.0	.53172	.29699	.23372	.26558	.0
HT		.0	.0	.0	.0	.0	.0	−.02989	.0	.0	.0	.0
HT^2		.0	.0	.0	.0	.0	.0	.00011	.0	.0	.0	.0
$\ln(HT)$		−.21217	−.59302	−.59685	−.25601	−.25776	.0	.0	−.38334	−.28433	−.31555	−.25138
PCT		.00301	.0	.0	.0	.0	.0	.00420	.0	.00190	.0	.0
$\ln(PCT)$		.0	.19558	.16488	.07260	.06887	.11050	.0	.09918	.0	.16072	.05140

[1] Definition of variables:

    BA = Stand basal area (square feet per acre)

    CCF = Stand crown competition factor

    DBH = Current diameter at breast height (inches)

    HT = Current height (feet)

    PCT = Current percentile in the stand basal area distribution

[2] Species codes are given in table 4.

[3] Habitat types are mapped onto habitat classes as shown in table 19.

Table 19.—Map of habitat types onto habitat classes by species for the crown ratio model (see eq. 13)

Habitat	WP	L	DF	GF	WH	C	LP	S	AF	PP	MH
						Species[1]					
130	2	2	2	2	1	1	2	2	2	2	1
170	2	2	2	2	1	1	2	2	2	2	1
250	2	2	2	2	1	1	2	2	2	4	1
260	2	2	4	2	1	1	2	2	2	1	1
280	2	2	4	2	1	1	2	2	2	1	1
290	2	2	4	2	1	1	2	2	2	1	1
310	2	2	6	2	1	1	4	2	2	5	1
320	2	3	7	2	1	1	5	3	2	6	1
330	2	2	4	2	1	1	5	2	2	1	1
420	2	4	8	1	1	1	2	1	2	1	1
470	2	4	8	1	1	1	2	1	2	1	1
510	2	5	5	2	1	1	6	2	2	8	1
520	3	6	9	3	1	1	7	4	2	7	2
530	4	7	10	4	1	1	8	5	3	9	2
540	4	7	10	4	1	1	8	5	4	9	2
550	4	7	10	4	1	1	8	5	4	9	2
570	5	8	11	5	1	2	9	6	4	3	3
610	5	8	11	5	1	2	9	6	4	3	3
620	5	4	8	6	1	2	10	7	5	3	4
640	6	1	1	1	1	1	11	8	6	1	1
660	6	10	12	7	1	1	11	8	6	1	1
670	1	9	12	7	1	1	12	9	7	1	1
680	6	10	13	7	1	1	11	8	6	1	5
690	1	1	1	1	1	1	1	10	1	1	1
710	7	11	3	8	1	1	13	11	8	1	6
720	1	1	1	1	1	1	1	1	1	1	1
730	6	1	3	7	1	1	14	1	9	1	1
830	6	1	1	1	1	1	3	12	10	1	1
850	6	1	1	1	1	1	3	12	10	1	1
999[3]	6	2	1	1	1	1	11	8	6	1	1

[1] Species codes are given in table 4.

    To estimate change in crown ratio, we predict crown ratio based on stand and tree attributes at the beginning and at the end of a cycle. We then subtract the first prediction from the second to obtain a difference. This difference is added to the actual crown ratio to effect the change.

    There are some additional operational constraints on this crown model. Theoretically, crowns should just touch when *CCF* is equal to 100. Below this threshold, we assume that the effect of density will be negligible. When *CCF* is less than 100, predictions made at the end of the cycle use the same *CCF* and *BA* values that were used to make predictions at the start of the cycle. We also assume that thinning will encourage crown development. However, when the stand is thinned from below, *PCT* is reduced for the residual trees, with the result that predicted crowns are smaller. To avoid this anomaly, when the stand is thinned we use the same *PCT* values when making predictions at both the start and the end of the cycle.

Behavior

    For most species, crown ratio decreases as the tree gets larger. A dominant tree (as measured by *PCT*) tends to have a larger crown than a similar-sized tree in a subordinate crown position (assuming the two trees are in different stands). The effect of increasing stand density is to reduce crown ratio. However, as trees become large, the predicted changes in crown ratio become very small (fig. 38).
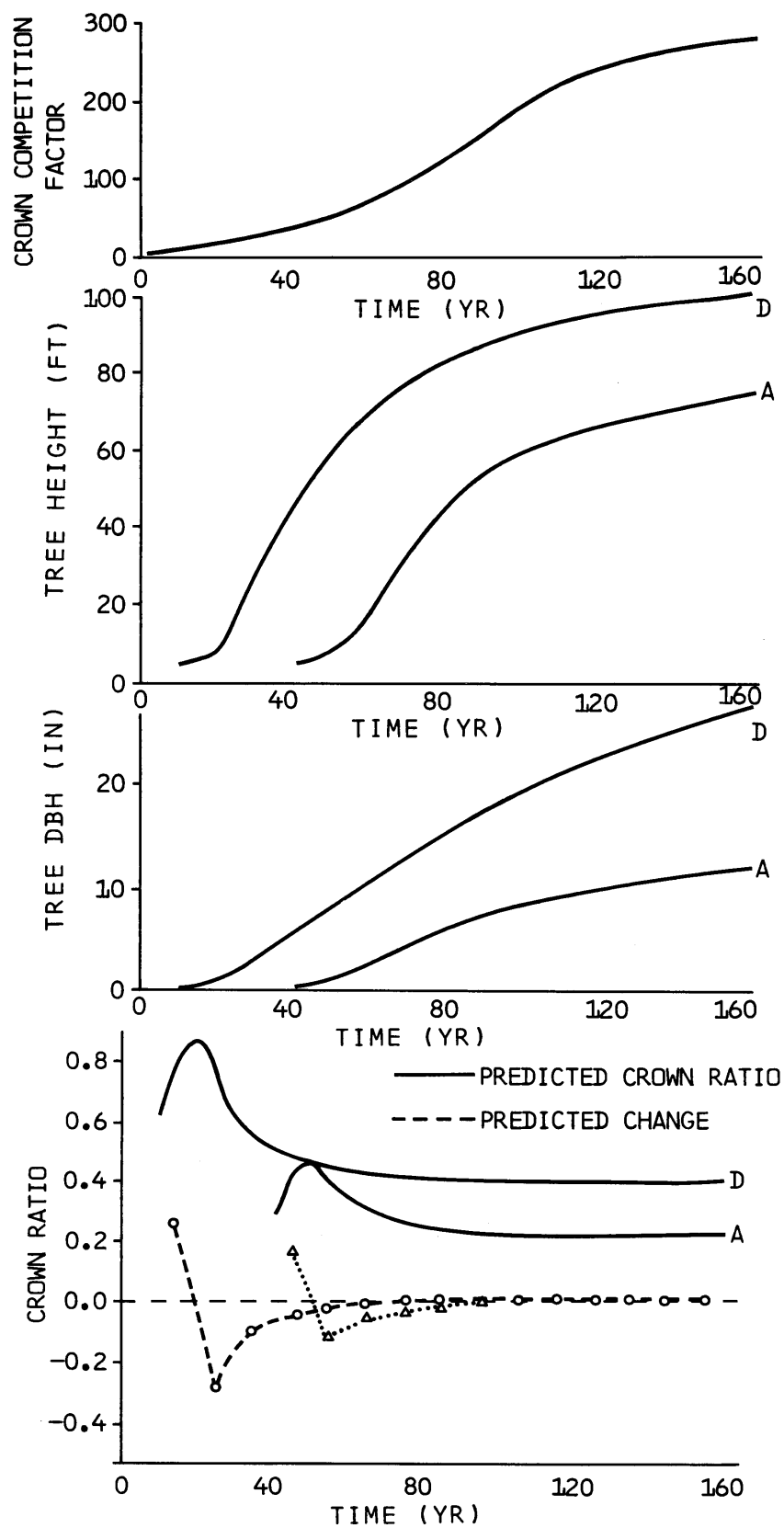
Figure 38.—Increase in stand density, height, and *DBH* over time. The trees shown are in dominant (D) and intermediate (A) crown positions. The lower graph shows how crown ratio changes relative to the other variables.

VOLUME CALCULATIONS

Individual tree volumes are computed to three merchantability standards. Calculations for total cubic foot volume (V_t) and Scribner board foot volume (V_b) are based on formulae involving transformations of total height (*HT*) and diameter breast height *(DBH).* An additional cubic foot volume estimate is derived from the total cubic foot estimate by using a Behre hyperbola to approximate tree form (Monserud 1980).

Total Cubic Volume

All of the total cubic foot volume equations, except for the equation for lodgepole pine, are of the general form:

$$V_t = b_0 + b_1(DBH)^2 \cdot HT + b_2 \cdot DBH \cdot HT \qquad (14)$$

The lodgepole pine equation is of the form:

$$V_t = b_0(DBH)^{b_1} \cdot (HT)^{b_2} \qquad (15)$$

where:

b_0, b_1, and b_2 = species-dependent regression coefficients (table 20).

