FORESTRY FUTURES

Proceedings
of

MIDWESTERN FOREST MENSURATIONISTS,

GREAT LAKES FOREST GROWTH AND YIELD COOPERATIVE,
AND THE
FORESTRY CANADA MODELING WORKING GROUP JOINT WORKSHOP
SAULT STE. MARIE
ONTARIO
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EDITED
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ONTARIO MINISTRY OF NATURAL RESOURCES,
GREAT LAKES FOREST GROWTH AND YIELD COOPERATIVE
AND
THE BIOMETRICS WORKING GROUP OF THE SOCIETY OF AMERICAN FORESTERS

FOREWORD

A joint workshop of the Midwestern Forest Mensurationists Group (MWFMG), Great Lakes Forest Growth and Yield Cooperative (GLFG&YC), and the Forestry Canada Modeling Working Group was held in Sault.Ste. Marie, in August 1991.

The main theme of the joint workshop was "Forestry Futures", an objective look at the future direction of forestry research, with emphasis on growth and yield as related to sustainable forest management. Seventy two delegates representing Forestry Canada, Ontario Ministry of Natural Resources, U.S. Forest Service, and various University Forestry Faculties attended the workshop.

The Midwestern Forest Mensurationists Group was organized in 1967 with about 20 members mainly from the Midwestern United States. Since then its membership has grown to well over three hundred from coast to coast in the U.S. and Canada.

Arising from the need for accurate and broadly useful information, The Great Lakes Forest Growth and Yield Cooperative is designed to encourage the development of forest growth and yield information. The primary objective of the cooperative is to foster the collection, pooling, and synthesis of such data within the Great Lakes Region of Canada and the United States, and to provide a strong data base for developing and refining forest growth and yield prediction methods. Since it inception in 1985, GLFG&YC has held semi annual meetings, often jointly with those of MWFMG.

The Forestry Canada Modeling Working Group, established in 1985, has served as a forum for Forestry Canada modelers for discussion and exchange of information. The Working Group has continued to function by holding approximately annual workshops. To broaden the level of information exchange, a joint meeting of the above three groups was organized. The joint workshop was held in Sault Ste. Marie, Ontario, in August 1991; it was scheduled to allow concurrent sessions and joint functions with the Midwestern Forest Economists Meeting.

A short opening address of welcome by Dr. Carl Winget, director general, Forestry Canada, Ontario Region, was followed by brief introduction of participants. Some 24 papers in four sessions on growth and yield, forest dynamics, inventory, and measurements were presented. In a poster and model demonstration session, additional information on recent research was presented in diverse areas such as growth and yield modeling, geographic information systems, wood supply analysis, and cost-benefit analysis. Thursday afternoon was allotted to guided tours of:

- the federal and provincial forestry establishments
- aviation and fire management centre and museum
- Turkey Lake acid rain study area
- St. Mary's Paper
- Lake Superior provincial park pictographs.

The workshop concluded with separate business sessions for the three groups.

I would like to extend sincere thanks to all speakers and poster presenters and to Drs. Monty Newnham, Tom Burk, Mike Bonnor, and John Moser for moderating workshop sessions. Special thanks are also due Dave Kennington, Pia Papadopol, Roj Miller, Rod Smith, Guy Smith, Stig Andersen and Steve Rossi for their assistance in making this workshop most successful.

Bijan Payandeh

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SECTION III - BUSINESS MEETING

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PAPERS

ONTARIO GROWTH AND YIELD PROGRAM

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History

Forest growth and yield work in Ontario has a history that stretches back at least 70 years. Early growth and yield work established in Ontario includes the Spruce Falls Pulp and Paper Company permanent sample plots, installed in the 1920's near Kapuskasing. Many of these plots have been maintained to the present day. Also in the 1920's T.W. Dwight, working for the provincial government, carried out a study of "the rate of growth of spruce and jack pine in the vicinity of the upper drainage waters of the Pic River", near Longlac Ontario (Dwight, 1931). Most mensurationists should appreciate how Mr. Dwight undertook a stem analysis study of tree growth and yield over 60 years ago with the purpose of "partly or entirely eliminating the stem analysis of trees" in future growth and yield work (Dwight, 1931).

In the late 1950's two major studies were carried out on a province-wide basis, the development of Normal Yield Tables for the primary tree species groupings in the province (Plonski, 1956), and the development of provincial cull tables for the major provincial timber species (Morawski et al., 1958). Unfortunately, the publication of the two works that resulted from these studies in the late 1950's was the last major coordinated effort in forest growth and yield in Ontario, with the result that the forest inventory and management system in this province is still based primarily on a foundation put in place more than 30 years ago. There has been other work in growth and yield in the province during the past 30 years, but it has been fragmented and uncoordinated, with numerous false and abandoned starts, and designed primarily to meet local, not provincial needs.

Examples of the uncoordinated efforts are numerous. Many companies operating in the northern part of the province have established permanent sample plots, but with differing goals, aims, and standards. Some were designed for inventory purposes only, with no trees measured below a large minimum diameter, and no tree heights measured at all; some have no individual tree numbers or measurements; some plots, although technically well set up, represent only the best sites and stands; and, many plots were measured for 10 or 20 years but abandoned in the 1960's or 1970's.

Regional offices of the Ministry of Natural Resources put in many plots across northern Ontario in the 1970's, but almost all were temporary sample plots based on stem analysis technology, and each Region had differing goals and standards. One Region measured all living trees in temporary sample plots and then extrapolated the information based on the stem analysis of 4 trees of quadratic mean diameter; another Region put in destructive sample plots where all the trees in a 10 metre by 10 metre quadrat were cut down for stem analysis; and, a third Region put in temporary plots with soil pits and the stem analysis of one or two dominant trees, and from this information developed site index curves and soil-site index relationships.

The provincial government, through main office and through its forest research arm (OFRI) established numerous PSP's in red pine plantations and hardwood stands in southern Ontario in the 1950's and 1960's. However, the red pine plots represent a very limited area provincially, and the hardwood plots are scattered with no discernable system for the various management options carried out in the plots.

In the 1980's there was a growing demand in Ontario for more and better growth and yield information. Plonski's Normal Yield Tables (Plonski, 1956) were no longer meeting the needs of foresters trying to move from the exploitation to the management of the province's forests. At the same time, regional initiatives were not effectively filling the gaps, and the permanent sample plots in existence were providing data, but no useful information or knowledge to the managing forester. A lot of money was being spent on growth and yield, but no significant progress was being made.

In late 1989 a decision was made to try to produce a growth and yield strategy for the province. A committee was struck, and input was solicited within MNR from across the province. A first draft was drawn up based on the input received, and circulated for comment. At this point it became obvious that there was no consensus within MNR on how to proceed with growth and yield. There was no agreement on what the needs were, or on the methods to be used to address those needs, or on the product development required to meet the needs, in both the short term and in the long term. It was also obvious that various user groups representing most aspects of forest resource management had a strong interest in obtaining improved growth and yield information, along with opinions about what information should be obtained, and how that information should be obtained. These user groups included those in the forest industry as well as within MNR, including on-the-ground forest managers, resource management planners, wood supply modellers, wildlife habitat specialists, forest inventory managers, ecosystem classifiers, silvicultural specialists, entomologists, geneticists, climatologists, as well as mensurationists.

A decision was then made in the spring of 1990 that a provincial growth and yield strategy should be developed by building consensus on how to proceed among all user groups interested in improved growth and yield information. This was to be accomplished by holding a series of three workshops, facilitated by an independent consultant. These workshops were to be attended by a wide range of provincial growth and yield experts, related specialists and interested users, and held in the spring of 1991.

The Process

At three growth and yield workshops held earlier this year the first task was to identify and bring to the table all user needs and concerns. Then an expert systems approach was used to build a working simulation model of forest growth and yield in Ontario, based on the collective understanding of all the workshop participants. This development of a working simulation model was used to introduce scientific rigor into the discussions about what factors are really involved in forest growth and yield. From the simulation model and based on described user needs a series of testable management hypotheses were derived. These hypotheses were then evaluated by the workshop participants and the significance to growth and yield of all inputs and outputs were evaluated and described. From this evaluation exercise there then followed a design and methodology workshop, where participants actually got down to the task of designing a provincial growth and yield program for Ontario, based on the previous user needs and on the results of the hypotheses evaluation workshop. This methodology design workshop was conducted in mid-April 1991.

The methodology design workshop had the goal of producing a detailed growth and yield work plan. This work plan was to include the list of tasks required to obtain improved short term growth and yield predictions. As well, the work plan was to include the tasks required to put a program in place to obtain long term answers in growth and yield, in the most efficient manner possible to satisfy all user groups and interested parties.

In the history of growth and yield in Ontario over the past 30 years much of the emphasis has been placed on obtaining short term, immediate-need predictions and results, with the effect that no mechanism has been put in place to obtain the long term answers. However, because those long term prediction mechanisms were not put in place in Ontario over the last 30 years, there is at the present time a very immediate need to provide new and better short term answers to current problems in growth and yield in Ontario. So we are left with the requirement in Ontario of putting a program and task list in place for the long term, while at the same time getting it up and running immediately. We need to provide the answers from the long term program tomorrow that resource managers required yesterday.

The task list for the Ontario growth and yield program necessarily includes the identification of the types and amounts of data and data analyses required for the program, the development of minimum standards for all field sampling, the identification of the types of models and modelling standards to be used, as well as the identification of knowledge gaps in growth and yield and related disciplines and the research requirements required to narrow these knowledge gaps. We also need a stratification scheme for growth and yield in the province - one that fits in with existing and proposed Forest Ecosystem Classification (Jones et al., 1983, Sims et al., 1989) and Ecological Land Classification (Wickware and Rubec, 1989) schemes. Given the above-noted requirements, we also need to know how much the entire program is going to cost, what the completion schedule is going to look like, and who is going to do what (an interesting question vis-a-vis industry in these recessionary times, when MNR is also in the process of a major reorganization).

The Results

Where are we now as related to growth and yield in Ontario? All the planned workshops have been completed, and the final strategy development report (growth and yield program plan) has been completed in draft form (Kurz et al., 1991) and circulated to all workshop participants and other interested parties. The draft report does not completely address all the required issues, but the outstanding issues will be identified in the final report so that they may be resolved at a later time.

There are several major items of interest for mensurationists in the draft Ontario growth and yield program plan (Kurz et al., 1991). Because of the need to provide immediate short term improved growth and yield information to users, the first new growth and yield models for Ontario will be based primarily on existing data. That existing data, as stated previously, is of quite variable quality because it was not necessarily gathered with the purpose of providing data for growth and yield models, or for the types of growth and yield models necessary today. The geographic coverage of most of the data sets is also quite restricted. Ontario is a huge forested area, slightly larger than the size of the combined states of Minnesota, Wisconsin, Michigan, Indiana, Ohio, Pennsylvania, New Jersey, New York, Rhode Island, Massachusetts, Connecticut, Vermont, and New Hampshire. The data that we currently have for growth and yield modelling over this vast area consists of approximately 1200 good PSP's. A good PSP is defined as one where all individual trees are numbered, all diameters are measured at each remeasurement, and a sample of heights is estimated. We have 120 good PSP's in mature and over-mature jack pine, black spruce and mixed conifer stands in north-central Ontario, 250 plantation spruce PSP's in north-central and north-eastern Ontario, 80 jack pine plantation plots in north-eastern Ontario, 200 red pine and 50 white pine plots primarily in south-western Ontario, 270 tolerant hardwood and 50 intolerant hardwood plots scattered through southern

Ontario, and 150 southern Ontario jack pine thinning and provenance trials (of questionable value, as they are outside the commercial range of jack pine in the province). In addition to these plots there are several hundred federal and provincial research plots in managed tolerant hardwoods and in red pine and white spruce plantations, all located in south-central and south-eastern Ontario.

