

A Computerized Tree Growth Projection System for Forest Resource Evaluation in the Lake States

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Abstract: A computerized tree growth projection system has been developed for the Lake States Region as part of a larger Forest Resources Evaluation Program (FREP). Incorporating data from more than 1500 permanent growth plots throughout the Lake States, this system projects tree growth, mortality, regeneration, and removals in stands with any mixture of tree species and sizes, for the full range of sites encountered in the field. It incorporates the latest published timber management guides for the Lake States. It can identify silvicultural treatment opportunities now and in the future from the plot data or representative tree lists for a single stand, a management unit, an entire forest property, or an entire state or region. It can also be used to update timber inventories and to project future yields and resource conditions in response to alternative silvicultural treatment opportunities for timber resource evaluation and assessment.

INTRODUCTION

A comprehensive inventory of forest resources is essential for land management planning, but by itself is not sufficient. An inventory provides a detailed picture of the resource at one point in time. The forest is not a static entity, but a dynamic biophysical system. A full description of such a system must contain not only an estimate of its present state, but also a description of its potential future change. Without provision for continual updating, an inventory only produces a fading portrait of a resource that is changing with each passing year as regeneration, growth, death, and cutting of trees takes place. To be fully useful to the land manager and planner, a complete resource inventory system should continually update the inventory to provide current data about the condition of the resource. It also should be capable of estimating future changes in the forest resource in response to a range of possible resource management alternatives, including that of no tree cutting.

A tree growth projection system is a necessary part of a dynamic forest

resource inventory system. It must be capable of updating and projecting timber inventories in a form suitable for evaluating resource management alternatives for large areas with diverse forest conditions. To do this, it must be able to handle all species and stand conditions in a forest area, require only a minimal amount of input data such as would be available from existing resource inventories, and be computationally efficient.

Developing a tree growth projection system capable of describing the dynamic behavior of complex ecological communities such as the intricately mixed northern hardwood-conifer forests of the Lake States has long challenged inventory specialists and growth modelers. Stand growth models have been developed for several single-species forest types such as Pinus resinosa Ait. (Buckman 1962), Picea mariana (Perala 1971), and Populus tremuloides (Schlaegel 1971). Such models have been useful in developing stand management recommendations for even-aged stands with a single species. However, models have been developed for only a few Lake States species, and existing models fail to describe the behavior of the mixed-species, mixed-sized stands common to the Lake States. Stand models have been developed for some mixed-species forest types for some areas of the Lake States (for example, Dale 1972, Ek 1974, and Moser 1972), but again coverage of the resource base is far from complete. Individual tree models for more general mixed-species stands (Ek and Monserud 1974) are expensive to run and require more data than is available from most forest inventories.

Available growth models have provided valuable insights into tree and stand growth, but by themselves are not adequate for a forest-wide tree growth projection system. Efforts to assemble individual growth models and link them into a more comprehensive system have been frustrated by the lack of common input requirements and data outputs, as well as incomplete coverage of the resource.

TRAS, a computer program for projecting timber volumes, was developed and used by the U.S. Forest Service to update inventories and project future timber volumes for large forest areas (Larson and Goforth 1970). However, this program was not designed as a stand model to account for interactions among size classes of trees in response to alternative silvicultural treatments. It lacks the ability to closely model biological tree response to stand treatments in the mixed forest ecosystems common in the Lake States in the detail needed for evaluating treatment opportunities.

The need is to develop a comprehensive tree growth projection system specifically designed to project tree growth for all species in all stands for large diverse forest areas in enough detail to update forest inventories and evaluate stand treatments.

THE PROJECTION SYSTEM

After several years of work, scientists at the North Central Forest Experiment Station of the Forest Service (U.S. Dep. Agric.) have completed and tested a computerized tree growth system for the forests of the Lake States Region. Developed using data from more than 1500 permanent growth plots in

all major forest types in the Region, the projection system reliably projects stand development with or without tree cutting for several decades for all forest conditions found in Michigan, Minnesota, and Wisconsin.

This system inexpensively projects individual tree growth, mortality, and regeneration, with or without tree removals, for products in stands with any mixture of tree species and sizes, and any density, over the full range of sites encountered in the field. The latest published timber management guides for the Lake States species are incorporated into the system. These are used to identify silvicultural treatment and timber harvesting opportunities, now and in the future, from the plot data or representative tree lists used to describe a single stand, management unit, or an entire forest property, state, or region. The projection system has been linked to the U.S. Forest Service's national forest inventory system in the North Central Region. However, it can be adapted readily to other growth projection needs.