The lodgepole pine equation was developed by Brickell,[11] and the ponderosa pine equations were developed by Myers (1964). The equations for all other species are from Stage (1966).

Table 20.—Coefficients for the total cubic foot volume equations; volume is computed from diameter breast height and total height (see eq. 14 and 15)

Species	Equation number	Coefficients		
		b_0	b_1	b_2
Western white pine	14	0.0	0.00233	0.0
Western larch	14	.0	.00184	.0
Douglas-fir	14	.0	.00171	.00386
Grand fir	14	.0	.00234	.0
Western hemlock	14	.0	.00219	.0
Western redcedar	14	.0	.00205	.0
Lodgepole pine	15	.00278	1.09410	1.04880
Engelmann spruce[1]	14	.0	.00171	.00386
Subalpine fir[1]	14	.0	.00171	.00386
Ponderosa pine:				
$(DBH)^2 \ni HT$ [6000	14	.03029	.00221	.0
$(DBH)^2 \ni HT >$ 6000	14	−1.55710	.00247	.0
Mountain hemlock[2]	14	.0	.00219	.0

[1] The equation for Douglas-fir is used to predict volumes for subalpine fir and Engelmann spruce.
[2] The equation for western hemlock is used to predict volumes for mountain hemlock.

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[11] Brickell, J.E. 1966. Personal communication, unpublished analysis on file with Leader, Quantitative Analysis of Forest Management Practices and Resources for Planning and Control Research Work Unit (INT-1302), USDA Forest Service, Intermountain Forest and Range Experiment Station, Moscow, Idaho.

Board Foot Volume

The board foot volume equations compute Scribner board foot volume to an 8-inch top assuming a 9-inch minimum *DBH* and a 1-foot stump. The equations were developed by Kemp[12] and are of the form:

$$V_b = b_0 + b_1 (DBH)^2 \cdot HT \qquad (16)$$

where:

b_0 and b_1 = regression coefficients that are dependent on species and *DBH* (table 21).

Other Merchantability Standards

The Prognosis Model computes cubic foot volume to an additional merchantability standard. The minimum *DBH,* top diameter, and stump height for this standard can be controlled by using the VOLUME keyword (see discussion in the section titled STAND MANAGEMENT OPTIONS). The default merchantability limits are:

Stump height	= 1 ft
Top diameter	= 4.5 inches
Minimum *DBH*	= 6.0 inches for lodgepole pine
	= 7.0 inches for all other species

Table 21.—Coefficients for the board foot volume equation (Scribner board foot to an 8-inch top); volume is predicted from diameter breast height and total height (see eq. 16)

	Coefficients				
	9.0 < DBH [20.5 in			*DBH* > 20.5 in	
Species	b_0	b_1		b_0	b_1
Western white pine	26.729	0.01189		32.516	0.01181
Western larch	29.790	.00997		85.150	.00841
Douglas-fir	25.332	.01003		9.522	.01011
Grand fir	34.127	.01293		10.603	.01218
Western hemlock	37.314	.01203		50.680	.01306
Western redcedar	10.742	.00878		4.064	.00799
Lodgepole pine	8.059	.01208		14.111	.01103
Engelmann spruce	11.851	.01149		1.620	.01158
Subalpine fir	11.403	.01011		124.425	.00694
Ponderosa pine	50.340	.01201		298.784	.01595
Mountain hemlock	37.314	.01203		50.680	.01306

Merchantable volumes are calculated by using the Behre hyperbola (Behre 1927) to approximate stem form. This function has a closed form integral that can be solved readily for variable limits of integration (Monserud 1980).

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[12] Kemp, P.D. 1956. Region 1 volume tables for cruise computations, USDA Forest Service, Northern Region Handbook R1-2430-31, Missoula, Mont.

Predicted Values

Regardless of the merchantability standards, volume is approximately proportional to DBH cubed. However, because periodic DBH and height increments decrease over time, the relationship between volume and time is more or less linear (fig. 39). As expected, the absolute difference between merchantable and total cubic foot volume increases with time. The relative difference decreases with time, however, and for large trees, differences are trivial (fig. 40).
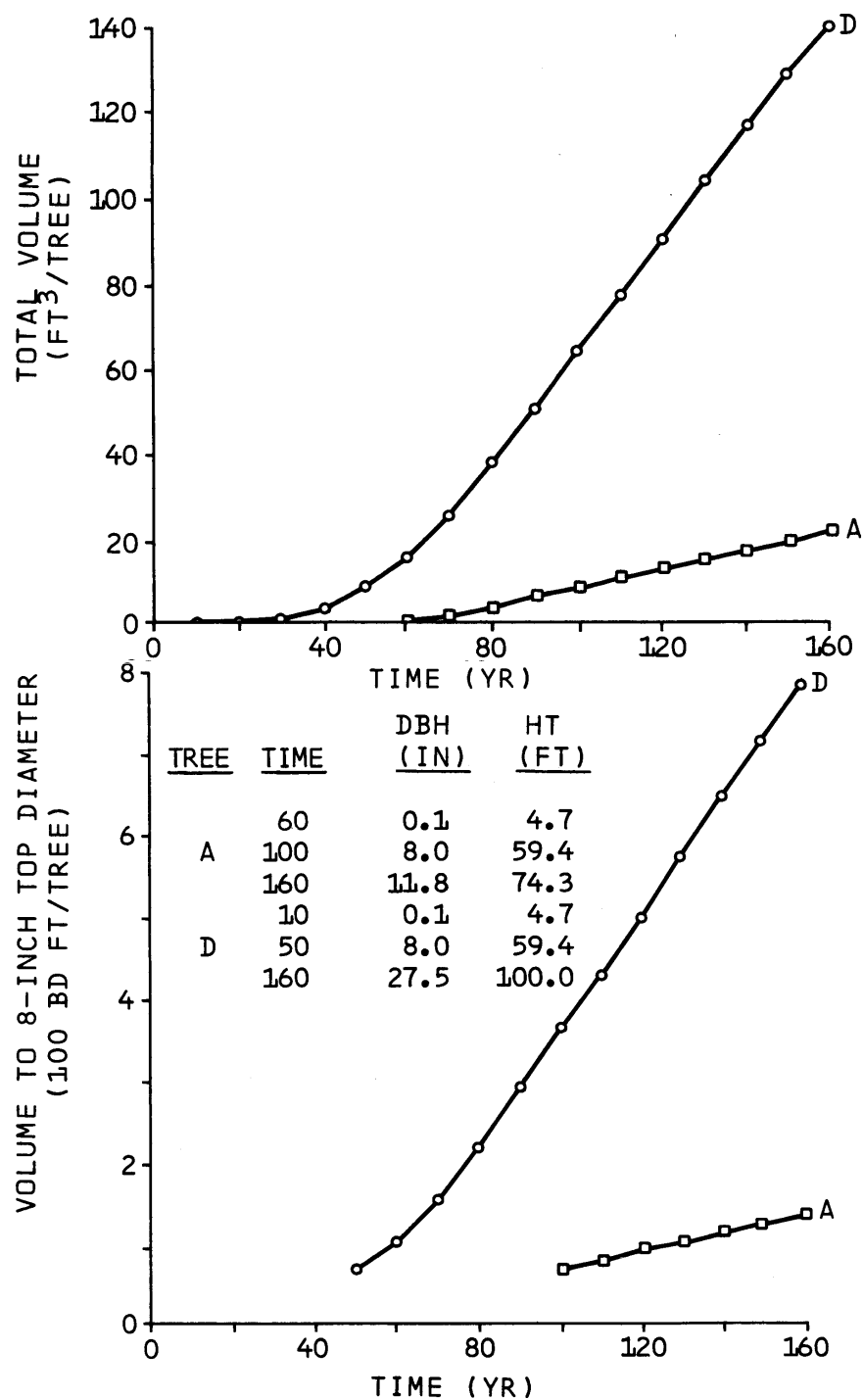

TREE	TIME	DBH (IN)	HT (FT)
	60	0.1	4.7
A	100	8.0	59.4
	160	11.8	74.3
	10	0.1	4.7
D	50	8.0	59.4
	160	27.5	100.0

Figure 39.—Scribner bd. ft. and total cubic foot volume predictions for dominant (D) and intermediate (A) Douglas-fir as simulated through time.