The majority of the land area and commercial timber in Ontario is in the north (although I should emphasize again that we are not just interested in timber in the forest growth and yield program in Ontario), yet only about 40 percent of our very limited set of PSP's are found in this part of the province, and the majority of these existing plots are in plantations with only one or two measurements! These existing good PSP's in the north can be supplemented with a further 260 spruce PSP's in north-eastern Ontario, where no individual trees were numbered, and approximately 2500 continuous forest inventory plots of all species in north-western Ontario, which have virtually no measured tree heights and a very large minimum diameter threshold. There are also data sets from across the province of stem analysis measurements, which are of course of very limited use in developing whole stand growth and yield models.

In addition to developing the first approximation growth and yield models for the province from existing data sets, the

Ontario growth and yield program will also look at using existing models, calibrated for Ontario conditions, for these first approximation models. Some U.S. models, most notably STEMS (Belcher et al., 1982), already contain modelled relationships for many Ontario species, and so hopefully could be easily adapted to Ontario conditions.

For the long term, the Ontario growth and yield program will be based primarily on permanent sample plots to be established across the province over the next 5 years. These permanent sample plots, with information and data to be entered and stored in a provincial data base, will be supplemented with stem analysis measurements and mortality estimates at the time of establishment, to provide immediate information for short term growth and yield modelling use. All permanent sample plots in the program will be set up and remeasured according to provincial minimum standards, and coordinated provincially to avoid duplication, overlap, and redundancy.

There are still several outstanding issues to be resolved. The size of the PSP's to be established is undecided, as is the home for growth and yield modelling in the province. We are trying to address some of these issues with consultant studies before we get too far advanced into the program. There is a limited amount of growth and yield modelling expertise in Ontario, and additional expertise will undoubtably have to be acquired and/or developed. The roles and responsibilities of industry and government in growth and yield are unresolved issues, as is the related issue of whether or not to carry out the program through the use of a co-operative type arrangement. These issues will necessarily have to be resolved before we begin full-scale implementation of the growth and yield field program in the spring of 1992.

Conclusion

Hopefully we are well on the way in Ontario to developing a modern forest growth and yield program over the next few years. If anyone is interested in our program plan, copies of the first draft are available now, and a major revision based on reviewer comments should be available from the author by mid-September. We welcome comments, criticisms, suggestions, or ideas related to the growth and yield program plan at any time.

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Growth and Yield / Stand Dynamics in the Northeast Region

N.L.Maurer [1]

Introduction

The Northern Forest Development Group has recently initiated a Growth and Yield program for the Northeast Region of the Ontario Ministry of Natural Resources. The program is intended to address immediate client needs by providing information and tools on forest growth, yield and stand development. The needs of forest managers can be summed up in a request that came from one of our industry clients "Growth and Yield, any aspect". This simple request emphasizes the need for the direction we have given to our regional program. The need for interim information that meets the immediate and short term needs of forest managers while we are gathering data from Permanent Sample Plots.

I would like to present to you a "nuts and bolts" outline of our program, briefly describe some of the products delivered to date, and tell you about were we are going in the future.

The Growth and Yield / Stand Dynamics Program

Client Needs

Our clients have identified these areas as requiring immediate attention:

- Modelling - Yield Curves
  - Growth Models
  - Wood Supply
- Inventory - Large Scale Photography
  - Ground Sampling
- Habitat - Stand Structure
  - Snags
  - Browse.

Using this client request list we formulated the program shown in Figure 1. Our program uses strategies identified in the Provincial Growth and Yield Program of: temporary sample plots, chronosequencing, and exploitation of existing data sets to generate interim information while a permanent sample plot network is being established. This information includes volume equations, inventory, yield curves, and habitat descriptions.

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[1] Regional Growth and Yield Projects Forester, Northern Forest Development Group, Timmins, Ontario

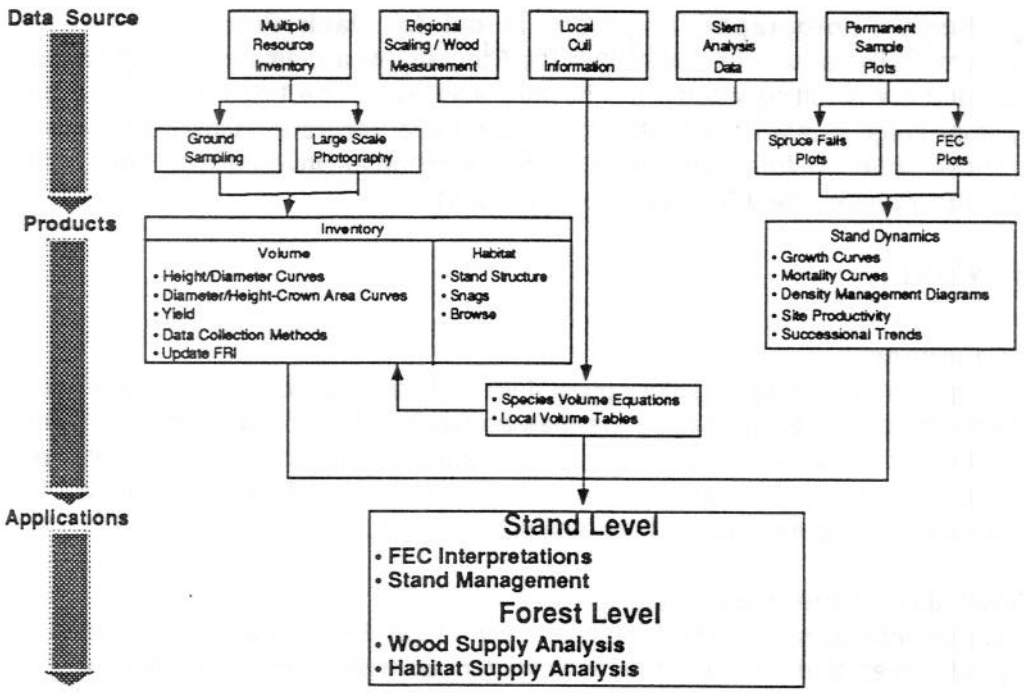


Figure 1: An outline of the Northeast Region Growth and Yield / Stand Dynamics Program.

Products to Date

Inventory

Ground Sampling Volume Inventory Procedure

We reviewed the existing inventory methods and compiled a ground sampling procedure for volume by species and stand that provides the forest manager with a defensible inventory of stand description and volume yield by species with a known precision. By monitoring the precision of the volume information we can maintain the data's suitability for input to validate yield curves. This procedure has been used to generate volume inventories for Timmins District.

Data Collection Standards

Through field testing common height and diameter measurement tools, we defined measurement precision standards and guidelines for data collection methods. Additional guidelines were then developed concerning the effect of measurement errors on volume per hectare estimates so that forest managers can make informed decisions about the measurement precision required for their inventory.

Test of a Large Scale Photography Inventory Model for Jack Pine

Using a jack pine stem analysis data set we tested the accuracy of a diameter prediction "Height-Crown Area" model and the resulting volume per hectare estimates. The test model demonstrated that the inventory from Large Scale Photography produces more accurate estimates of volume per hectare than those obtained from our current Forest Resources Inventory or from inventory stand descriptions and Plonski Yield Tables (Plonski, 1981).

Volume and Yield

Local Volume Equations

A component of the ground sampling inventory procedure is data collection to produce local height-diameter relationships for each species that can be used with the equations developed by Honer *et al.*, 1983, to produce local total and gross merchantable equations. A local total volume per tree equation for the Gogama Area and a local validation of Honer's jack pine volume equations were completed using an existing stem analysis data set.

Input to NORMAN Jack Pine Yield Curve

Northern Region is presently using a modified version of the FORMAN wood supply model: NORMAN. The yield curves that drive the model were derived mainly from a mixture of literature review and expert opinion. Using the jack pine stem analysis data set we compiled point estimates of yield (net merchantable volume per hectare by age) that are being used as input to validate the NORMAN wood supply model jack pine yield curve.

Site Productivity

Site Index by FEC Group for Black Spruce

Spruce Falls Power and Paper Company Ltd., located in the clay belt of Northeast Region, has been measuring their permanent sample plots since 1930. The data set has been analyzed to produce site index curves for black spruce organized by Forest Ecosystem Operational Groups. This our first quantitative look at productivity between Ecosystem Groups.

Near Future

Inventory

Snag Inventory Procedure
35 species of wildlife are dependent on dead trees. Snags are a critical habitat element for resident species such as woodpeckers, flying squirrels, pine marten and chickadees. With improved forest management and potentially shorter stand rotations, special efforts may be required to maintain the snags component in a forest from one rotation into the next. Critical questions relate to abundance of snags in stands of different types and ages and to the life expectancy of snags. In a pilot project, we tallied all dead standing trees by species, dbh, height and condition in Gogama using a BAF 2 prism cruise. The condition codes are described in Figure 2. An analysis of the data is in progress to determine variability and subsequent sample sizes for prism cruising and whether prism cruising is an expedient approach to sampling snags.

Browse Estimation Techniques
The current Forest Ecosystem Classification typing of forest stands provides an indication of which browse species occur in different stand types. However, adequate characterization of stand quality for herbivores requires some knowledge of available biomass (kg/ha). Last winter, we ran trial browse surveys in forest stands in Timmins and Kapuskasing to assess a sampling methodology. Clusters of five $5m^2$ circular plots were tallied for all woody stems greater than 50 cm tall. One subplot was randomly selected and all browsable twigs were clipped to a specified diameter for oven dried weights. In addition, the first occurrence of each browse species was measured for height and basal diameter and clipped. We intend to derive regression equations for browse biomass with independent variables including stem density, average stem height, and overstory cover.

A second approach to regression equations would be via allometric relationships between individual stem dimensions and biomass. Expected products include the regression equations and a sampling protocol to measure independent variables during operational cruising.

Volume Inventory for 2 Management Units
The Timmins Crown Unit and Quebec and Ontario Paper Company Ltd. are conducting ground sample volume inventories in allocated stands. Results of these two inventories will also be used to complete local cumulative volume tallies for both units. In addition, we will be comparing the local volume tallies to increase our knowledge of the geographic scope of the height-diameter relationship.

As our inventory data base grows we will be using the species-age yield points as input to validate species' yield curves for the NORMAN model.