Input to the projection system is a list of individual trees that represent a forest stand. At a minimum, the list must have the tree species and diameter breast high of each tree listed, along with each tree's expansion factor to indicate the number of trees per acre each tree represents. Other information should include tree condition (alive, cut, or dead), and stand variables such as site index and age. Tree growth, mortality, and regeneration are projected for any time period (in increments of a year) or sequence of periods selected by the user.

A major advantage of this projection system is that the integrity of the individual tree list is maintained throughout the projection period, so no information about the resource is lost through aggregation. At the end of each projection period, the system produces an updated list of trees in the same format. Thus, programs available to summarize data from the initial tree list or inventory can be used to summarize data from the program output tree lists as though they were a new inventory. It will be necessary to update other data that are subject to change that are not handled by the projection system at present, such as land use or ownership change, changes in site index due to change in forest type, and special tree measurements such as merchantable bole length, log grades, or cull percent.

Silvicultural treatment prescribed for each acre each year or time period is identified by kind of treatment and forest type. A cost algorithm determines the cost of each treatment by time period for the acres indicated. Trees to be cut are designated by the appropriate silvicultural treatment. The system then projects stand development forward for the desired number of years with the trees left after cutting. If desired, the process may be repeated. Timber harvested in each time period can be produced in detail, including cubic foot volume by species and 2-inch diameter class within each type. Mortality volumes can also be summarized in detail. Inventory volumes before and after each cut can also be obtained in the same way. The difference in future stand development with and without treatment can be identified from this information and can be used for economic appraisal of stand treatment opportunities, either on an individual stand or forestwide basis.

The timber projection system has been tested extensively and has provided results well within acceptable limits of accuracy. The tests consisted of

projecting first occasion inventory plots, which had not been used to develop model coefficients, and comparing the projected value with actual values that were recorded on successive [sic] plot measurements.

The system was designed for inexpensive computing so thousands of survey plots could be updated annually to provide current Regionwide inventory data. Computing costs have been about 6 cents to project the tree list from a single plot for 10 years and develop summaries of inventory and harvest volumes.

USE OF THE SYSTEM

This Lake States system has been used to update all the survey plots in Wisconsin, from the most recent inventory (1967-69) to 1978. Removals for timber products were accounted for to provide a current inventory estimate. Similar inventory updates have been done for individual national forests in the Lake States. Plans are to periodically update each state-wide inventory as needed to provide estimates of the current status of the forest resource throughout the Region in as much detail as the original inventories.

The system also has been used to update and project inventories of individual national forests, of all state-owned land within a state survey unit, and of other forest land in response to silvicultural treatment opportunities for timber production. The output showed timber volumes harvested and timber volume inventories by decade for the next fifty years.

The development of individual stands in several National Forest Compartments in Michigan was projected for fifty years, both with and without timber cutting, to show how the system could be adapted to the Forest Service's compartment examination procedures. These illustrate only some of the ways the system can be used.

THE SYSTEM'S POTENTIAL

This timber growth projection system is designed to be the core of a larger Timber Resource Evaluation System, that will evaluate timber management opportunities on a local, state, or regional basis from an economic, social, or ecologic point of view. The evaluation system is still being developed, but the output from the projection system can be used with existing evaluation procedures and programs. The mathematical structure underlying the timber projection system was designed to allow for including other components of the ecosystem besides trees--for example, a link between trees and understory vegetation is now being developed.

The timber projection system developed for the Lake States has tremendous potential. Now, for the first time, we have a computerized system that can project forest resource development in response to timber cutting, or no timber cutting, for all forest conditions in the Region. It answers the long-felt need for a method to project future renewable resource supplies in response to treatment for evaluating management opportunities. It will be useful for timber management planning and program development for state and

regional resource assessments. Further, it can be used to update resource inventories to provide a reliable current estimate of present resource conditions.

The concepts used in developing the timber projection system are general and have potential for wide application. We plan to continue development of FREP as rapidly as possible, expanding the system to the rest of the North Central Region and to other resources. We also plan to work with others to test the applicability of the FREP tree growth projection system to other regions of the United States.

Another exciting concept will be to incorporate the tree growth projection system into the remeasurement design of forest inventories. A first step of the new inventory procedure could be to classify plots established at the time of the previous survey into disturbance classes. This might be done using LANDSAT data, conventional photography, or a combination of the two. Undisturbed plots could be grown to the date of the present survey using the tree growth projection system. These plots could then be sampled to determine what corrections, if any, need to be made in the projections to represent current inventory conditions accurately. Disturbed plots could be remeasured on the ground, together with new plots such as might be found in agricultural areas that have reverted to forest. These plots would be processed in the conventional way. The two data sets would then be combined to form the information base for the new survey.