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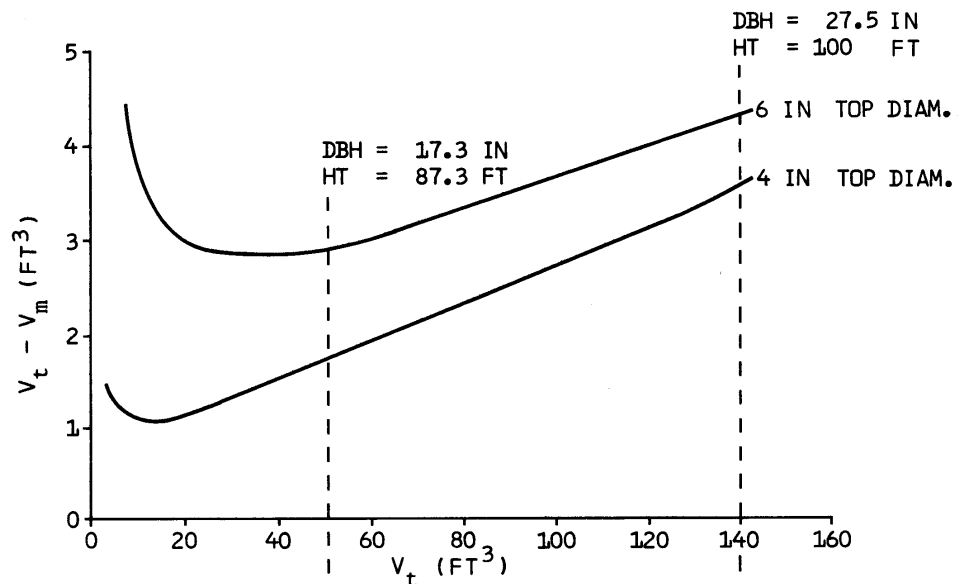
Figure 40.—Difference between predicted total cubic foot volume (V_t) and cubic foot volume to two top diameters (V_m) over time. One-foot stump height assumed; species is Douglas-fir.

USING THE PROGNOSIS MODEL AS A COMPONENT OF A PLANNING SYSTEM

So far, we have described "using the Prognosis Model" from the viewpoint of interacting with a computer. We have discussed how to prepare input and how to interpret output, and we have tried to give some insight as to how input is converted to output. All the while, we have adroitly sidestepped consideration of why you might want to use the model.

The Prognosis Model was designed to be a component in a forest management planning system. In this regard there are two levels of application: planning for individual stands and planning for large ownerships that are comprised of many stands. In the first case, we prescribe a specific silvicultural treatment, and we want to evaluate how the treatment influences the development of the stand. In the second case, we establish a broad management policy and we want to evaluate how that policy influences the yield from the ownership over time. The Prognosis Model is adapted to both of these applications.

Resource Allocation and Harvest Scheduling

The Prognosis Model will represent a wide range of stand management activities. The influence of these activities on timber production is explicitly represented and linkages are provided for evaluating pest impacts and estimating interactions with output from other resources. As a result, the Prognosis Model is ideally suited for the preparation of yield tables to be used with algorithms that optimize the allocation of resources.

INVENTORY CONSIDERATIONS

The application of the Prognosis Model to forest planning is enhanced by an inventory system that is based on clusters of sampled stands (Stage and Alley 1972). Future yields are estimated for each sample stand **prior to** aggregation into classes. It is not necessary that all stands within a class produce yields or be scheduled for treatment at the same time. Therefore, errors of aggregation are avoided in the specifications of appropriate stand prescriptions and in the calculation of yields when the prescriptions are invoked. If the conditions

and proposed prescriptions for adjacent stands are considered in the preparation of prescriptions, then the clustering of sample stands will provide the basis for better representation of interactions among stands. This combination of inventory and yield calculation was used in the preparation of a harvest schedule for the Bitterroot National Forest (Stage and others 1980).

Not all existing inventories are designed around examinations of stands. Single plots or plot-clusters widely dispersed over an ownership have been a mainstay of forest inventory design for many years. It is feasible to use this model to compile and project data for a forest inventoried with such designs. In these cases, the concept of "stand" is extended to include aggregates of plots that are as nearly alike with respect to habitat type, slope, aspect, elevation, and tree size classes as is possible. A minor difficulty may arise if the number of tree records in the aggregate exceeds the dimensions of the tree-list arrays in the model. In that case, the classes should be defined more narrowly, or arbitrarily split prior to projection. Re-aggregation after projection is always possible. Moeur and Ek (1981) have shown that errors of aggregation across plots and stands may not be great if no management is simulated.

The aggregation errors may not be serious if all plots in an aggregate receive the same prescription for management at the same times. Unfortunately, a scattered plot design does not permit one to determine whether treatments prescribed for a small plot or plot-cluster will be applicable for an operational tract.

PEST IMPACTS

The use of the Prognosis Model for forest planning is further enhanced by linkage to models that predict the interaction between specific pests and stand and tree development. Currently, there are three Prognosis Model extensions that are designed to simulate pest outbreaks and resultant stand damage:

DFTM—a Douglas-fir tussock moth population dynamics model (Brookes and others 1978);

MPB—a mountain pine beetle population dynamics model (Crookston and others 1978); and,

WSBW—a western spruce budworm population dynamics model (McNamee and others 1980, Colbert and others 1981).

These models are represented by substantial computer programs that must be linked to the Prognosis Model. In a projection, they interact dynamically with the Prognosis Model tree list. Each extension requires special input to describe certain model parameters and management options. This input is controlled with a keyword language that is identical in structure to the system described in this manual. The special input is inserted in the projection run stream, in a contiguous packet of keyword records that begins with the appropriate acronym (DFTM, MPB, or WSBW) and ends with the END record. The options available, and the keywords used to invoke them, are (or will be) described in separate manuals (Monserud and Crookston 1982; Burnell and Crookston[13,14]).

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[13] Burnell, D.G. and N.L. Crookston. 1980. Computing algorithms used in the mountain pine beetle model: an extension to the stand prognosis system. Review draft on file with Leader, Quantitative Analysis of Forest Management Practices and Resources for Planning and Control Research Work Unit, Intermountain Forest and Range Experiment Station, Moscow, Idaho.
[14] At this writing the WSBW model is still under development and preparation of a user's manual has not begun.

MULTIRESOURCE ALLOCATION PROBLEMS

Timber management policy and resulting timber yields have a great deal of influence on the yields of other resources from the forest. Models that predict various resource yields should interact dynamically. An example of this type of application is the Gospel-Hump multipurpose resource development plan that is currently in preparation.[15] This plan is being developed using models that predict water yields, water quality, resident and anadromous fish populations, and elk and moose populations. These models are linked to timber production through two Prognosis Model extensions that predict shrub cover and browse availability (Irwin and Peek 1979) and tree canopy coverage (Moeur 1981). These extensions, SHRUB and COVER, are invoked in a manner analogous to the use of the pest impact extensions described in the previous section. The parameters and options associated with these extensions are documented elsewhere (Moeur and Scharosch[16]).

Stand Prescription

In large-scale planning applications, policies are established to direct stocking control and harvest activities, and scheduling is dependent on stand development over time. The THINAUTO and SPECPREF options represent opportunities for dynamic implementation of policy without user intervention. In contrast, on the level of the individual stand, we are frequently concerned about specific trees and their environment. In this context, we are usually more familiar with stand structure. The Prognosis Model can be used to evaluate trial markings or other thinning options that are tailored to alter the structure of a specific stand.

When the Prognosis Model is used in this mode, its limitations must be carefully considered. Features such as the calibration procedure and the individual tree design are intended to localize the predictions to represent a specific stand. However, many sources of variation are still unaccounted for. Some of these sources, such as differences in tree vigor, incidence of disease, and insect damage will be visible to the knowledgeable silviculturist but not to the model. Projections must be viewed as reference points from which to estimate how the real stand can be expected to develop. If the expected departures are significant and if subsequent economic analyses of the output are required, then keywords that modify the model (see appendix A) can be invoked to bring the output into agreement with the expectations of the silviculturist. Obviously, this procedure must be used with deliberate caution.

REGENERATION SYSTEMS

The evaluation of a stand prescription may require the simulation of a regeneration treatment and the subsequent development of a regenerated stand. A Prognosis Model extension, ESTAB, has been developed to meet this need for the cedar-hemlock ecosystem in the Inland Empire. Currently, the regeneration establishment model is being linked directly to the Prognosis Model. It is also being expanded to represent other habitat types. ESTAB is used in a manner similar to other extensions, and input options are described in a separate manual (Stage and Ferguson 1982).

ECONOMIC EVALUATION OF PRESCRIPTIONS

The economic ramifications of individual stand prescriptions can be evaluated with an independent extension called CHEAPO. Unlike other Prognosis Models extensions, CHEAPO does not interact dynamically with the Prognosis Model. It does, however, use special Prognosis Model output as input. A manual describes CHEAPO options and their implementation (Medema and Hatch 1979).

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[15] Preliminary report on file with Leader, Quantitative Analysis of Forest Management Practices and Resources for Planning and Control Research Work Unit, Intermountain Forest and Range Experiment Station, Moscow, Idaho.

[16] Moeur, M.E., and S. Scharosch. 1981. COVER and BROWSE extensions to the Prognosis Model. Rough draft on file in Moscow, Idaho (see footnote 15).

SUMMARY

In this manual we describe the Prognosis Model in terms of model structure and behavior, options and input requirements, interpretation of output, and planning applications. The document is an accurate and complete representation of the model in its present form. However, as time passes, the Prognosis Model will undoubtedly undergo substantial modification. We will attempt to maintain the user's manual and, to the extent possible, the performance stability of the Model.