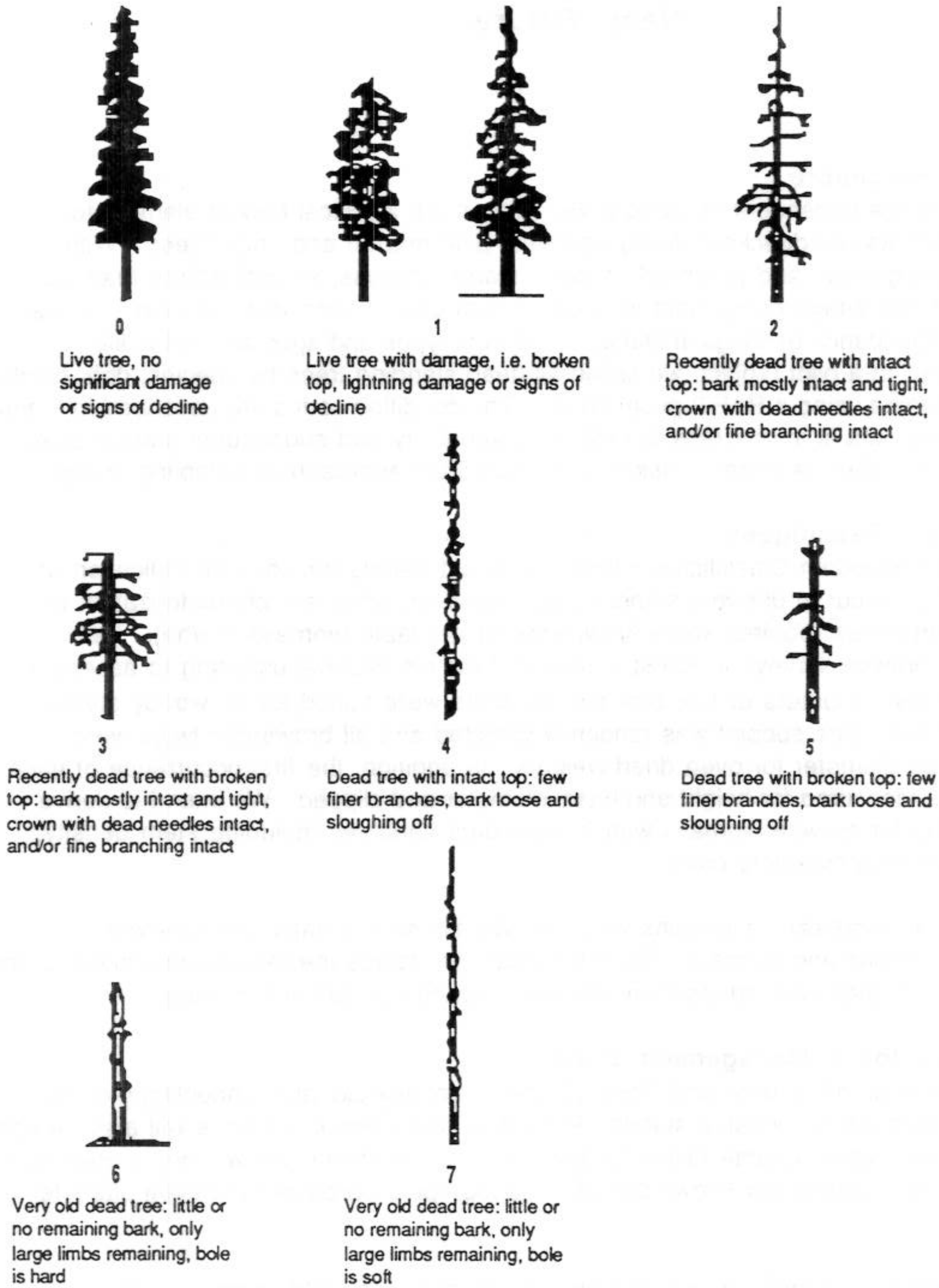


Figure 2: Condition codes for Tree and Snag Inventory.

Production and Validation of Inventory from Large Scale Photography

Prior to beginning the ground sample inventory on the Timmins area limits of the Quebec and Ontario Paper Company Ltd., a cooperative project between the company, the Ministry of Natural Resources and Dendron Resource Surveys Ltd. was initiated that will produce an inventory from large scale photography and validate the stand volume per hectare estimates based on ground sampling and roadside yield.

Volume and Yield

Validation of Species' Volume Equations and Yield Curves

Local black and white spruce stem analysis data sets are available for validating species' total and gross merchantable volume equations. Analysis is scheduled for this winter. The black and white spruce data sets will also be compiled into net merchantable volume per hectare yield estimates for input into the validation of the NORMAN wood supply model spruce yield curves.

For the remaining commercial species we will be using our regional scaling data base to test the accuracy of volume equations.

Preliminary Plantation Yield Curves

We are currently working with our clay belt counterparts in Quebec to compile preliminary plantation yield curves for jack pine and black spruce. The project is analyzing a combination of our stem analysis data, inventory from the Survey of Artificially Regenerated Sites conducted by the Ministry of Natural Resources, and plantation yield data from Quebec.

Local Cull Information

To date our cull information consists of cull tables developed by Morawski *et al.*, revised 1978. These cull tables have served us well but our clients require product oriented tables that reflect local conditions. Preliminary work on updating cull information is being done by Chapleau District.

Permanent Sample Plots

We are looking toward establishing a permanent sample plot network, as partner of the Provincial Program, in 1992.

Site Productivity

Site Productivity for Black Spruce and Jack Pine

A cooperative project, initiated in 1989, between Northern Forest Development Group, Petawawa National Forestry Institute, and Spruce Falls Power and Paper Company Ltd. is analyzing the permanent sample plot data collected by Spruce Falls since 1930. Models are being developed to predict tree growth, development of stand structure and stand break-up. The Phase 1 report by Whynot and Penner (1990) is currently under revision for re-issue. The Modelling phase is progressing, in cooperation with Quebec and Ontario Paper Co. Ltd. Another product of this analysis will be a density management diagram for black spruce in the clay belt.

A jack pine site index study is being conducted by Lakehead University.

Treatment Response

Thinning

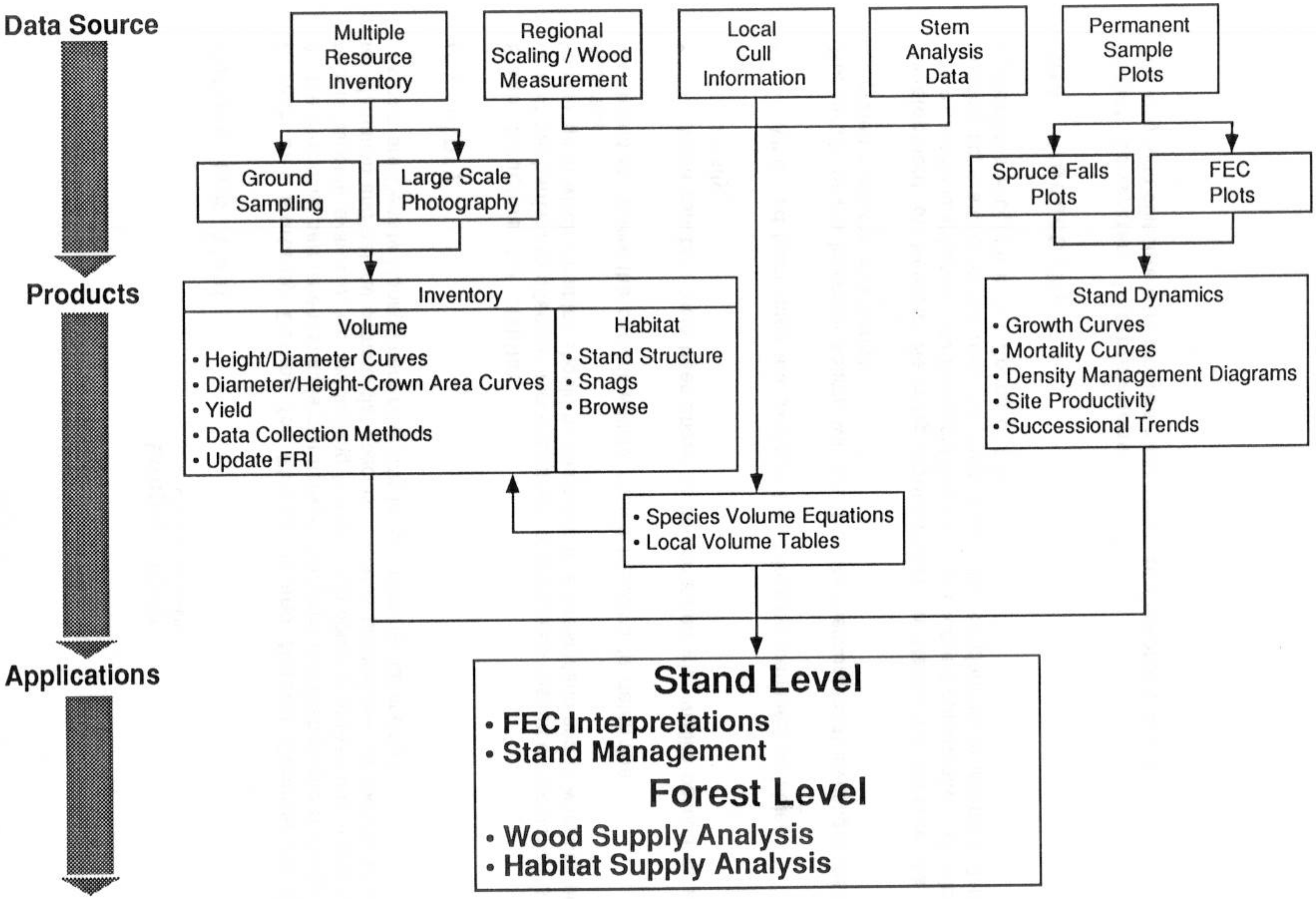
This fall we plan to analyze and report results for jack pine from 2 juvenile spacing and 1 mature thinning project.

Peatland Drainage

Forestry Canada is continuing to monitor response to drainage in the peatlands of the Wally Creek area of Cochrane District.

Successional Trends

Through analysis of data collected for Forest Ecosystem Classification we will derive Succession Curves by Operational Group for major understory species following clear cutting, mechanical site preparation, herbiciding and fire. We will also be deriving an Edaphic grid for relative timber productivity potential. Preliminary work in chronosequencing old growth cover type successional pathways has been proposed.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Longer Term

Volume and Yield

Growth and Mortality Curves for Plantation and Natural Commercial Species
As the Provincial permanent sample plot network becomes established and remeasurement results become available, we are looking forward to producing growth and mortality information for plantation and natural commercial species. Another product we are looking to derive from this data are Density Management diagrams for our commercial species.

Inventory

Stand Structure for Habitat
One of the barriers to effective implementation of integrated resource inventories is a lack of knowledge of which variables should be measured in a forest stand and to what degree of accuracy.
We intend to review the current wildlife habitat literature to determine:

- Which variables have been shown to be correlated with wildlife occupancy and/or density

- What field techniques are available for estimating identified variables.

The results of the literature search will direct future mensurational investigations related to integrated resource inventories.

Development of Remote Sensing Applications in Resource Inventories
The extensive land base in the Northeast Region is an excellent opportunity to develop Remote Sensing applications for our resource inventories. We are planning to initiate a Remote Sensing Applications Program in the Spring of 1992.

Site Productivity

Forest Ecosystem Interpretations
The long term objective is to produce Yield Tables by Operational Group.

Treatment Response

Successional Trends

Continuing work in identifying successional pathways for the FEC Operational Groups.

Peatland Drainage

Continuing work monitoring long term response to drainage in the Wally Creek area by Forestry Canada.

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SOURCES OF VARIATION IN THE MODEL ONTARIO PLANTATION

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As all of you are now aware, Ontario is presently in the thick of formulating a growth and yield strategy. I won't bother repeating what Roj has already said about the main points of the strategy, but there is a strong push within the formulation to pursue a stratification system to aid in the gathering and subsequent use of growth and yield data. It has been suggested that this stratification take the form of a two way edaphic grid using moisture and nutrient availability. The basis for recommending this course of action was largely circumstantial evidence and the combined advice of many experts in the field. It remains however, an untested and unproven strategy in real terms.

A small study was set up back in 1989 to take a closer look at a similar type of grid, and its potential for providing a framework around which growth and yield prediction may develop. This summer I was contracted by the Ministry to review the data from this study to provide some answers. This paper today is an abbreviated version of a summary of some of those results. Analysis of this data is still ongoing to some degree, and very little real 'analysis' will be presented - and I do not offer this as an apology, only a warning. In fact, much of what I will say will be based on circumstantial evidence and gut feeling. The sample size is somewhat less than ideal, leaving many questions raised unanswered. Despite this, I hope I can provide some entertainment.

This particular study is a fairly narrow one, designed to identify the sources of variation within a tightly controlled sample. The idea was to hold as many variables as possible as constant, and vary the site within a limited range of conditions. A number of assumptions accompany the design of the project that become critical.