This procedure could substantially reduce the cost of today's remeasurement surveys but still provide a detailed tree list of each plot that may be used in the projection system.

Acknowledgment: The timber growth projection system was developed jointly by a team of researchers at the North Central Station. This team included Dr. Rolfe A. Leary, Jerold T. Kahn, Roland G. Buchman, Gary Brand, Brad Smith, Margaret Holdaway, Jerrilyn LaVarre Thompson, and Linda Christensen, each of whom had responsibilities for major aspects of the study. A collection of papers outlining the system in some detail is being published as USDA Forest Service General Technical Report NC-47, North Central Forest Experiment Station, St. Paul, Minn.

APPENDIX¹

A general description is given here of the input needed, how the parts are put together, and what output is produced.

Input

The input consists of a parameter deck and a tree list. A tree list consists of tree species, d.b.h., crown ratio, and quality class for a group of individual trees. Also required are the following plot attributes: site index, stand age, and plot size.

Parameter deck

The parameter deck specifies two groups of input values: (A) user selected options and (B) numerical constants needed by each portion of the growth processor.

Numerical constants are used for

- Assigning species group codes to individual trees
- Crown ratio function coefficients
- Silvicultural treatment specifications
- Volume equation coefficients
- Mortality equation coefficients
- Potential growth function coefficients
- A species grouping priority matrix (used for combining species when more than three species occur on a plot)

These values are determined from calibrating the model on a specific data base of permanent (remeasured) plots.

Projection-related options that may be selected by the user are

- Length of projection cycle (years)
- Number of projection cycles
- Type of growth projection desired (validation, projection, or update).

The number of years the tree list is projected is determined by the number and length of the cycles. The projection is limited to a maximum, of 100 years but it may be in the form of 100 cycles of one year each or one cycle of 100 years. The length of the cycle determines how often summaries are made and the tree list examined for management opportunities.

¹ This material is abstracted from a forthcoming publication: Hahn, Jerold T., and Gary Brand, A program for implementing a generalized forest growth projection system. USDA Forest Serv. Gen. tech. Rep. NC-47, North Central Forest Exp. Stn., St. Paul, Minn.

Three different types of growth projections can be selected: validation, projection, and update. A validation run uses a tree list with measurements recorded for several different years. The tree list is projected from the initial measurement to the final measurement. Projected and actual measurements are compared to determine the accuracy of the model. A projection run begins with initial conditions and grows the trees for a specified length of time to estimate future conditions. An update run begins with initial conditions from the past and grows the trees to the present. Known product removals are used to extract the trees that produce those products from the tree list.

Tree list

The tree list can be in one of three different formats: (1) a list format, (2) a unit record format as used by the U.S. Forest Service Renewable Resources Evaluation (forest survey) projects, or (3) a computer-readable format in which the user is responsible for supplying the necessary computer code for input and output routines.

PROGRAM ORGANIZATION

Besides providing input/output capability, the program controls when the different parts of the system are used according to the options selected. The listing below gives all the subroutine and function [sic] names, their calling routines, and a brief statement of their purpose. The program has seven parts:

1. The main calling program
2. A function, VALUE, where all mathematical equations are located
3. Input subroutines
4. A subroutine for aggregating the input tree list
5. Stand treatment subroutines
6. Stand growth subroutines
7. Output subroutines.

Subsystem TRES (Timber Resource Evaluation System) of
program FREP (Forest Resources Evaluation Program)

1. Main program

Program TRES

Main calling routine, sets up and initializes arrays, performs housekeeping functions, organizes calling of subroutines.

2. Mathematical functions

Function Value

Called from RMASTR, RSURTP, GROW, ISUM, OUTPT1, and OUTPT2. Computes values for crown ratio, potential growth, modifier, mortality, and volume.

3. Input

Subroutine READ

Called from TRES

Reads user-selected options and numerical constants
and echo-prints all values.

Subroutine RMASTR

Called from TRES

Reads data from binary files in N.ASZER format into arrays
TRS and ITRS.
Initializes array parameters.

Subroutine RSURTP

Called from TRES

Reads data from files in forest survey unity record format
into arrays TRS and ITRS.
Initializes array parameters.

Subroutine OPENRD

Called from RSURTP.

Unblocks forest survey unit record file and supplies one
record at a time to RSURTP.
Has entry point READIT.

Subroutine RUSER

Called from TRES.

Supplied by user to read their data file into arrays IRS
and ITRS.

4. Aggregation of species

Subroutine FIT

Called from TRES, SCREEN, and REMOVE.