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APPENDIX A: REPRESENTING DIFFERENCES BETWEEN THE REAL WORLD AND THE MODEL

Introduction

In our discussion of the Prognosis Model we presented a relatively high level abstraction of tree growth processes and silvicultural practices. To develop this abstraction, the geographic and ecologic scope of the model was carefully restricted and the influence of many potentially descriptive variables was ignored. However, we feel that the model does a reasonably good job of projecting yields for managed and unmanaged stands in the Northern Rocky Mountain area.

We recognize that situations exist where the model may perform poorly. We have added several control variables that should facilitate improvement of performance in these situations. First, we have added a built-in scaling procedure that adjusts the intercept terms in the small tree height increment model and the diameter increment model so that predicted growth matches observed growth for the median trees. Scale factor calculations can be modified or bypassed.

Second, we have represented random effects in the model in various ways (Stage 1973b), and there are options that alter or entirely suppress the application of random effects.

Third, we have supplied options to input multipliers for all the increment functions. Additional options that affect the behavior of the mortality models can be targeted to specific species and to specific cycles.

Finally, we have supplied some options that provide input and output flexibility that may be useful in large-scale applications or when the program malfunctions.

This appendix will discuss the keywords that provide these options. These options are not intended as a vehicle for molding Prognosis output to match preconceived notions of stand development. The range of the Prognosis Model can be effectively extended by judicious use of scaling factors and multipliers. However, changes should be approached with caution, and they should be based on increment and yield data. In most cases where extensive modification is necessary, reestimation of some or all model parameters is in order. If data are available, estimation procedures are fairly routine (Stage 1973b, 1975; Cole and Stage 1972; Hamilton and Edwards 1976).

Calibration of Scale Factors

The increment models that were discussed in the preceding section are based on the best available data. For the most part, the data are representative of growing conditions in the Inland Empire, and the models produce relatively unbiased estimates of growth. However, it is reasonable to expect considerable variation about the expected value of the predictions for any set of values of the predictor variables. Many sites that we perceive to be the same, in terms of the variables used to predict growth, are in fact different, and the differences are reflected in growth rates. The tree is the ultimate integrator of site factors, and tree growth is the ultimate indicator of site capability.

We use available increment data to modify predictions. Most commonly, data are available for periodic *DBH* increment. Periodic height increment, on smaller trees, can be readily measured as well.

The scaling procedure (Stage 1973b), when stripped of statistical condiments, is really quite simple. The affected models are both linear with logarithmically scaled dependent variables. Therefore, the model intercepts are, in effect, growth multipliers. We predict an increment to match each observed increment for a species and sort the differences. The median difference is then added to the model for that species, on the logarithmic scale, as an additional intercept term.

The diameter increment scale factors are attenuated over time. We assume that, on long-term projections, the base model is a more stable estimate of growth potential than is the scale factor. The attenuation is asymptotic to one-half the difference between the initial value of the scale factor and 1. The rate of attenuation is dependent only on time.

The calculation of scale factors can be suppressed by inserting

NOCALIB

in the keyword file. There are no associated parameters. This option is useful when comparing the influence of site characteristics such as elevation, habitat type, slope, aspect, and location on stand development.

One possibility for extending the effective range of the Prognosis Model is to use the scale factors as a means of calibration. If a representative inventory of stands from a new area is available with increment data, the stands can be projected with the Inland Empire version for a single cycle to generate scale factors. If there is a consistent bias in the scale factors for any species, the average value of the scale factors for that species can be entered into the Prognosis Model in subsequent runs, and the model will be adjusted accordingly **prior to** scaling. In effect, the average scale factor becomes a new estimate of the model intercept. The factors for the *DBH* increment model are entered using

READCORD.

The factors for the small tree height increment model are entered using

READCORR.

Although no built-in calibration of the large tree height increment model is available, we have included a facility to preload multipliers for this model as well. These multipliers are entered with

READCORH.

None of these keywords use any of the parameter fields. However, all require two supplemental data records to enter the scale factors. The factors are coded as multipliers in the following order:

Supplemental   **Multiplier**

record number	Columns	for species
1	1-10	White pine
	11-20	Western larch
	21-30	Douglas-fir
	31-40	Grand fir
	41-50	Western hemlock
	51-60	Western redcedar
	61-70	Lodgepole pine
	71-80	Engelmann spruce
2	1-10	Subalpine fir
	11-20	Ponderosa pine
	21-30	Mountain hemlock

Decimal points should be explicitly punched. You need only enter the scale factors that differ from 1 as zero or blank values will be interpreted as equal to 1. Scale factors entered with the READCORD, READCORR, and READCORH records are **not** attenuated over time.

Scale factors that are entered in the above manner can be used in subsequent projections in the same run stream without being reentered. This is accomplished by inserting

REUSCORD
REUSCORR
and/or REUSCORH

in the keyword file for the projection in which the scale factors are to be reused. None of the parameter fields are used and no supplemental data records are required.

The calibration procedure described above changes the increment prediction in a proportional manner. It does not influence the relative effects of the predictor variables and there is no change in the shape of the response surface.

Our models are high-level abstractions. The connections between our set of predictor variables and physiological processes that actually control tree growth are, at best, tenuous. Therefore, it is unreasonable to assume that growth responses in locations with substantially different environmental limitations will be the same. It is more likely that the shape of the response surface in these locations, relative to our set of predictor variables, will be different. When this is the case, the models should be refit.

Random Effects

Random effects are incorporated in the Prognosis Model in the manner described by Stage (1973b). This description has been updated to reflect changes in program control variables and included below.

The program assigns all random effects to the distribution of errors associated with the prediction of the logarithm of basal area increment. Basal area increment was selected to reflect the stochastic variation because the effects of differing diameter growth rates extend in highly nonlinear ways through most of the remaining components of the model. This distribution of errors 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 fast estimate is derived from the regression analysis that developed the prediction function (table 22), and the second estimate is the standard deviation of the differences between the recorded growth for the sample trees in the population (transformed to the logarithm of basal area increment) and their corresponding regression estimates. The weights assigned to these two estimates are (1) the number of observations by habitat type in the data base for the model

for the prior component of error, and (2) the number of growth-sample trees in the stand for the second component of error (Mehta 1972).

Table 22.—Standard errors $(S_{y \cdot x})$ associated with the basal area increment regressions

Species[1]	$(S_{y \cdot x})$
WP	0.5130
L	.5520
DF	.5801
GF	.5612
WH	.5384
C	.5709
LP	.4927
S	.5535
AF	.5806
PP	.5069
MH	.4592

[1] Species codes are defined in table 4.

The random component of change in tree *DBH* 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, and 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.

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 *DBH* and the number of trees per acre represented by the source tree record. The trees-per-acre value of the original tree record is reduced to 60 percent of its current value. The two new records are given 15 and 25 percent of the original value; thus, the three records together still represent the same number of trees per acre.

Each of these three records is associated with one of the three portions of the error distribution characterizing the deviations about prediction (fig. 41). The first record, representing 60 percent of the population (approximately the center of the distribution), is given a prediction corresponding to the average value of the deviations in that portion of the Normal distribution. This "biased" point is indicated by A in figure 41. 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. With this method, the weighted average prediction for the three records is equal to the estimate associated with the original record.

Regardless of the method used, there is an implicit assumption that the period-to-period correlation between unexplained errors in growth predictions is zero.

Unless otherwise specified, records will be tripled twice or until additional tripling would exceed the program storage capacity for tree records (currently set to 1350). The maximum number of triples can be increased or decreased by using the NUMTRIP record or suppressed entirely with the NOTRIPLE record.

$$C = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-1.04} \frac{x e^{-x^2/2}}{0.15} dx$$
$$= -1.549$$

$$A = \frac{1}{\sqrt{2\pi}} \int_{-1.04}^{0.675} \frac{x e^{-x^2/2}}{0.60} dx$$
$$= -0.1423$$

$$B = \frac{1}{\sqrt{2\pi}} \int_{0.675}^{+\infty} \frac{x e^{-x^2/2}}{0.25} dx$$
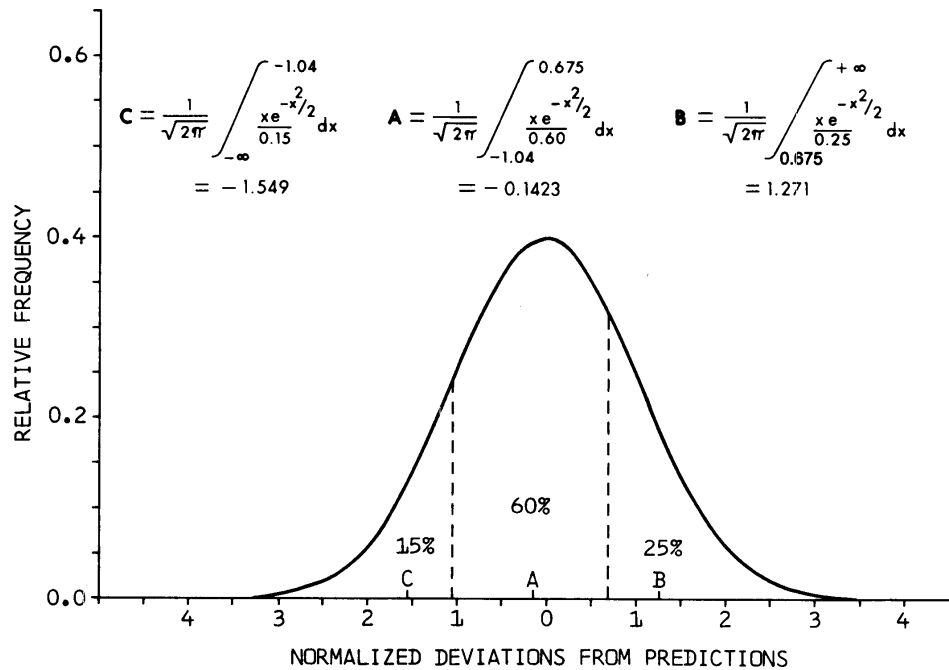$$= 1.271$$

Figure 41.—Location of prediction points (A, B, and C) for three fractions of the Normal distribution.