Plantation jack pine was chosen as the test sample because of:

- its great abundance in selected locations
- its abundance in relatively pure conditions in plantations
- the presence of historical records and d) the consistency of silviculture and establishment techniques.

To eliminate both age and climate effects, ideally we would have preferred to hold year of establishment constant, but that being insufficient for an adequate sample, a 3 year span was allowed. The chosen span of 14-16 years was a balance between having plantations old enough to have shaken the effects of establishment off, and have been growing as a stand for some time, and recent enough to possess records acceptably complete, and been established with techniques similar to those used today.

Macroclimate was held constant by sampling within a small geographical range in Kirkland Lake district. The consistency of establishment treatments, and the use of historical records allowed us to hold many of the cultural treatments within reasonable bounds. This included replanting, tending, spacing, seed source, planting method, site prep, and holding method. Plots were established in matched pairs of areas with >80% jack pine by basal area.

Three site 'types' were chosen to compare, based on the simplest form of stratifying using moisture regime and soil texture class. The three types were dry medium and coarse sand, dry fine sand, and fresh coarse loam. The classification of a plot was dependant on a description of a single soil pit located after examining a grid of auger samples. Lab analysis of texture only was conducted.

The simplified nature of this stratification reflected the use of such a system in the field. The important features of the system were simplicity, identity, flexibility, and based on universally accepted criteria.

24 pairs, or 48 permanent growth sample plots were established in the summer of 1989, roughly evenly distributed among all 3 site types. And, in the buffer of 33 of these plots, destructive sampling of trees of quadratic mean dbh and dominant height took place providing stem analysis data.

RESULTS

Since the result of consequence in a growth and yield model is volume, stand MAI from the PSP data was considered the most relevant productivity variable. Average height at a constant age (15 years) was used as an indication of potential productivity.

After examining the original stratification scheme in terms of a simple ANOVA, and through manipulation devising a slightly altered version, 22% - 41% of the variation could be captured by a site stratification system. Regression pushed R-squared values close to 50%, but the use of a stratification even on this limited data range produced results equal to that typical of most soil/site studies. Combining site and age variables pushed regression R-squares up over the 50% level, but the remaining 50% was still on the loose. The search was on.

In spite of our assumptions concerning the elimination of establishment effects, the year of establishment turned out to be strongly correlated with early height growth of the stand. Although this declines rapidly with age, its effect can still be seen at the present, accounting for a noticeable portion of the variation. On the other hand, the influence of site on height, can be seen to increase with age. So far, things seemed to be working out well.

After this, I took a shot at regressing average height and MAI against categorical plantation identity. A single plantation could have anywhere from 2 to 11 plots, and from 1 to 3 site types. The R-squares proved both average height and MAI could be predicted better from knowing the plantation number than the site they are on. Although the correlation between plantation and site was fair, it is not possible to explain this solely on that basis. A simple plot of the plots grouped by plantation shows an inconsistent relationship between similar sites between plantations.

There was no denying at this point that the influence of not only the year of establishment, but the exact conditions of establishment are critical to the initial stages of development and that these differences can remain relevant many years later. A detailed examination of the records showed some minor variation in site prep, weather at time of planting, holding method, planting date, delay between site prep and planting, etc. etc.. But little indication of why one series of plots established in the same year even, performed so differently, and apparently without respect for our carefully laid out stratification system. The exception, plantation 4, was the only one noted to have been planted with stock that was noted as only "fair to poor". This is little consolation if this is indeed the case. It may satisfy our curiosity in this case, but poor planting stock affecting the growth of stands 15 years hence is not a good omen for empirical growth and yield strategies in the new forest.

The reality of this situation is mirrored in an examination of the Survey of Artificially Regenerated Sites (SORAS) data. The SOARS project was to report on the condition, extent, composition, and growth of the artificially regenerated forest in Ontario. From 1984-87, over 3,000 sample plots were randomly located in plantations over the age of 10, and seeded areas over the age of 15. The data from SOARS jack pine plantations could be considered to represent the population for comparison against the Kirkland Lake sample.

Using the same site criteria, and similar stand criteria, it is estimated that the Kirkland Lake data set accounts for 61% of the jack pine sites, yet only 25% of the range of stand conditions. A considerable portion of jack pine plantations stand on the sites we are studying. However, site alone cannot account for most of the variation within that. The remaining 75% of the stands (literally 1,000's of hectares) is being influenced by factors other than site, or most likely other factors in combination with site. Initial stand conditions are the first to come to mind in light of our findings earlier, as are the amount of competition, since we eliminated studying this potential from the start. This despite numerous studies in Ontario and the northern midwest that jack pine is only marginally affected by variables such as provenance, planting method, planting quality, and site preparation methods.

I'm not trying to say that initial plantation conditions play the most important role in deciding the ultimate yield of a plantation. It seems as if some of the plantations are in fact outgrowing initial conditions, as we had hoped - but it is taking more time than we had thought, and, In light of the magnitude of some of the differences in stand measurements right now, it is unlikely all of these plantations will outgrow their handicaps.

Another bothersome question is related: Why would average stand height of the SOARS plots possess standard deviations and ranges close to double that of the Kirkland Lake sample? Height growth in jack pine is supposedly density independent. Perhaps this, and many other assumptions of jack pine based on isolationary studies should be reconsidered. Perhaps it is the preconceptions about building a better growth and yield machine that had better be questioned. There is no simple solution beyond Plonski's general level tables. Using faster and more powerful analytical techniques that we are now capable of, blinded us to the real questions, because answers were so much easier. Now even the excuse of poor data is becoming a thing of the past. Are we in fact building a so called "new" growth and yield strategy using old ideas with new money and analytical power?

The question is rhetorical, but raises an interesting point. Typically, empirical techniques of model formulation necessarily involve circumstance cause and effect relationships. These relationships are based on process only to the degree to which the forest, stand or tree is responding to site conditions, natural or otherwise. Most modellers know all about this and accept it, since it has always been the most reliable method of controlling variation and, to be honest, giving reliable answers. What the users will soon discover however, is that there is no flexibility in such a system; a new strata always being the answer to bettering the model. Empirical approaches thus assume a complete understanding of the problems to be solved.

How comfortable should we really be with accepting this approach without identifying real process? In answer, I'll tell you the last relevant piece of information from the Kirkland Lake study: the results are backwards. The moderate degree of success we got in having site explain productivity and potential productivity is in complete opposition to every other soil/site study done in natural jack pine stands in Ontario. The coarsest, driest site which performed so well for us in Kirkland Lake has always been identified as the poorest site in natural stands.

Am I advising that site not be used to stratify growth and yield data collection and use? On the contrary, I'm saying it must be respected as representing a large bold step, and taken very seriously. It is not a simple matter to move from general level normal growth curves to using stratified models. As a single step solution it will very likely fail in my opinion. If what growth and yield has been in the past remains as a prevailing attitude, it will likely fail too. Conducting only mathematical cause and effect modelling from isolated studies has kept the lid on real understanding of growth processes and in many cases real needs. It seems that by mucking around with forest sites in an unnatural manner, we have created an even greater need to understand the natural processes that take place.

The alternatives for Ontario now are severely limited. No process oriented work is ongoing, nor proposed to any significant degree; prolonged and justified dislike for the present system is rampant; and a ecologically based system will provide the opportunity to proceed with ecological, silvicultural, genetic, and establishment studies in parallel with the basic data gathering growth work. The level of understanding and commitment necessary for implementing such a system however goes far beyond that assumed in the past, and possibly the present.

NATIONAL GROWTH MODELLING PROPOSAL

by

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ABSTRACT

The Forestry Canada Modelling Working Group is seven years old. It has served as a forum for scientists to discuss and exchange information on progress, problems and methodologies, but a proposal has now been made that Group members cooperate on a Canada-wide growth modelling project.

The project has two major tasks: first, the cooperators agree on a growth model framework. The type of model selected will depend on purposes and needs. Second, the cooperators develop modules or components which are "attached" to the framework. Each cooperator will develop new modules or components, or calibrate existing ones, to suit regional needs.
Advantages and disadvantages of this approach are discussed, and the current status is outlined.

INTRODUCTION

Considerable interest exists nation-wide in developing better growth and yield information. As an example, the Second Report by the Standing Committee on Forestry and Fisheries (November 1990) states that growth and yield research is critical, and recommends that ForCan directs its own research projects to long-term studies which bear national implications and are unlikely to be performed by others, such as growth and yield modelling and analysis. Also, client surveys indicate that the need for better growth and yield information is high.

With these considerations in mind, I thought that the ForCan growth and yield scientists, scattered across the country in small groups, might combine their efforts and cooperate in a growth modelling project. At the annual meeting of the ForCan Modelling Working Group last December, I discussed the general concept with some of our scientists. They expressed more support than scepticism so a proposal was sent to ForCan establishments, soliciting comments and support. The responses were almost universally positive. We went another round to get more specific information about the involvement and contribution of individual scientists. Again, we received good support. So we are now at the point where some details have to be worked out, and some commitments have to be made.

THE PROPOSAL

The proposal has two parts: first, the cooperators agree on the framework or architecture of the model and, second, they develop modules or components which can be attached to the framework.

The model framework will depend on the specific purposes and uses of the model. For example, it may be designed to estimate future growth and yield for inventory updates, AAC calculations and timber supply analyses. It may predict growth of a stand from establishment until harvest, starting at any intermediate point, for natural or managed stands. Modelling the effect of silvicultural treatments (e.g. thinning and fertilization) on stand growth may also be included. A model which meets these objectives will likely be a combined stand and tree growth model.

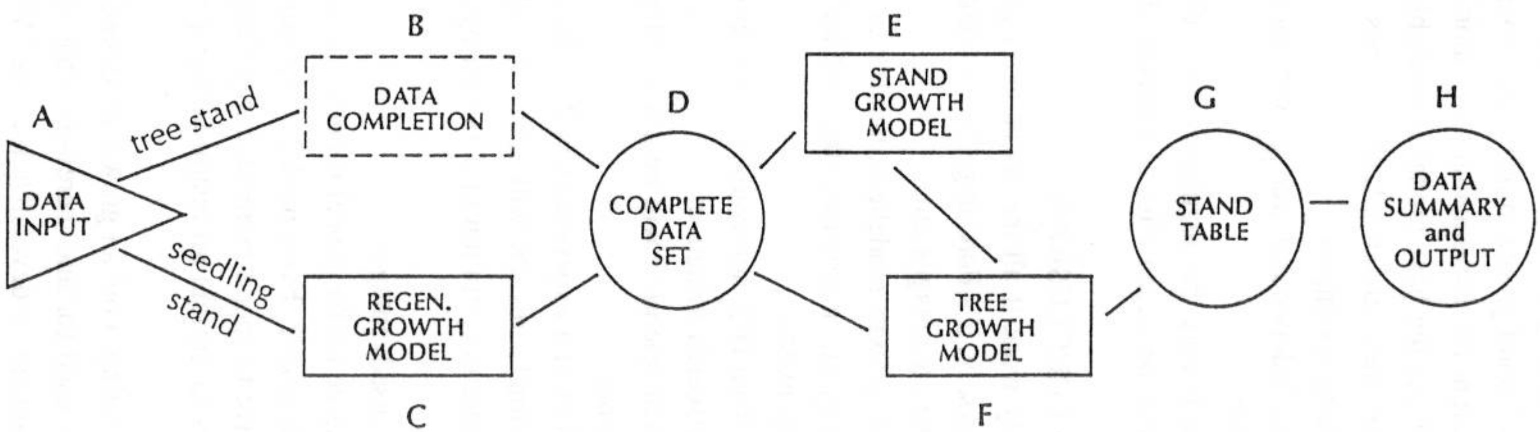
In developing the components, cooperators must initially agree to develop a basic set of components which create a useable model, i.e. one which can be used to grow trees or stands. Subsequently, model components will be developed by individual project cooperators to meet regional requirements. For example, NoFC may develop a model for aspen. One of the uses of the model may be to update AFS inventories. Components will therefore be designed to use as input such data as are available from AFS inventories. Another forester may want to investigate the effect of defoliation on aspen growth. To do so he 'only' needs to develop a growth reduction component and attach it to the model, he does not need to develop the whole model.