Classifies trees in arrays TRS-ITRS into projection groups.

5. Stand treatment

Subroutine SCREEN

Called from TRES.

Screens plots for possible treatment and/or sets up treatment
schedule.

Subroutine COVTYPE

Called from SCREEN.

Determines cover type using live trees in tree list.

Subroutine TREAT

Called from SCREEN.

Performs silvicultural treatments prescribed in SCREEN.

6. Stand growth

Subroutine GROW

Called from TRES.

Grows trees, selects trees for mortality, updates TRS and ITRS array.

Subroutine REMOVE

Called from CROW

Removes trees to meet specified annual removals for updates or trees recorded as having been removed by remeasurements.

Subroutine ISUM

Called from GROW, OUTPT1, TRES

Summarizes trees into classification groups and computes group totals.

7. Output

Subroutine OUTPT1

Called from TRES.

Outputs summaries for specified points in time.

Subroutine TFILE

Called from TRES.

Outputs updated forest survey unit record file.

Subroutine OPENWR

Called from TFILE.

Writes blocked unit record tape.

Has entry points WRITIT and CLOSWR.

Subroutine OUTPT2

Called from TRES.

Outputs file for validation tests.

Subroutine OUTUR

Called from TRES.

Supplied by user to output updated tree list to their specifications.

When all input (parameters and tree list) has been read, the tree list is partitioned into species groups and size classes by subroutine FIT, called from the main program, TRES.

Selecting the option to manage the stand as it is being projected, causes subroutines SCREEN, COVTYPE, and TREAT to be called. COVTYPE, which is also called at the end of a projection by OUTPT2, determines the cover type and TREAT performs the silvicultural treatments selected in SCREEN. Trees selected for removal are designated as cut and the live trees are again divided into species and diameter groups by a recall of subroutine FIT. This allows the changes in species composition caused by cutting to change the species groups thereby changing the numerical constants used to project the plot.

The tree list is projected one year at a time for the number of years in a cycle by subroutine GROW, REMOVE and ISUM. The crown ratio function, potential growth function, and modifier function are used to determine individual tree growth. Dead trees are determined using the mortality function and the pseudo-random number generator.

OUTPUT

Four different output types are possible:

- (1) "Yield table" type output containing such variables as basal area and number of dead trees, number of surviving trees, basal area and sum of diameters on a per plot and per acre basis, and cut tree volumes on a per acre basis. This output is given by subroutine OUTPT1 and is available at the end of each cycle as well as at the beginning and end of the projection period.
- (2) A new Renewable Resources Evaluation (forest survey) unit record file (subroutine TFILE and OPENRD).
- (3) A file for validating the projection system. This is produced by subroutine OUTPT2 and has meaning only if two or more measurements have been made on the plot. The file produced by OUTPT2 is ordinarily stored on disk and analyzed by a separate user-written program.
- (4) A user-designated output file (subroutine OUTUR).
- (5)

LITERATURE CITED

- Buckman, Robert E. 1962. Growth and yield of red pine in Minnesota. U.S. Dep. Agric., Tech. Bull. 1272, 50 p., illus. Wash., D.C.
- Dale, Martin E. 1972. Growth and yield predictions for upland oak stands 10 years after initial thinning. USDA Forest Serv. Res. Paper NE-241, 21 p., illus. Northeastern Forest Exp. Stn., Upper Darby, Pa.
- Ek, Alan R. 1974. Nonlinear models for stand table projection in northern hardwood stands. Can. J. For. Res. 4(1):23-27.
- Ek, Alan R., and Robert A. Monserud. 1974. FOREST: a computer model for simulating the growth and reproduction of mixed species forest stands. Res. Rep. Sch. Nat. Resour., Univ. of Wis., Madison, Wis. 85 p., illus.
- Larson, Robert W., and Marcus H. Goforth. 1970. TRAS--a computer program for the projection of timber volume. U.S. Dep. Agric., Agric. Handb. 377, 24 p., illus.
- Moser, John W., Jr. 1972. Dynamics of an uneven-aged forest stand. Forest Sci. 18(3):184-191.

Perala, Donald A. 1971. Growth and yield of black spruce on organic soils in Minnesota. USDA Forest Serv. Res. Paper NC-56, 16 p., illus. North Central Forest Exp. Stn., St. Paul, Minn.

Schlaegel, Bryce E. 1971. Growth and yield of quaking aspen in northcentral Minnesota. USDA Forest Serv. Res. Paper NC-58, 11 p., illus. North Central Forest Exp. Stn., St. Paul, Minn.