NUMTRIP   field 1:   The maximum number of cycles in which tree records will be tripled if there is sufficient room in the tree record storage files. A value of 0.0 suppresses the tripling feature; default = 2.

NOTRIPLE uses none of the parameter fields and is analogous to specifying NUMTRIP with 0.0 in field 1.

The region of the Normal distribution from which random increments are drawn is bounded by ± 2 standard deviations. These bounds can be changed with the DGSTDEV record:

DGSTDEV   field 1:   The number of standard deviations that define the bounds of the Normal distribution for random error estimates. Values less than 1.0 will completely suppress the random draw; default = 2.

Random errors are drawn from the Normal distribution by using Batchelor's technique as described in Tocher (1963). This technique requires three pseudorandom uniform numbers to produce each Normal deviate. The uniform pseudorandom numbers are generated with the Marsaglia-Bray composite algorithm (Marsaglia and Bray 1968).

The uniform random number generator is automatically reseeded prior to each Prognosis run so that a given set of tree records and control variables will always produce the same projection output in a specific computing environment. Because the random number generator is dependent in part on the way that a computer stores data and does arithmetic, the output for a given set of input records may vary slightly between computer installations.

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It is possible to manually reseed the random number generator and thus produce variation in projection results. There are three seeds involved and they can be replaced with the RANNSEED record:

RANNSEED   field 1:   first seed; default = 1409859205.

            field 2:   second seed; default = 402656419.

            field 3:   third seed; default = –328609067.

Seeds can be replaced individually or as a group. The new seeds should be odd integer values. If they are otherwise, they will automatically be converted to odd integers by truncating fractions and/or adding 1.

Growth Modifiers   The increment and mortality predictions can be arbitrarily modified on a species- and cycle-specific basis. We have included growth modification features primarily for experimental purposes. They may be useful for simulating effects, such as response to fertilizer, that are not now incorporated in the Prognosis Model. They may also be used to test the sensitivity of stand yield predictions to variation in the different aspects of tree growth, regardless of the cause of variation.

The growth multipliers can be entered using one or more of the following records:

BAIMULT – input multiplier for predicted basal are increment.

MORTMULT – input multipliers for predicted mortality rate.

HTGMULT – input multipliers for predicted large tree height increment.

REGHMULT – input multipliers for predicted small tree height increment.

REGDMULT – Input multipliers for predicted small tree diameter increment. These multipliers are not used in Inland Empire version 4.0 because a single model is used to predict *DBH* increment for all trees. However, other regional variants have distinct small-tree *DBH* increment models and multipliers can be input.

With the exception of the keyword, the records for entering growth model multipliers are identical:

BAIMULT
MORTMULT
HTGMULT
REGHMULT
REGDMULT   field 1:   Cycle in which growth multiplier is to be applied. Once multipliers take effect, they remain in effect until replaced with a subsequent request. If blank, multipliers take effect at the start of the projection.

            field 2:   Species number (see table 4) to which multiplier is to be applied; default = all species.

            field 3:   The value of the multiplier to be used; default = 1.0.

There is an additional method by which the mortality predictions can be modified. One component of the mortality model is an estimate of maximum basal area attainable on each habitat type. The estimate can be replaced for a projection by using the BAMAX record.

BAMAX   field 1:   Maximum basal area to be used to control mortality predictions in the projection; default values are listed by habitat type in table 15.

The BAMAX option has proven to be useful when applying the Prognosis Model outside of the Inland Empire. For example, grand fir stands in the Blue Mountains of northeastern Oregon exhibit growth rates that are similar to rates experienced on grand fir habitat types in north Idaho. However, the stands in the Blue Mountains do not appear to attain the stand densities that are possible in the Inland Empire. A maximum basal area can be entered as described above. Mortality predictions will then assure that the maximum is not exceeded, but growth rates will be unaffected.

Special Input Features

Some Prognosis Model applications require the repeated use of a set of keyword records. For example, when the same form and defect correction factors or multipliers are used for a large number of projections, the associated keywords must be entered with each projection. As an alternative, keywords that are used frequently can be stored in an auxiliary machine-readable file. The auxiliary file is then accessed by using an ADDFILE record in each projection:

ADDFILE   field 1:   Dataset reference number for auxiliary keyword file; must be greater than 16; no default value.

The ADDFILE usually may be inserted anywhere prior to the PROCESS record. You should be mindful, however, of the restrictions relating to TREEFMT, SPCODES, and TREEDATA. When ADDFILE is used, a job control statement must be provided to assign the auxiliary file to the appropriate dataset reference number.

If multiple projections are submitted as a single runstream, the auxiliary keyword file or tree record file may be reentered without providing additional job control statements. This is accomplished by using the REWIND record to reposition the read pointer in the appropriate file.

REWIND   field 1:   Dataset reference number for input file that is to be reread; default equal to 2.

The REWIND must precede the associated ADDFILE or TREEDATA records in any projection where tree records of the auxiliary keyword file are reread.

Problem Determination

The remaining options relate to the determination of causes of program malfunctions. In the course of development of the Prognosis Model, we have generated a good deal of specious code. Such problems are inherent in programming. To trace these problems, we have added many output statements that report the results of intermediate calculations on a tree-by-tree basis. Most of these special output statements remain in the current version of the code and can be invoked with the DEBUG option in any or all cycles. A word of caution: the DEBUG option generates a great deal of output. For example, the entire output (figs. 6-9) for the hypothetical prescription for stand S248112 requires seven pages. This stand has a relatively small complement of sample tree records. However, when the

DEBUG output is requested for the calibration phase and the first cycle, the entries in the stand composition table for the year 1987 occur at the end of the 18th page of the output.

DEBUG	field 1:	Cycle in which DEBUG output will be printed. If blank, DEBUG output will be printed for the entire projection. When the request includes cycle 1, the DEBUG output will begin immediately and continue through the calibration phase.

   The Prognosis Model has evolved over a period of a dozen years and will continue to change. As a result, many versions of the program are in current use, and there will be many future modifications of the code. It is now difficult to reconstruct the origins of any version. As a result, we have initiated a system of code management that will allow us to trace the course of development of future versions. An integral part of the code management system is an output table that reports the date of last revision for each subprogram in the Prognosis Model. This special output is requested with the DATELIST record. There are no associated parameters.

APPENIDIX B: SUMMARY OF CODES USED IN
THE PROGNOSIS MODEL

Table 23.—Codes for the Forests represented in the Inland Empire version of the Prognosis Model

Forest	Code	Forest	Code
Bitterroot	3	Kaniksu	13
Clearwater	5	Kootenai	14
Coeur d'Alene	6	Lolo	16
Colville	7	Nezperce	17
Flathead	10	St. Joe	18

Table 24.—Codes for habitat types represented in the version of the Prognosis Model [1]