Each ForCan establishment will consult and cooperate with clients within its own region in developing components and sharing data. ForCan establishments may also cooperate among themselves in these tasks, and in developing complete models for individual species.

Figure 1 helps to illustrate the points made above. It shows the framework, i.e. the major components and the linkages among them, of a growth model being developed at the PFC. Components A through D deal with the creation of a complete data set for the young tree stand to be grown; if the input data in A are complete, components B and C will not be used. In E and F, the stand data from D are grown separately, for as long a period as desired. At the end, the two projections are reconciled and a stand table is produced in G. This table is used with height-diameter equations and other data to generate a full set of tree and stand characteristics.

PFC Prototype Stand Growth Model

Overview Flow Chart



The framework and linkages shown in Figure 1 are of the type which ForCan cooperators must agree on initially. Next, they must jointly develop the basic set of components. For example, component E labelled "stand growth model" may consist of a series of equations by which stand basal area and top height are incremented, and mortality and ingrowth are predicted. With the completion of these tasks the base model is available for use: cooperators can replace existing components with new ones, attach additional ones, calibrate an existing system for different species, and so on. Some examples:

- an existing distance independent tree growth model (component F) may be replaced by a distance dependent one;
- components E and F may be augmented to account for thinning and fertilization; or- an economics module may be added after component H, to convert volumes into values.

DISCUSSION AND CONCLUSIONS

This venture will only work if all the cooperators gain from it, if the advantages outweigh the disadvantages. Conversely, if a ForCan growth modeller feels he will not gain from participating, he will not do so. The advantages are:

- a "critical mass" of growth modellers, lacking in individual ForCan establishments, will be available in a joint project;- a structure (the ForCan Modelling Working Group) for sponsoring such a project already exists;
- additional funding from HQ, not available for regional modelling efforts, may be available for this national scope research initiative;
- research of individual scientists will be advanced by using the prototype model as a basis for testing new components;
- the exchange of ideas and experiences will be facilitated;
- better and more timely results will reach the client community; - cooperation in model development will foster cooperation in data sharing;

There are two main disadvantages:

- cooperators must agree on the model framework, i.e. the major components and their linkages, and must develop the major (base) model components jointly; and
- cooperators will have to spend more time travelling, meeting and talking to each other.Neither disadvantage appears to present an insurmountable obstacle.

At the end of this meeting, ForCan growth modellers will start to make the hard decisions: what should the model be used for and therefore, what should be the model framework? Should we use an existing framework or develop a new one? What are the base components? Who is going to participate, and who will do what part? We must also select a coordinator for the project, for communications and coordination purposes. Further, we will discuss data sharing, and the establishment of an electronic communications network.

In conclusion, the proposal has received a good response so far, most ForCan growth modellers have expressed interest in participating. Now the expressions of intent must be translated into positive action.

An Unevenaged Growth and Yield Model for Ponderosa Pine

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Abstract. A system of algebraic difference equations is presented for projecting stand level number of pole trees, survivor number of merchantable trees, and survivor basal area. Ingrowth is indirectly derived from a projection equation that estimates the total change in the number of pole trees. The individual tree growth equation and mortality function are consistent with the stand level projection equations. The ingrowth diameter distribution is modeled with a parameter recovery method for the Uniform distribution. The species of ingrowth trees are predicted from equations that are a function of habitat series and cumulative ratios of trees per acre by species.

Additional key words: Pinus ponderosa, differential equations, components of growth, Uniform distribution, habitat type.

While the bulk of southwestern ponderosa pine (Pinus ponderosa) is managed by the United States Forest Service with even-aged practices, the USDI Bureau of Indian Affairs in east-central Arizona has trust responsibilities for large tracts of tribal timberlands of ponderosa pine that are managed by uneven-aged practices. The Fort Apache Indian Reservation possesses approximately 506,000 commercial acres of ponderosa pine, and it represents a vital natural resource for timber production, large game habitat, and recreation revenues.

As noted by Murphy and Farrar (1988), considerable progress has occurred in uneven-aged growth and yield methodology since the first models were pioneered by Moser and Hall (1969). Hann and Bare (1979) traced the historical background of uneven-aged management and they recognized the important contribution of the northern hardwoods diameter class growth model by Ek (1974). The Leslie matrix model methodology has been applied to diameter class growth models, and the new stage classified, density dependent matrix models (Solomon et al. 1986; Haight and Getz 1987), are reported to have computational advantages over individual tree growth models.

Hyink and Moser (1983), Lynch and Moser (1986), and Murphy and Farrar (1988) obtained compatibility between stand level uneven-aged models and diameter distribution models. The term compatible implies that the same estimates are obtained from yield equations and implicitly derived yield from diameter distributions. These authors utilized the parameter recovery method to obtain parameters for the Weibull probability density function.

Pienaar and Harrison (1988) and Harrison and Daniels (1988) have demonstrated techniques for obtaining compatibility between stand level yield projections and individual tree basal area growth projection models in even-aged stands. This study uses a system of difference equations to project several stand density attributes. An extension of the Pienaar and Harrison methodology is presented for achieving compatibility between stand level and individual tree basal area growth. The ingrowth component is obtained indirectly as the arithmetic difference of two difference projection equations, and it is distributed by the Uniform distribution utilizing a compatible parameter recovery method.

MODEL DEVELOPMENT

DATA

The data used to develop the uneven-aged ponderosa pine model came from 0.2 acre Continuous Forest Inventory (CFI) plots that were established on the Fort Apache Indian Reservation in 1968 and remeasured in 1974 and 1984. Three plots (placed 330 feet apart) were systematically located on a 6600 foot grid over the forest type on the Fort Apache Indian Reservation.

The trees of commercial species and size (dbh $\geq$ 5.0 inches) are permanently identified on each CFI plot. Data collected for each remeasurement included: dbh to the nearest 0.1 inch; dwarf mistletoe rating; classification of mortality, cut, or ingrowth. Individual tree heights were obtained by sub-sampling at each remeasurement period.

STAND LEVEL EQUATIONS

The following variables are used for the stand level equations of the ponderosa pine type. All variables exclude any measurement of noncommercial woodland species.

N_{pk} = number of merchantable pole trees (5 in. $\leq$ dbh < 12 in.) per acre at time k, excluding ingrowth.

t = the projection length in years.

N_k = number of merchantable trees (dbh $\geq$ 5.0 in.) per acre at time k, excluding ingrowth.

N_{sk} = number of merchantable sawtimber trees (dbh $\geq$ 12 in.) per acre at time k, excluding ingrowth.

N_{Ik} = total number of merchantable pole trees (5 in $\leq$ dbh < 12 in.) per acre at time k, including ingrowth.

I_N = number of ingrowth trees per acre at time k, i.e. trees that had dbh less than 5.0 in. at the beginning of the projection interval but exceeded 5.0 in. and are alive at the end of the projection interval.

I_B = the basal area per acre in square feet of I_N.

B_k = merchantable stand basal area (dbh $\geq$ 5.0 in.) per acre in square feet at time k, excluding ingrowth.

S = ponderosa pine site index (Stansfield et al. 1991).

E = stand elevation in hundreds of feet.

During the projection period, pole trees that are larger than 5.0 in. at time 0, may either die, survive, or move into the sawtimber class. The movement into the sawtimber class will be referred to as upgrowth. A hypothesized model for the instantaneous change of pole tree upgrowth and survival in uneven-aged stands is:

$$\frac{dN_p}{dt} = aN_p^b$$

where

a, b = model coefficients.

After solving the separable differential equation, reparameterizing, and fitting to the difference model by nonlinear least squares, the number of pole trees excluding ingrowth may be expressed as:

$$N_{pt} = \left[N_{p0}{}^{0.312586} - 0.005731\,t\right]^{3.199196} \qquad (1)$$

The length of the projection period has an invariant effect on the model, and if t=0, $N_{pt}=N_{p0}$.

A hypothesized model for the relative instantaneous change of merchantable tree survival is:

$$\frac{1}{N}\frac{dt}{dN} = a + b\,\frac{1}{N_p+1}\,\frac{d(N_p+1)}{dt}$$

where a, b are model coefficients. After transformation, reparameterizing, and fitting in the difference form, the model may be expressed as:

$$N_t = N_0\left(\frac{N_{pt}+1}{N_{po}+1}\right)^{0.233783} e^{(-0.001379\,t)} \qquad (2)$$

where e is the base of natural logarithms. This model is invariant to the length of the projection period and is logical if t=0. The number of sawtimber trees at time t may be estimated as the difference between equation (2) and equation (1):

$$N_{st} = N_t - N_{pt}$$

A hypothesized model for the instantaneous change of merchantable stand basal area in square feet per acre is:

$$\frac{dB}{dt} = aB^bS^cE^d(N^e + N_s^f + g)$$

where a, b, c, d, e, f, and g are model coefficients. After transformation, reparameterizing, and fitting in the difference form, the projection equation for stand level survivor basal area may be expressed as:

$$B_t = \left[B_0^{0.4317396} + 0.001588\,S^{0.344513}\,E^{0.722349}\,k_1\right]^{2.316211} \qquad (3)$$

where

$$k_1 = \left(\frac{N_t^{\,0.552844} - N_0^{\,0.552844}}{0.5528844} + \frac{(N_{st}+1)^{0.310164} - (N_{so}+1)^{0.310164}}{0.310164} + 0.234381\,t\right)$$

The modeling of ingrowth is a difficult task, and past efforts of directly modeling ingrowth or the instantaneous change in ingrowth (Ek 1974, Moser 1972, Hann 1980, Hyink and Moser 1983, and Lynch and Moser 1986) have not explained a high percentage of variation. Several of the ingrowth models contain predictor variables that are well correlated with ingrowth but fall short as causal mechanisms of ingrowth. The proposed model also contains predictor variables that are highly correlated with ingrowth, however ingrowth is indirectly computed. A hypothesized model for the total instantaneous change in merchantable pole trees that includes upgrowth, survival, and ingrowth is:

$$\frac{1}{N_I}\frac{dN_I}{dt} = a + b\frac{dN}{dt} + c\frac{dB}{dt} + d\frac{dN_s}{dt}$$

where

a, b, c, and d = model coefficients.