Code[2]	Abbreviation	Habitat type name
130	PIPO/AGSP	*Pinus ponderosa/Agropyron spicatum*
170	PIPO/SYAL	*Pinus ponderosa/Symphoricarpos albus*
250	PSME/VACA	*Pseudotsuga menziesii/Vaccinium caespitosum*
260	PSME/PHMA	*Pseudotsuga menziesii/Physocarpus malvaceus*
280	PSME/VAGL	*Pseudotsuga menziesii/Vaccinium globulare*
290	PSME/LIBO	*Pseudotsuga menziesii/Linnaea borealis*
310	PSME/SYAL	*Pseudotsuga menziesii/Symphoricarpos albus*
320	PSME/CARU	*Pseudotsuga menziesii/Calamagrostis rubescens*
330	PSME/CAGE	*Pseudotsuga menziesii/Carex geyeri*
420	PICEA/CLUN	*Picea/Clintonia uniflora*
470	PICEA/LIBO	*Picea/Linnaea borealis*
510	ABGR/XETE	*Abies grandis/Xerophyllum tenax*
520	ABGR/CLUN	*Abies grandis/Clintonia uniflora*
530	THPL/CLUN	*Thuja plicata/Clintonia uniflora*
540	THPL/ATFI	*Thuja plicata/Athyrium filix-femina*
550	THPL/OPHO	*Thuja plicata/Oplopanax horridum*
570	TSHE/CLUN	*Tsuga heterophylla/Clintonia uniflora*
610	ABLA/OPHO	*Abies lasiocarpa/Oplopanax horridum*
620	ABLA/CLUN	*Abies lasiocarpa/Clintonia uniflora*
640	ABLA/VACA	*Abies lasiocarpa/Vaccinium caespitosum*
660	ABLA/LIBO	*Abies lasiocarpa/Linnaea borealis*
670	ABLA/MEFE	*Abies lasiocarpa/Menziesia ferruginea*
680	TSME/MEFE	*Tsuga mertensiana/Menziesia ferruginea*
690	ABLA/XETE	*Abies lasiocarpa/Xerophyllum tenax*
710	TSME/XETE	*Tsuga mertensiana/Xerophyllum tenax*
720	ABLA/VAGL	*Abies lasiocarpa/Vaccinium globulare*
730	ABLA/VASC	*Abies lasiocarpa/Vaccinium scoparium*
830	ABLA/LUHI	*Abies lasiocarpa/Luzula hitchcockii*
850	PIAL-ABLA	*Pinus albicaulis-Abies lasiocarpa*
999	OTHER	

[1] From Pfister and others 1977.

Table 25.—Tree species recognized by the Prognosis Model with coding conventions.

Common name	Scientific name	Default input code	Numeric code
Western white pine	*Pinus monticola*	WP	1
Western larch	*Larix occidentalis*	L	2
Douglas-fir	*Pseudotsuga menziesii*	DF	3
Grand fir	*Abies grandis*	GF	4
Western hemlock	*Tsuga heterophylla*	WH	5
Western redcedar	*Thuja plicata*	C	6
Lodgepole pine	*Pinus contorta*	LP	7
Engelmann spruce	*Picea engelmannii*	S	8
Subalpine fir	*Abies lasiocarpa*	AF	9
Ponderosa pine	*Pinus ponderosa*	PP	10
Mountain hemlock	*Tsuga mertensiana*		11

Table 26.—Aspect codes

Aspect	Azimuth (degrees)	Code
North	337.5-22.5	1
Northeast	22.6-67.5	2
East	67.6-112.5	3
Southeast	112.6-157.5	4
South	157.6-202.5	5
Southwest	202.6-247.5	6
West	247.6-292.5	7
Northwest	292.6-337.5	8
Level	----	9

Table 27.—Slope codes

Slope angle (%)	Code
[5	0
6-15	1
16-25	2
26-35	3
36-45	4
46-55	5
56-65	6
66-75	7
76-85	8
μ86	9

Table 28.—Crown ration codes

Crown ratio (%)	Code
1-10	1
11-20	2
21-30	3
31-40	4
41-50	5
51-60	6
61-70	7
71-80	8
μ 81	9

Table 29.—Interpreting damage codes (*IDCD*)

Code	Interpretation
73	Tree top is missing
74	Tree top is dead
all others	ignored

Table 30.—Interpreting tree history codes (ITH)

Code	Interpretation
5	Tree died during mortality observation period; record is used to backdate density for model scaling.
6, 7	Tree died prior to mortality observation period; record is ignored.
9	Special record (planar intercept in Region 1 inventory); record is ignored.
1,2,3,4,8	Various categories of live trees; records are projected.

Table 31.—Interpreting tree value codes (*IMC*)

Code	Interpretation
1	Desirable tree
2	Acceptable tree
3	Live cull
8	Non-stockable point
All other codes are interpreted as 3	

APPENDIX C: PROGNOSIS MODEL WARNING MESSAGES

Introduction

Everyone makes mistakes. This section is intended to alert you to the mistakes most frequently made while using the Prognosis Model and to explain the sometimes cryptic messages printed by the system when specific errors are detected. Before we proceed, you should be aware of the following assumptions made by the programmers who wrote the error-handling portions of the model:

The tree data file is always correct; the Prognosis Model does not check the tree data file for errors. For example, the Prognosis Model will accept a tree that is 400 feet tall and 2 inches in diameter. However, computational errors will likely result when the model tries to predict this tree's growth.

Supplemental data records (those that follow some keyword records, such as STDIDENT and TREEFMT) are always correctly coded; the Prognosis Model does not check supplemental data records. For example, errors that are due to an incorrectly specified tree data format will probably generate incorrect results and/or error messages that **seem** to be completely unrelated to the tree data format.

The most frequently committed error is misplacing a TREEDATA record before a SPCODES or TREEFMT record. The model prints warning message SPS07 (see the detailed explanation of SPS07) when this sequence is detected. The second most frequently committed error is miscoding the tree data format specification (see TREEFMT record). This error usually causes all of the trees to be grouped in the "other" species category. It may also cause the Prognosis Model to read every other tree record. This error may be detected by checking that the number of records read per species (see the calibration statistics table—fig. 6) is correct for the tree data file.

The Prognosis Model may print several other error messages besides those listed in the next section. Sometimes the message is printed only by an extension, such as the tussock moth model. If you are using one of the extensions, consult the applicable user's manual. At other times, the message indicates a probable system error. If your run contains a message that is not described in this or another appropriate manual, contact your consultant.

Error Message Descriptors

SPS01 ERROR: INVALID KEYWORD WAS SPECIEFIED. NUMBER OF RECORDS
        READ = XXXX

Program Action

If the Prognosis Model cannot interpret a keyword, it is ignored. Supplemental information displaying the keyword specified precedes this error message.

User Response

   Find the incorrect keyword, correct it, and rerun the projection. If you are using a version of the model that contains one or more extensions (such as, the tussock moth or mountain pine beetle insect models), it is possible to get this error message when you have specified a valid keyword but have placed it in the incorrect position in the runstream. Consult the applicable user's manual for details.

SPS02 ERROR: NO "STOP" RECORD IN KEYWORD FILE; NUMBER OF
        RECORS READ = XXXX

Program Action

The projection is terminated.

User Response

   If this error occurs after the desired projection is over, no further action is needed.
   If the message is printed before the projection is over, the probable error is the mis-placement of an end-of-file indicator in the runstream. If you use IBM equipment you very likely misplaced any record starting with // or /* . On UNIVAC equipment, a misplaced or miscoded record with an @ sign can cause the same error. Check and correct your runstream and rerun the projection.

SPS03 WARNING: FOREST CODE INDICATES THE GEOGRAPHIC LOCATION IS OUTSIDE
        THE RANGE OF THE MODEL

Program Action

The growth models use the nearest National Forest to identify geographic location. When the forest code is incorrectly specified or missing from the STDINFO keyword, a National Forest central to the geographical range of the version you are using is assumed.

User Response

   Choose the most applicable forest code for your purpose and code it on the STDINFO keyword card. If the default is most applicable, no response is necessary.

SPS04 ERROR: A REQUIRED PARAMETER IS MISSING OR INCORRECT:
        KEYWORD IGNORED.

Program Action

Supplemental information displaying the keyword record you specified precedes this error message.

Some of the keyword records require that one or more parameters be specified and that they are within a particular range of values. For example, you may not request that the model run for more than 40 cycles; therefore, coding 50 in field 1 of the NUMCYCLE record will result in an error. Note that incorrectly entering numeric data can easily result in a value being out of range. The value "20" entered in field 1 of the NUMCYCLE record will be read by the program as "200" if the "2" is in column 18 and the "0" is not followed by a decimal point.

SPS05 ERROR: KEYWORD MISSPELLED: FIRST 4 LETTERS MATCH A VALID
KEYWORD. NUMBER OF RECORDS READ = XXXX

Program Action

The Prognosis Model assumes that the correct keyword has been found and continues processing. Supplemental information displaying the keyword record you specified precedes this error message.

User Response

If the assumption made by the model is correct, ignore the error. Otherwise, correct the keyword spelling and resubmit the projection.

SPS06 ERROR: COLUMN 1 OF KEYWORD RECORD WAS BLANK. NUMBER
OF RECORDS READ = XXXX

Program Action

The record is ignored; supplemental information displaying the record you specified precedes this error message.

User Response

Probable causes of this error are the presence of a stray record in the runstream or the misplacement of a supplemental data record. Correct the mistake and rerun the projection.

SPS07 WARNING: A TREEFMT OR SPCODES RECORD FOLLOWS A
TREEDATA RECORD

Program Action

The Prognosis Model continues processing.

User Response

Carefully check your keyword file to assure that TREEFMT, SPCODES, and TREEDATA records are in the proper order. Also assure that the dataset reference number on the TREEDATA record matches the job control statement which, in turn, references the tree record file.

SPS08 ERROR: TOO FEW PROJECTABLE TREE RECORDS. PROJECTABLE
RECORDS: XX; TREE RECORDS: XXXX; STAND ID: XXXXXXXX.

Program Action

This error occurs when, after the tree data have been read, a PROCESS record is encountered, and the minimum of two projectable tree records has not been read. If there are fewer than two projectable tree records, the projection of this stand is terminated; however, the next stand in the runstream is projected.

User Response

The most probable cause is attempting to project a very small stand. You may have to delete the stand from your analysis or combine it with an adjacent stand. You may use two TREEDATA records to combine stands.

If the error message indicates that several tree records were read but none were accepted by the Prognosis Model for processing, the most probable causes are incorrectly specifying the tree data format or placing the TREEFMT after the TREEDATA card (see SPS07).

SPS09 WARNING: PLOT COUNTS DO NOT MATCH DATA ON THE DESIGN
RECORD; DESIGN RECORD DATA USED.
PLOT COUNT = XX; NONSTOCKABLE COUNT = XX

Program Action

The Prognosis Model uses the plot count to calculate the trees per acre represented by each tree record. The nonstockable count deducts non-stockable points (such as, rock outcroppings and roads) from the stand area for density calculations. This warning message is printed when either the plot count or nonstockable count differs from the values coded on the DESIGN record.

User Response

Check the trees/acre values as printed in the stand composition and sample tree record tables. If the output is acceptable, no response is necessary.

One probable cause of incorrect plot counting is incorrectly specifying the tree data format thus causing the model to read the plot identifications from the wrong columns. The presence of a TREEDATA card before the TREEFMT card is another probable cause.

SPS10 ERROR: OPTION/ACTIVITY STORAGE AREA IS PULL; REQUEST(S)
IGNORED

Program Action

If the storage area which holds activities that are specified to occur at a specified date or cycle (such as, thinning requests) is full when options are specified, the program ignores the keywords and continues. Note that there may be occasions when this error is printed during the projection; in this case, the overfilling was a result of the program attempting to dynamically schedule activities.

User Response

The program can hold several hundred activities and a thousand parameters. Try to limit the number of activities to stay within the memory areas within the program. If you cannot limit your problem ask your programmer to increase the activity storage area. (Note to pro-

grammers: Increase the dimensions of the arrays within the OPCOM common area and change the values of *MAXPRM* and *MAXACT* in BLOCK DATA accordingly.)

SPS11 ERROR: REQUESTED EXTENSION IS NOT PART OF THIS PROGRAM.

Program Action

   The Prognosis Model ignores the keyword and continues processing. Usually, several SPS01 (invalid keyword) error messages follow this error because most extensions require their own set of keywords.

User Response

   You must use a version of the program that contains the extension you require; consult the applicable user's documentation for your computer center and acquire the correct program name. Change your job control statement accordingly and rerun the projection.

SPS13 ERROR: THE MAXIMUM NUMBER OF USABLE TREE RECORDS HAVE
               BEEN PROCESSED. NUMBER READ = XXXX; SUBPLOT
               COUNT = XXX

Program Action

   The Prognosis Model can handle 1,350 projectable tree records or 200 plots from a given stand. When either of these values are exceeded the projection is terminated.

User Response

   If the plot count is exceeded but the tree record count is not, the probable causes are an incorrectly specified tree data format or the occurrence of a TREEDATA card before the TREEFMT card (see error SPS07). Either can cause the plot identification codes to be read from the wrong columns of the tree records. In some cases, the format is accurate—the stand simply has over 200 plots. In these cases, you can change the format specification to read the plot identification from a blank or constant column on the tree records. Then specify the actual count on the DESIGN record and ignore warning message SPS09.
   If the tree record count is too high, you may have to split the stand. One technique is to systematically select plots for deletion from the tree record file.

APPENDIX D: SUMMARY OF KEYWORD USE, ASSOCIATED PARAMETERS, AND DEFAULT CONDITIONS

Note: Appendix D contains summaries of keywords that are presented in this manual (page references are given if further clarification is needed). Within each category, keywords are arranged alphabetically.

Rules for Coding Keyword Records

1. All option keywords start in column 1.
2. The numerical values (parameters) needed to implement an option are contained in seven numeric fields that are 10 columns wide. The first parameter field begins in column 11. A decimal point should be punched for all values that are not integers. Integer values should either be right-justified in the numeric field or followed by a decimal point.
3. Blank numeric fields are not treated as zeroes. If a blank field is found, the default value will be used. If zeroes are to be specified, they must be punched. Thus, only the numeric values that are different from the default parameter values need to be specified.
4. All supplemental data records associated with a keyword must be provided if the keyword is used.
5. When two or more conflicting options are specified, the last one specified will be used.

CONTROLLING PROGRAM EXECUTION

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
INVYEAR (8)	Specify the starting date for a projection **field 1:** Year in which simulation is to begin	0
NUMCYCLE (8)	Specify the number of cycles in a projection **field 1:** Number of cycles to be projected Maximum number of cycles is 40.	1
PROCESS (8)	Marks the end of an input file for a single projection in a runstream and triggers the beginning of the simulation. Must be present or projection will not run.	
STOP (8)	Signal the end of Prognosis Model runstream	
TIMEINT (8)	Specify the length of any or all projection cycles. **field 1:** Number of a cycle whose length is to be changed. **field 2:** Number of years to be simulated in the cycle(s) referenced in field 1.	Change all cycles 10 years

ENTERING STAND AND TREE CHARACTERISTICS

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
DESIGN (10)	Enter inventory design parameters **field 1:** Basal area factor for variable radius plots. **field 2:** Inverse of fixed plot area. **field 3:** DBH separating trees measured on fixed area plot from trees measured on variable radius plot. **field 4:** Number of plots used to inventory stand. **field 5:** Number of nonstockable plots in stand inventory. **field 6:** Stand weight for aggregation of projections.	40 ft^2/tree 300 plots/acre 5 inches Count the plots Count the plots Number of plots
GROWTH (20)	Identify methods used to measure and input mortality and height and diameter increment data. **field 1:** Method used to measure diameter increment **field 2:** Length of diameter increment measurement period. **field 3:** Method used to measure height increment. **field 4:** Length of height increment measurement period. **field 5:** Length of mortality observation period.	0 (past increment) 10 years 0 (past increment) 5 years 5 years
MGMTID (11)	Enter an alphanumeric code to identify the silvicultural treatment simulated in a projection. The code does not affect the projection but is printed with each output table and on each line in the Summary table. **Supplemental record:** enter management identifier in first four columns.	Default code is "NONE" (MGMTID record not input); if supplemental record is blank, management identifiers not printed.
SPCODES (19)	Identify species codes used on the input tree records **field 1:** Numeric code for the species for which the code is to be changes **Supplemental record:** Species code or codes, left justified in consecutive 4-column fields. If all codes are replaced, they must be entered in order of numeric code. If only one code is replaced, it is entered in the first 4 columns.	Change for all species Default values are given in table 4; a blank entry on the supplemental record will be interpreted as a blank.
STDIDENT (11)	Enter stand identification code and descriptive title to label the output. **Supplemental record:** Stand identification code is entered in columns 1-8; title is entered in columns 9-80.	

ENTERING STAND AND TREE CHARACTERISTICS (con.)

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
STDINFO (12)	Enter data that describe the site on which stand is located.	
	field 1: National forest on which stand is located.	18 (St. Joe)
	field 2: Stand habitat type code.	260 (PSME/PHMA)
	field 3: Stand age.	0 years
	field 4: Stand aspect code.	9 (level)
	field 5: Stand slope code.	0 (< 5%)
	field 6: Stand elevation code.	38 hundred feet
	field 7: Stand site index.	0
TREEDATA (18)	Read tree data from dataset referenced by the unit number recorded in field 1.	
	field 1: Dataset reference number.	2
TREEFMT (19)	Provide a format statement that describes the layout of a tree record.	See table 5
	Two Supplemental records: A FORTRAN execution time format statement.	

SPECIFYING MANAGEMENT ACTIVITIES

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
BFFDLN MCFDLN (24)	Enter species-specific parameters for log-linear form and defect correction equation for board foot volume estimates (BFFDLN) or merchantable cubic foot volume estimates (MCFDLN).	
	field 1: Numeric code for the species for which the equation is to be changed. The default equation supplies a multiplier of 1.0 for each species.	Change all species
	field 2: Intercept term for log-linear equation.	0.0
	field 3: Slope coefficient for log-linear equation.	1.0

(con.)

SPECIFYING MANAGEMENT ACTIVITIES (con.)