After transformation, reparameterizing, and fitting in the difference form, the model may be expressed as:

$$N_{It} = N_{p0}e^{(0.0393979\,t + 0.009635(N_t - N_0) - 0.004285(B_t - B_0) - 0.007907(N_{st} - N_{s0}))} \quad (4)$$

The number of ingrowth trees per acre may be indirectly derived by the subtraction of equation (1) from equation (4):

$$I_N = N_{It} - N_{pt} \quad (5)$$

PARAMETER RECOVERY, INGROWTH DISTRIBUTION, AND SPECIES CLASSIFICATION

Following the solution of equation (5), it is possible to predict the basal area of ingrowth trees. The basal area of ingrowth trees is an increasing function of the number of ingrowth trees, the projection interval, and a decreasing function of the number of merchantable trees per acre at time k excluding ingrowth. The following equation for ingrowth basal area per acre was fitted using nonlinear least squares:

$$I_B = \frac{0.164764\, I_N^{\,1.027342}\, e^{(0.020460\,t)}}{N_t^{\,0.057734}} \quad (6)$$

Under the assumption that the ingrowth component is best described as an annual pulse function, and that the inverse j-shape of diameters does not become apparent until mortality is observed, the use of the Uniform distribution for modeling the diameter distribution of ingrowth was attempted. The Uniform probability density function for the ingrowth component is defined as:

$$f(x) = \frac{1}{(b-a)} \qquad a \le x \le b$$

where a and b define an interval and x is the random variable (dbh). The "a" parameter may be set to equal 5 inches. The "b" Uniform distribution parameter is recovered by recognizing that

$$d_{qI}^2 = \int_5^b \frac{x^2}{b-5}\,dx = \frac{b^3-5^3}{3(b-5)} \qquad (7)$$

where

$$d_{qI}^2 = I_B/(0.005454\ I_N)$$

The term $b^3 - 5^3$ may be factored as $(b-5)(b^2 - 5b + 25)$, making it possible to solve for the "b" Uniform parameter from equation (7) as

$$b = \frac{-5 + \sqrt{25 - 4\left(25 - \frac{3\,I_B}{0.005454\,I_N}\right)}}{2} \qquad (8)$$

Once the ingrowth trees are distributed to diameter classes, they must be classified by species. Although this system of growth and yield equations is intended to be utilized with the ponderosa pine type, other species such as Douglas-fir (Pseudotsuga menziesii) and white fir (Picea abies) are present in the ponderosa pine type, especially at higher elevations or in shaded north aspects at lower elevations. The following species classification model is a cumulative fraction that ranges from values of 0 to I_N

$$R_i = I_N\left(\frac{\sum_1^i N_i}{N_t}\right)^{0.661794}\left(\frac{\sum_1^i N_i}{N_t}\right)^{0.395911X_1}\left(\frac{\sum_1^i N_i}{N_t}\right)^{1.003416X_2} \qquad (9)$$

where

R_i = cumulative fraction of ingrowth for species 1 up to species i

i = species

- i = 1 species is ponderosa pine
- i = 2 species is Douglas-fir
- i = 3 species is southwestern white pine (Pinus strobiformis)
- i = 4 species is white fir
- i = 5 species is aspen (Populus tremuloides)
- i = 6 species is blue spruce (Picea pungens).

I_N = number of ingrowth trees per acre evaluated at time k=t.

N_t = total number of merchantable trees (dbh $\geq$ 5.0 in.) per acre evaluated at time k=t excluding ingrowth.

N_i = number of merchantable trees (dbh $\geq$ 5.0 in.) per acre evaluated at time k=t for species i excluding ingrowth.

x_1 = 1 if habitat series is PSME (Douglas-fir climax habitat)
0 otherwise
x_2 = 1 if habitat series is ABLA or ABCO (corbark fir or white fir climax habitat)
0 otherwise

When the index i=6, then ΣN_i then must equal N_t, and consequently $R_6=I_N$. To compute the number of ingrowth trees that are classified for species i, one must subtract R_{i-1} from R_i. For example, the number of Douglas-fir ingrowth trees equals R_2-R_1. These Douglas-fir trees are then evenly distributed among the ingrowth trees from 5.0 inches to the "b" Uniform distribution parameter.

INDIVIDUAL TREE MORTALITY AND GROWTH

Stand level mortality of commercial trees per acre is computed with equation (2) and by taking the difference between N_0 and $\hat{N}_t$. In addition to the knowledge of stand level mortality however, the prediction of individual tree mortality can be of great importance. Presented below is a method that distributes mortality across the range of dbh values for the individual tree list at the beginning of the growth interval. Similar to the Harrison and Daniels (1988) cumulative ratio model of mortality, this approach provides compatible estimates between individual tree mortality and stand level mortality. The use of the cumulative mortality equation below requires that the tree list be ranked in ascending order by dbh. The following model was fitted by nonlinear least squares:

$$cm_j = (N_0 - \hat{N}_t)\, k_2^{k_3} \qquad (10)$$

where

$$k_2 = \frac{d_{jo} - (d_{\min}-1)}{d_{\max} - (d_{\min}-1)}$$

$$k_3 = e^{\left(-10.1939\, k_2{}^3 - (0.00215443\, B_0)^3 - 0.21384\, (B_t - B_0) - 0.019019\, (N_0 - N_t) + 0.014117\, t\right)}$$

cm_j = cumulative number of trees (dbh $\geq$ 5.0 in.) that die up to the j th tree during the growth interval t. The trees are ranked in ascending order by dbh.
d_{jk} = the diameter at breast height for the j th tree at time k.
d_{min} = minimum diameter observed in tree list at time 0.

d_{max} = maximum diameter observed in tree list at time 0.

B_k, N_k, and t = stand level variables previously explained.

The mortality represented by each individual tree is computed by substracting successive values of the cumulative function: $cm_j - cm_{(j-1)}$. It should be recognized that equation (10) provides estimates of individual tree mortality that is consistent with the total tree survival function, equation (2).

The individual tree basal area growth and projection equations of Harrison and Daniels (1988) and Pienaar and Harrison (1988) provide compatible estimates with the stand level basal area projection equations. Both of these models were developed from plantation data and they predict that individual tree basal area growth increases as dbh increases. While this is a logical function for even-aged stands, it is not uncommon to encounter uneven-aged stands where the basal area growth of a thrifty pole tree exceeds the basal area growth of a large old-growth tree. As a consequence, a new uneven-aged model for individual tree growth was needed.

Attempts to model an individual tree diameter squared projection function with ratio functions similar to the Pienaar and Harrison (1988) were unsatisfactory. These models displayed biased behavior over at least one of the geographic regions of the extremely diverse topographic and climatic conditions of the Fort Apache Indian Reservation. Finally we chose a parameter prediction method and fit the following linear model to 24, 1 inch diameter classes:

$$d_{jt}^2 - d_{j0}^2 = a d_{j0}^2 \frac{B_t}{B_0} t + b d_{j0}^2 \frac{N_t}{N_0} t + c d_{q0} t \qquad (11)$$

where

d_{q0} = quadratic mean diameter of merchantable trees (dbh $\geq$ 5.0 in.) of the stand at the beginning of the projection interval.

a, b, and c are coefficients to be estimated.

The equation above posseses the logical behavior when t=0, and $d_{jt}^2 = d_{j0}^2$. Equation (11) was fitted to 24 diameter classes beginning with the 5 inch class and incrementing by 1-inch classes. Trees greater or equal to 31 inches were included in the 24 th class. When the 24 estimated values of $\hat{a}$ and $\hat{b}$ were plotted over d_{j0}, a linear trend was apparent while the $\hat{c}$ parameter displayed no linear relationship. The $\hat{a}$, $\hat{b}$, and $\hat{c}$ parameters of the general model, equation (11) may be predicted with the following equations:

$$\hat{a} = 0.094824 - 0.002815\ d_{j0} \qquad (12)$$

$$\hat{b} = -0.099949 + 0.003053\ d_{j0} \qquad (13)$$

$$\hat{c} = 0.1273624 \qquad (14)$$

When equations (12-14) are inserted into equation (11), the individual tree diameter squared and basal area of trees at time t may be computed. If the individual tree basal areas are summed and compared to B_t, the values will rarely be identical. Following the procedure of Pienaar and Harrison (1988), consistency between the stand level basal area projection equation and the implicit basal area of the individual tree diameter squared model is obtained by adjusting the individual tree estimate with the following correction factor:

$$\frac{B_t}{\left[0.005454 \sum_{j=1}^{N_t} \left(d_{jo}^2 + \hat{a} d_{jo}^2 \frac{B_t}{B_0} t + \hat{b} d_{jo}^2 \frac{N_t}{N_0} t + \hat{c} d_{q0} t \right)\right]} \qquad (15)$$

From the summation operator in equation (15), it is apparent that only those individual trees that survive during the entire projection interval are grown. When equation (11) is rearranged and the correction factor is applied, the final expression for individual tree diameter squared projection is obtained:

$$d_{jt}^2 = \frac{183.3465 B_t \left(d_{jo}^2 + \hat{a} d_{jo}^2 \frac{B_t}{B_0} t + \hat{b} d_{jo}^2 \frac{N_t}{N_0} t + \hat{c} d_{q0} t \right)}{\sum_{j=1}^{N_t} d_{jo}^2 \left(1 + \hat{a} d_{jo}^2 \frac{B_t}{B_0} t + \hat{b} d_{jo}^2 \frac{N_t}{N_0} t \right) + \hat{c} N_t d_{q0} t} \qquad (16)$$

where
$\hat{a}$, $\hat{b}$, and $\hat{c}$ are defined by equations (12), (13), and (14) respectively. This equation is used for all trees in the ponderosa pine type, regardless of species. The individual tree dbh of tree j at time t equals: $d_{jt} = \sqrt{\bar{d}_{jt}^2}$.

AN EXAMPLE OF THE STAND TABLE PROJECTION PROCEDURE

For the ease of presentation, an example will be provided using seven trees measured on a 10 BAF point sample from a typical uneven-aged stand of site index 75, and located at an elevation of 7000 feet. The diameters, species classification, and corresponding trees per acre of the "in" trees and other stand attributes at the beginning of the growth interval are presented in Table 1. The growth interval for this example is seven years.

From equation (1) and the information provided in Table 1, the calculated number of pole trees per acre at year 7 is 151.5. Using this pole tree estimate and equation (2), the predicted number of surviving number of merchantable trees per acre at year 7 is 172.1. As the number of pole trees decreased by 4.1 trees, and the total number of merchantable trees decreased by 2.7 trees, it is reasonable to assume that 1.4 or more pole trees grew into the sawtimber class. The number of sawtimber trees at year 7 equals the subtraction of the predicted value of equation (1) from equation (2), or 20.6 trees per acre. Stand basal area of merchantable surviving trees at year 7 is computed now with equation (3) and equals 76.2 sq. ft.

From equation (10) it is possible to compute the number of trees by diameter or dbh class that will die during the projection interval. In general, the relative proportion of mortality by diameter increases as dbh increases. The survivor trees by dbh class are presented in Table 1, and are obtained by substracting the mortality by dbh class from the number of trees at time 0. The individual trees may be grown in the unrestricted form by inserting equations (12-14) into equation (11). If this is performed with the example, the sum of individual tree basal areas implicitly predicts a stand basal area of 76.9 square feet. The correction factor is computed from equation (15) and is 0.9913. Finally individual tree diameters may be obtained by inserting the appropriate values into equation (16) and taking the square roots. The adjusted individual tree diameters at year 7 are presented in Table 1.

The computations above are used for the survivor component of the stand. To know the total basal area per acre and trees per acre of the stand at the completion of the projection period, the ingrowth component must be added.

From equation (4), the total number of pole trees standing at the completion of the projection period is computed to be 192.4 trees per acre. Using equation (5), it can be verified that the predicted number of ingrowth trees equals 40.9 trees per acre. The basal area of the ingrowth is obtained from equation (6) and it equals 6.4 square feet per acre. The ingrowth trees are then allocated uniformly to diameters and are conditioned so that implicit basal area of the ingrowth diameter distribution is equivalent to the stand stand level prediction of ingrowth basal area. From equation (8), the "b" Uniform distribution parameter is computed to be 5.7. This implies that the 40.9 ingrowth tree are evenly distributed between 5.0 and 5.7 inches dbh.

The total basal area per acre at the end of the projection interval equals the sum of the basal area of the survivor and ingrowth components, or 82.6 square feet. The total number of trees per acre at the end of the projection period, derived from the sum of the survivor and ingrowth components, is 213 trees per acre.

Before completing the computations of this example the ingrowth trees must be classified by species. From Table 1, it is apparent that there are 124.6 ponderosa pine and 47.5 Douglas-fir survivor trees per acre on a PSME habitat series. From equation (9), the number of ingrowth trees allocated to the ponderosa pine species is 29.1. The remaining number of ingrowth trees, or 11.8 trees, are designated as Douglas-fir trees. The distribution of each speices is evenly spread from 5.0 to 5.7 inches of dbh.

Table 1
Survivor tree stand table

dbh of "in" trees (d_{j0})	species	trees/ac. t=0	sub total	basal area/ ac., t=0	trees/ac. t=7	dbh of survivor trees, t=7	basal area/ ac., t=7
pole trees							
5.0	PP	73.3		10	73.1	5.8	13.2
6.2	DF	47.7		10	47.5	6.9	12.3
9.3	PP	21.2		10	20.6	9.8	10.8
11.7	PP	13.4	155.6	10	12.7	12.1	10.2
sawtimber							
14.3	PP	9.0		10	8.3	14.7	9.8
16.1	PP	7.0		10	6.7	16.5	9.9
24.1	PP	3.2	19.2	10	3.1	24.5	10.1
TOTAL			174.8	70	172.1		76.2

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Predicting Growth of Scots Pine on Drained Peatland in Finland

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Abstract

Growth and yield estimation requires a identification of the objectives of estimation, delineation of influential factors and their quantification, clarification of relationships, and prediction. The SINKA data set represents an unique source of individual tree growth data from stands on drained peatland.

Competition indices and random parameter modelling techniques were applied to seven pine-dominated plots in the SINKA data set. By quantifying stand, plot, and tree level variation, it was possible to identify weaknesses in the selection of explanatory variables. Surprising results for the relationship between competition indices and growth rates indicate that site productivity should be explicitly incorporated into any predictive model.

Background

Finland has 26 million ha forest, scrub, and wasteland and, of this, approximately one third is classified as peatland. Starting in the 1930s, and up to 1987, 4.47 million ha or approximately half of the peatland had been drained for forestry purposes. Comparatively little research has been done in Finland on the growth of forests on drained peatland after modification of hydrology and nutrition. Trees in many of the drained stands are reaching merchantable size, and guidelines for cutting and silvicultural prescriptions are required based on growth and yield studies.

Objective

The original objective of this investigation was to estimate the relative importance of inter-tree competition on individual tree growth in pine stands in drained peatlands. Later, the objective was modified to investigate sources of variation in the growth of pine. How important were various sources of variation in tree growth? Were the individuals within a stand relatively uniform with respect to growth?

Problem

Some of the difficulties encountered in this investigation are common to most growth prediction studies but some are unique to drained peatland.

Characterization of the site was extremely difficult. No widely accepted site classification scheme for drained peatland is available in Finland. Classification of undrained bogs is based on dominant tree species, peat topography, and indicator vegetation. This qualitative classification scheme has weak links to productivity. No equivalent classification scheme exits for drained peatlands which have an even wider range in hydrological and nutrient conditions. The changes following drainage include reduced hydrological problems, some nutritional disorders, and possible increases in mineralization rates. In addition, soil compaction following drainage poses a mensurational problem because the trees appear to rise out of the ground when soil subsides around the root collar.

The heterogeneity of stands also poses problems. These forests have largely arisen since the 1930s, when significant areas of land were drained. Therefore, they have few historical equivalents. The first stands that grew after drainage are particularly variable because resonse to drainage is variable, ingrowth can be significant, the age of the stand at the time of drainage varies, and the stands usually consist of a mixture of species. The age and species mixture, as well as changes in the site following drainage, make it difficult to classify these sites by traditional methods such as site index.

Data

The data were collected from a series of permanent sample plots established in the mid-1980s to monitor the growth of forests on drained peatland in middle and north Finland. Approximately 300 stands were randomly selected from the Finnish National Board of Forestry records. Three circular plots per stand were established, the size of the plot being adjusted according to basal area such that the three plots contained approximately 100 trees (the lower dbh limit was 4.5 cm if the stand was past the pole stage, 2.5 cm otherwise). The plot centre was permanently marked and various stand attributes, including drainage information, were recorded. The trees were marked with paint and species and dbh recorded. A smaller subplot was superimposed on the main plot and trees on these subplots are referred to as "sample" trees. At the time of plot establishment the sample trees were cored at breast height and past (under bark) 5-year dbh growth recorded as well as breast height age in some cases. Total height was measured and past 5-year height growth estimated for the sample trees. Diameter at 6m above ground was recorded for the taller sample trees. Signs of external damage (abiotic and biotic) were noted.

A total of seven stands were selected for further analysis (see Table 1). These stands were dominated by Scots pine (*Pinus sylvestris*), had no obvious nutritional or hydrological problems, and had not seen silvicultural activities in the past 20 years. Once a stand is transformed from its original understorey mire vegetation to understorey vegetation more typical of mineral soils, the theory is that hydrology takes care of itself. Barring extreme events such as frost and very wet years, evapotranspiration is assumed to take care of hydrology.

TABLE 1. A summary of the plots used in this investigation

Stand	ncoord (km N)	ecoord (km E)	elev (m)	dd (> 5C)	site[1]	trophy	water (cm)	drainage (yr)
9	7180	461	70	1030	VSR	3	-	
14	7204	453	70	1010	VSR	3	-	
16	7180	413	60	1020	RhSN	2	-	
17	7179	412	50	1030	RhSN	2	-	
20	7172	478	100	1020	KgR	4	-	
406	7352	458	150	894	RhSN	2	48	
409	7352	454	140	902	VLR	1	13	

1. Site types after
VSR = tall sedge pine mire
RhSN = herb-rich sedge fen
KgR = paludified pine forest
VLR = eutrophic pine fen

Method

Tree basal area was used as an indicator of tree size because dbh was measured on all trees. The relative growth rates of basal area (bargr), a unitless measure of growth somewhat adjusted for tree size, was used to indicate the tree's growth:

$$\text{bargr} = \frac{ba_2 - ba_1}{ba_1(t_2 - t_1)}$$

A maximum line was fit to the basal area relative growth rate data (Figure 1) which indicated the growth potential of a tree of a given basal area. The vigour of a tree was defined as a tree's basal area relative growth rate divided by the potential growth rate:

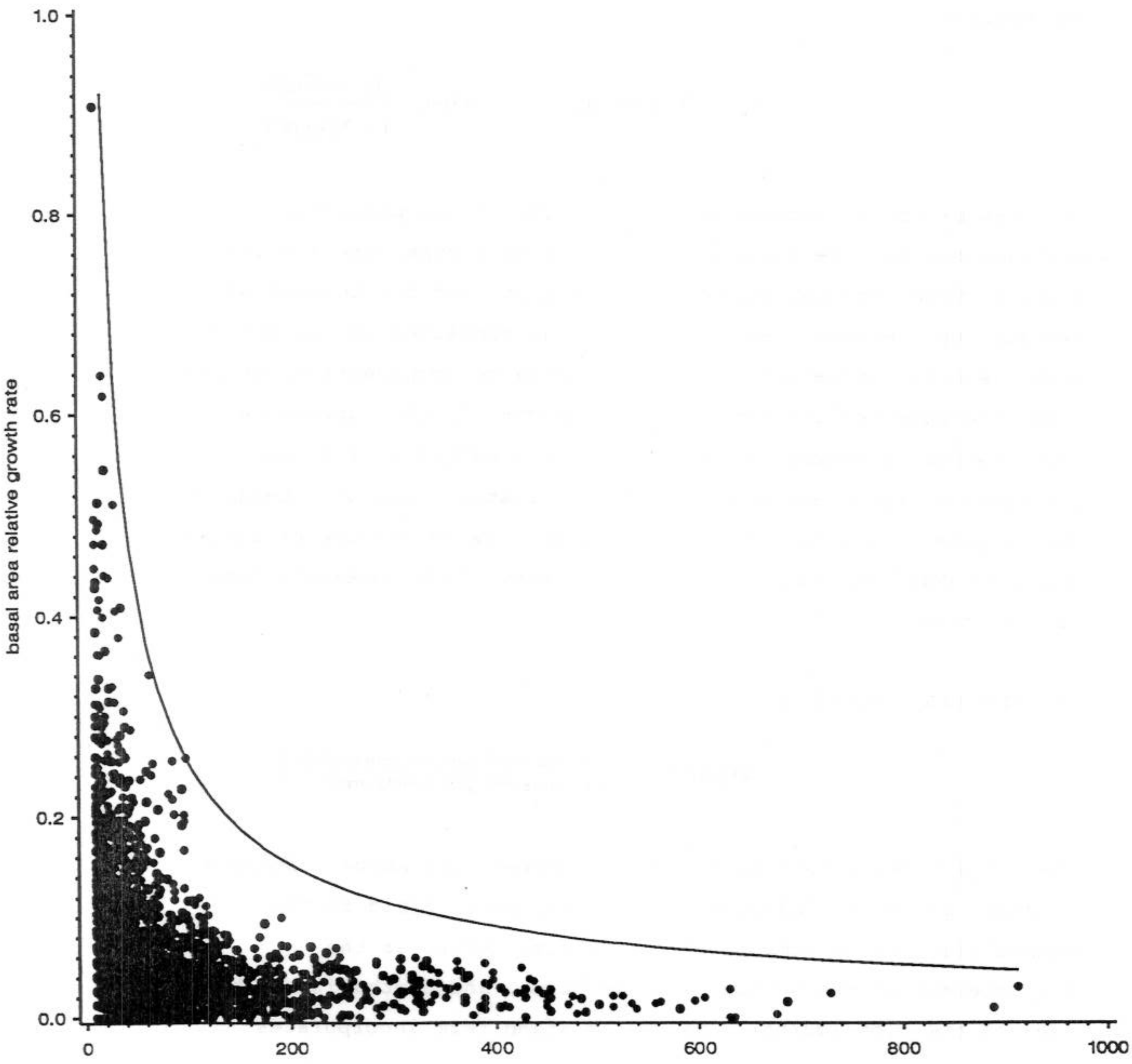
$$\text{vigour} = \frac{\text{bargr}}{\max(\text{bargr})}$$

Competition indices were based on the work of Pukkala (1989). The angle sum was computed by determining the horizontal angle formed by the subject tree's centre and the sides of the neighboring stems at 1.3 m above the ground and weighting by basal area:

$$\text{anglesum}_j = \sum_{i \neq j} \text{angle}_i \times \left(\frac{ba_i}{ba_j}\right)^{1.6}$$

The larger and closer the neighboring trees, the larger the angle sum. The centre of competition was calculated by assuming the tree of interest had coordinates (0,0) and by calculating the average coordinates of the neighboring trees, weighted by basal area. The distance from the centre of competition to the target tree indicates the symmetry of the neighboring trees around the target tree.

Figure 1: The maximum basal area relative growth rate



Competition fields are another approach to measuring resource sharing of trees. The potential demand of a tree is related to its size. Available resources are then allocated to all the trees, proportional to demand. The competition index measures the extent to which the available resources meet a tree's demand and are a function of the tree's size, the proximity and size of neighbors, and the resources available. The actual computational method follows that of Pukkala (1989) but basal area was substituted for height.

Variance components have been used to estimate the magnitudes of the variation and to localize coefficients. The general form of the model is:

$$y_i = X_i\alpha + B_i + \varepsilon_i \qquad \text{where } \frac{\beta \cdot N(O,D)}{\varepsilon \cdot N(O,\sigma^2 I)}$$

Thus the b-vector contains terms which add to the prediction variance but not the prediction mean. In this case, the a-vector contains terms for between-stand variability and the between-plot variability. Between-tree variability was contained in the error term. Several estimation methods for variance components exist and yield the same results for balanced designs. In this unbalanced case, method of moments (also known as the method of fitting constants of Henderson's method III) estimators were used because the computations were relatively straightforward and the estimates unbiased (Milliken and Johnson 1984). Lappi (1986) presents some of the theory.