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
BFFDPOLY MCFDPOLY (23)	Enter species-specific parameters for polynomial form and defect correction equation for board foot volume estimates (BFFDPOLY) or merchantable cubic foot volume estimates (MCFDPOLY). **field 1:** Numeric code for the species for which the equation is to be changed. The default equation supplies a multiplier of 1.0 for all species. **field 2:** Intercept term for polynomial equation. **field 3:** Coefficient for linear term in polynomial equation. **field 4:** Coefficient for quadratic term in polynomial equation. **field 5:** Coefficient for cubic term in polynomial equation. **field 6:** Coefficient for quartic term in polynomial equation.	 Change all species 1.0 0.0 0.0 0.0 0.0
CUTEFF (21)	Change the assumed effectiveness of thinning for all thinning activities. **field 1:** New value for global cutting efficiency parameter.	 0.98
MCFDLN	Parameters same as for BFFDLN.	
MCFDPOLY	Parameters are the same as for BFFDPOLY.	
MINHARV (22)	Specify minimum acceptable harvest standards for board foot volume, merchantable cubic foot volume, or basal area per acre by cycle. **field 1:** The cycle in which minimum harvest standard will be applied. **field 2:** The minimum acceptable harvest volume in merchantable cubic feet per acre. **field 3:** The minimum acceptable harvest volume in board feet per acre. **field 4:** The minimum acceptable harvest in square feet of basal area per acre.	 Applied in all cycles 0 ft^3/acre 0 bd.ft./acre 0 ft^2/acre
SPECPREF (26)	Change the species component of the removal priority formula. **field 1:** Date at which change is to be implemented. **field 2:** Numeric code for species whose removal priority is to be changed. **field 3:** Species preference value.	 Implement at star of projection Ignore the recruits 0

(con.)

SPECIFYING MANAGEMENT ACTIVITIES (con.)

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
TCONDMLT (27)	Change the impact of tree value class on the determination of removal priority.	
	field 1: Date at which change is to be implemented.	Implement at start of projection
	field 2: New tree condition class multiplier.	100
THINABA THINATA (27)	Schedule thinning from above to a basal area per acre (THINABA) or trees per acre (THINATA) target.	
	field 1: Date that thin is scheduled.	Schedule at start of projection
	field 2: The residual stand density.	Ignore the request
	field 3: Cutting efficiency parameter specific to this thinning request.	0.98
THINAUTO (28)	Schedule automatic stocking control. As nearly as is possible, stand density will be maintained within a range determined by the minimum and maximum percentage of normal stocking entered in fields 2 and 3.	
	field 1: Date that automatic stocking control is scheduled to begin.	Begin at start of projection
	field 2: Percentage of normal stocking that defines the lower limit for stand density.	45%
	field 3: Percentage of normal stocking that defines the upper limit for stand density.	60%
	field 4: Cutting efficiency parameter specific to automatic stocking control request.	0.98
THINBBA THINBTA (27)	Schedule thinning from below to a basal area per acre (THINBBA) or trees per acre (THINBTA) target.	
	field 1: Date that thinning is scheduled.	Scheduled at start of projection
	field 2: The residual stand density.	Ignore the request
	field 3: Cutting efficiency parameter specific to this thinning request.	0.98
THINDBH (24)	Schedule the removal of a segment of the *DBH* distribution.	
	field 1: Date that thinning is scheduled	Scheduled at start of projection
	field 2: Smallest *DBH* in the segment of the *DBH* distribution to be removed.	0 inches
	field 3: Largest *DBH* in the segment of the *DBH* distribution to be removed.	999inches
	field 4: Cutting efficiency parameter specific to this thinning request.	0.98

(con.)

SPECIFYING MANAGEMENT ACTIVITIES (CON.)

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
THINSPRSC (24)	Schedule prescription thinning. Harvest trees that were marked for removal on the input tree records.	
	field 1: Date that prescription thinning is scheduled.	Scheduled at start of projection
	field 2: Cutting efficiency parameter specific to this thinning request.	0.98
VOLUME (22)	Redefine the merchantability limits for the merchantable cubic foot volume equation.	
	field 1: Cycle in which limits defined below will be implemented.	Implement at start of projection
	field 2: Numeric code for the species for which limits are to be changed.	Change for all species
	field 3: Minimum *DBH*.	6 inches for lodgepole pine 7 inches for all other species
	field 4: Minimum top diameter.	4.5 inches
	field 5: Stump height.	1 foot

CONTROLLING PROGRAM OUTPUT

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
COMMENT (48)	Enter a comment that will be reproduced in he Input Summary Table.	
	Supplemental records: Enter your comment using all 80 columns on as many records as desired. Signify the end of your comment by supplying a record with the word "END" entered in the first 3 columns. The 4th column must be blank.	None
ECHOSUM (48)	Request the summary output be copied to retrievable data storage file.	
	field 1: Dataset reference number for output file.	4
TREELIST (47)	Print a list of all sample tree records.	
	field 1: Cycle in which tree list is to be printed.	Print tree list in all cycles

LINKAGE TO PROGNOSIS MODEL EXTENSIONS

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
CHEAPO (86)	Generate output file required for subsequent execution of the CHEAPO economic analysis program. **field 1:** Dataset reference number for CHEAPO output file	11
COVER (86)	Invoke the COVER option in the shrub and cover extension; specify foliage biomass prediction option. **field 1:** Method to be used to compute foliage biomass.	2
DFTM (85)	Indicates start of special keyword file for the Douglas-fir tussock moth extension.	
END (85)	Indicates end of special keyword input file for any extension.	
ESTAB (86)	Indicates start of special keyword input file for the regeneration establishment extension.	
MPB (85)	Indicates start of special keyword input file for the mountain pine beetle extension.	
SHRUB (86)	Invoke the BROWSE option of the shrub and cover extension. **field 1:** Number of years since stand was regenerated. **field 2:** Number of years shrub output will be printed. **field 3:** Habitat type code for processing SHRUB option.	Stand age; see STDINFO 40 years Stand habitat type; see STDINFO
WSBW (85)	Indicates start of special keyword input file for the western spruce budworm extension.	

GROWTH PREDICTION MODIFIERS AND SPECIAL I/O OPTIONS

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
ADDFILE (95)	Specify a dataset reference number for a supplemental keyword record file. **field 1:** Dataset reference number.	None
BAIMULT HTGMULT MORTMULT REGDMULT REGHMULT (94)	Enter multiplier to change prediction of tree basal area increment (BAIMULT), large tree height increment (HTGMULT), mortality rate (MORTMULT), small tree diameter increment (REGDMULT), or small tree height increment (REGHMULT). **field 1:** Cycle in which growth multiplier is to be applied. **field 2:** Numeric code for species to which growth multiplier is to be applied. **field 3:** Growth multiplier.	Apply in all cycles Apply to all species 1.0
BAMAX (95)	Modify the maximum basal area used to control mortality predictions. **field 1:** Maximum basal area.	See table 17
DATELIST (96)	Instruct program to print date of last revision for Prognosis Model subprograms and common areas.	None
DEBUG (96)	Request printout of the results of most program calculations in any or all cycles. **field 1:** Cycle in which debug output is to be printed.	Print in all cycles
DGSTDEV	Change the limits of the Normal distribution from which random errors are drawn for increment predictions. **field 1:** Number of standard deviations that defines the bounds of distribution.	2.0
HTGMULT MORTMULT	Parameters same as for BAIMULT Parameters same as for BAIMULT	
NOCALIB (90)	Suppress calculation of scale factors for large tree diameter increment model and small tree height increment model	Calculate scale factors
NOTRIPLE (93)	Suppress tree record tripling feature.	Tree records tripled twice
NUMTRIP (93)	Change the number of times tree records will be tripled. **field 1:** Number of triples.	2.0
RANNSEED (94)	Reseed the random number generator. **field 1:** Replacement for first seed. **field 2:** Replacement for second seed. **field 3:** Replacement for third seed.	1409859205 402656419 –328609067

(con.)

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
READCORD READCORH	Enter multipliers for the diameter increment model (READCORD), the height increment model	

Wykoff, William R.; Crookston, Nicholas L.; Stage, Albert R. User's guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 112 p.

The Stand Prognosis Model is a computer program that projects the development of forest stands in the Northern Rocky Mountains. Thinning options allow for simulation of a variety of management strategies. Input consists of a stand inventory, including sample tree records, and a set of option selection instructions. Output includes data normally found in stand, stock, and yield tables and details on selected sample trees. Preparation of input, interpretation of output, and model formulation are described. Guidelines are given for potential uses and limitations.

KEYWORDS: growth and yield, forest management, planning, growth projection, stand models, tree increment, tree mortality

Keyword (page reference)	Keyword use and associated parameters	Default parameter or conditions
READCORR (90)	(READCORH) or the small tree height increment model (READCORR) that are incorporated prior to model calibration. **Supplemental record 1:** Multipliers for white pine, larch, Douglas-fir, grand fir, western hemlock, western redcedar, lodgepole pine, and Engelmann spruce. **Supplemental record 2:** Multipliers for subalpine fir, ponderosa pine, and mountain hemlock.	Default value for all multipliers is 1.0
REGDMULT REGHMULT	Parameters same as for BAIMULT Parameters same as for BAIMULT	
REUSCORD REUSCORH REUSCORR (91)	Use multipliers that were entered with a READCORD, a READCORH, or a READCORR in a previous projection in the same runstream.	
REWIND (95)	Causes the computer to move the read position pointer to the beginning of the dataset referenced by the unit number entered in field 1. This record is useful when multiple projections are made with the same tree record file in a single runstream. **Field 1:** Dataset reference number.	2

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

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Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

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Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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