The general model is

$$\text{vigour} = \left\{ \begin{array}{c} \text{fixed (dd, ba, field, comp + centre, plotba)} \\ \text{random (stand, plot (stand), error)} \end{array} \right\}$$

where the fixed effect dd is growing degree days above 5 degrees Celsius, ba is the individual tree basal area, field is the competition field, comp is the angle sum, centre is the displacement of the centre of competition, and plotba is the basal area of the plot (m2/ha). The random stand term incorporates variability due to drainage, site, age, precipitation, insect and disease damage, etc. The random plot within-stand term incorporates variation in density and local site. The random error term incorporates between-tree variability, that is, age, competition, genotype, microclimate, etc.

Results

The results of fitting the various models are presented in Figure 2 and Table 2. The error term was relatively stable for all models. Degree days and plot basal area reduced stand variability. Competition field did not significantly improve the model while the angle sum and the distance of the centre of the competition from the tree were significant. Stand level variation was the largest variance component and was also the most responsive to changes in the model.

Is inter-tree competition significant on these sites? Angle sum and centre of competition significantly improved the model for predicting vigour. However, the correlation was positive between angle sum and vigour. This somewhat unexpected result may be explained by examining the effect on the variance components of adding angle sum to the models. The expected effect of an individual tree competition measure is to reduce the random error term. In this case, the angle sum reduced the stand level variation. It appears that angle sum is acting here as a surrogate for site. More and larger neighbors increase the angle sum and also indicate a more productive site with fewer hydrological problems due to increased evapotranspiration. Isolating the benefits (increased evapotranspiration, positive correlation with site) of competition from the negative effects (competition for limited resources) was not attempted in this study. This confounding of positive and negative effects may also lead to weak correlation between competition field and vigour. Therefore, the effects of inter-tree competition could not be isolated.

TABLE 2. The correlations between the dependent variables and vigour are presented. The correlation sign is followed by its significance level. * indicates 0.05 > p > 0.01 and ** indicates p < 0.01. Blank cells indicate the variable was not used in the model.

model	basal area	degree days > 5C	plot basal area	competition field	angle sum	centre
1	+**					
2	+**	+n.s.				
3	+**			+n.s.		
4	+**		+n.s.			
5	+**				+*	-*
6	+**	+n.s.			+*	-*
7	+**	+n.s.	+n.s.			
8	+**	+n.s.	-n.s.		+*	-*

Discussion and Conclusions

Competition indices are easily misunderstood. They may be positively correlated with growth even when overall measures of growing stock, such as plot basal areas, are included in the model. The beneficial effects of neighbors on peatlands are not readily quantified. The importance of tree evapotranspiration in regulating hydrology may mask negative effects of competition. This merits further investigation because it has implications for thinning and harvesting prescriptions. Thinning may not necessarily have positive effects on growth of the remaining stems.

Variance components can be useful indicators in model building. In this case, the relative size of the components indicated that the greatest unexplained variation was at stand level. This also proved to be the most responsive component to changes in the model. The variance components also gave some indication of the contributions of the various fixed variables to the model.

Although tree competition indices may be expected to reduce tree level variability, in this case they reduced stand level variability, as shown by the variance components. Therefore, variance components, by indicating where the most unexplained variation lies, can point to fruitful areas to look for variables. In this study, variables which explained differences at the stand level proved to be the most useful in reducing unexplained variation. The influence of fixed parameters on the variance components may also aid in the interpretation of parameters. Partitioning of the unexplained variation is intuitively appealing since variables can be measured at different scales.

Acknowledgments

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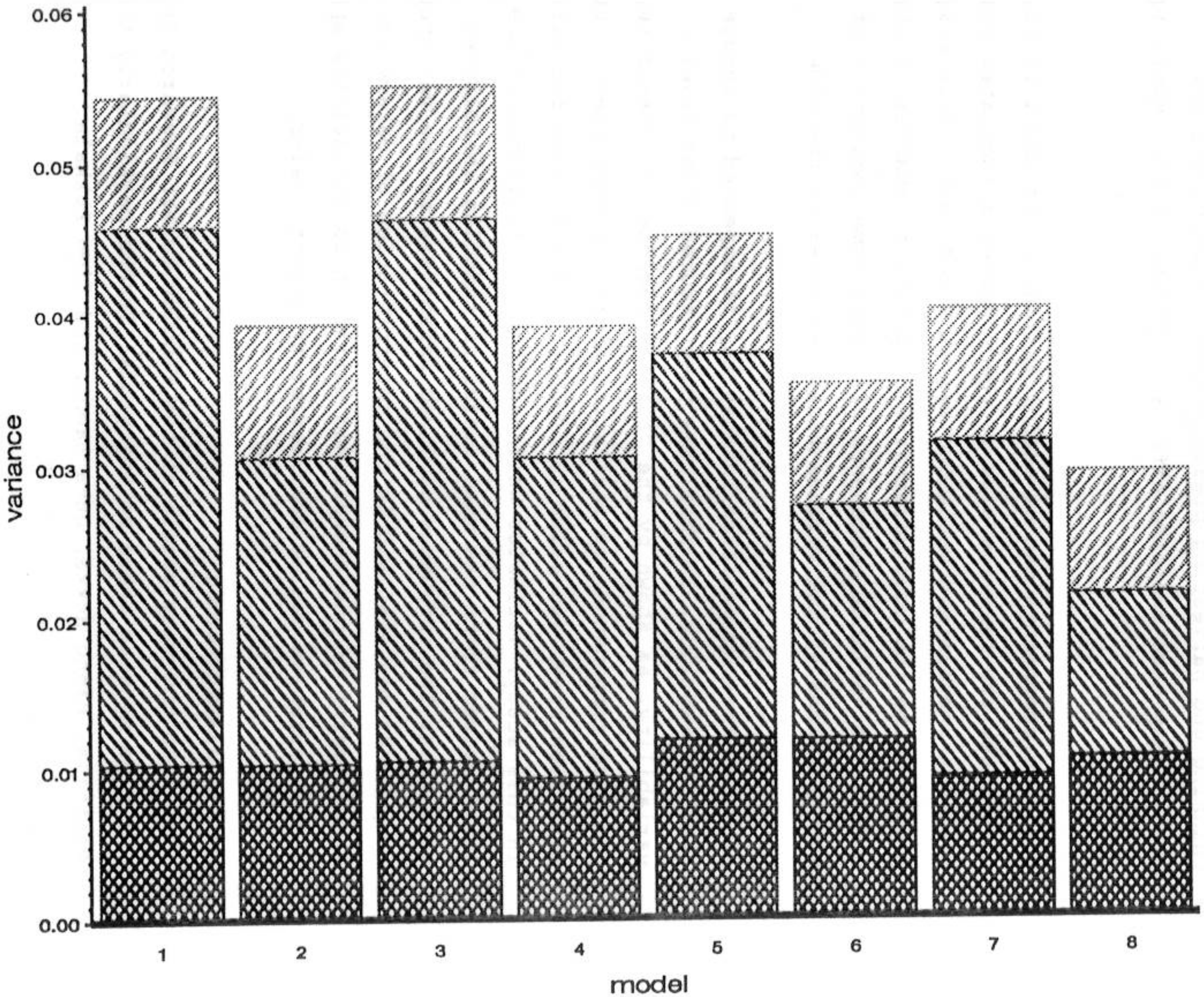
Figure 2. The variance components associated with each model (see table 2 for model descriptions). The tree level variance is stacked above the stand level variance which is above the plot level variance.



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SOME RESULTS OF FITTING A PROCESS-BASED GROWTH MODEL TO RED PINE

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ABSTRACT:

Several improvements have recently been made to the management-oriented growth process model of Sievanen et al. (1988, CJFR). As in the original model, dimensional change equations are built up by combining a carbon balance approach with assumed relationships among tree biomass components. Now, however, tree diameter increment is expressed as a function of four generalized construction and maintenance coefficients; these coefficients are explicit combinations of well-identified physiological and biometrical coefficients. This increment model, in combination with independent models of crown recession and stand mortality, leads to a growth model that can be reasonably well calibrated using standard measurements taken on permanent plots. Fitting involves specification of global constants, coefficients that are constant across plots, and coefficients that vary among plots. Multiple responses are fit simultaneously, resulting in a potentially complicated error structure. The basic components of the model will be identified and results of fitting to a series of red pine plots will be discussed.

UPLAND OAK GROWTH AND YIELD SIMULATOR THINNING ROUTINE INFLUENCED BY GRADE[1]

Daniel A. Yaussy[2]

Abstract: Generalized logistic regression was used to distribute trees into four potential tree grades for three upland oak species groups: white oak, black oak, and other tree species. The potential tree grade is defined as the Forest Service tree grade that a tree will likely achieve when it grows into the 16 inch diameter class. The methods were then incorporated into OAKSIM; an upland oak, even-aged, individual-tree growth and yield simulator. The thinning algorithm in OAKSIM was modified to favor the higher quality trees in each diameter class. Results from the simulator are compared to actual stands marked for thinning.

INTRODUCTION

Many growth and yield simulators for Eastern hardwoods contain options for thinning trees from the projected stand, (Ernst and Stout 1991). Some simulators alllow unrealistic options for these thinnings such as elimination of all trees above or below a threshold diameter and/or elimination of an entire species. In reality, foresters in the field evaluate a tree's potential value and its spacing in relation to other trees.

To quantify the value potential of a tree in a simulator, some form of quality must be assigned. Models have been developed which allow the distribution of butt-log grades over diameter at breast height (dbh) (Ernst and Marquis 1979, Myers and others 1986, Dale and Brisbin 1985). This method provides a snapshot of quality, but does not indicate the potential quality of the trees. Lyon and Reed (1987) developed discriminant functions to assign tree grades to Northern species and then provided additional discriminant functions which predicted future tree grades based on initial grades. These functions were incorporated into an uneven-aged stand-level simulator, PROQUAL, which was based on the SHAF model by Adams and Ek (1974). It is unknown whether the grade distributions influenced the periodic harvests.

This paper presents potential grade (Gp), a variable which accounts for the change in tree quality over time. Methods for estimating the probability distribution of Gp as a function of stand age and dbh are also described. Equations are presented for three species groups found in even-aged, upland-oak stands. Finally, these equations are incorporated into OAKSIM (Hilt 1985a), an even-aged, individual-tree simulator.

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VARIABLE DEFINITION

Forest Service tree grading standards include dbh restrictions of 16" for a grade 1 tree and 13" for a grade 2 (Hanks 1976). Gp disregards these dbh restrictions and surface defects that will disappear as the tree grows. Gp is defined as the actual Forest Service tree grade the tree will attain when it grows into the 16" diameter class. When a tree enters the 16" class, Gp and actual tree grade will be identical. Gp is a discrete variable with four categories: grade 1, grade 2, grade 3; and below grade. Actual tree grade can be determined directly from Gp and dbh. For example, a tree with Gp = 1 and dbh = 12.4 would have an actual grade of 3. As the dbh increases beyond the 12.6" and 15.6" thresholds, the actual grade would change to 2 and then to 1.

DATA SOURCE

Individual tree measurements of dbh and Gp were collected on permanent plots in Kentucky and Ohio in a study of the effects of thinning on growth and yield. Plot ages for these managed stands were determined from the dominant and codominant trees and ranged from 30 to 130 years. Site index was between 60 and 100. Better than 70 percent of the basal area of these stands was oak. Trees were divided into three species groups which are:

1. White oak group - white oak (Quercus alba), chestnut oak (Q. prinus) and post oak (Q. stellata).

2. Black oak group - black oak (Q. velutina), scarlet oak (Q. coccinea), red oak (Q. rubra).

3. Other trees - yellow-poplar (Liriodendron tulipifera), red maple (Acer rubrum), hickory (Carya spp.) and other species.

Although Forest Service tree grades allow a 10" minimum dbh for a grade 3 tree, a 12" local market standard was followed in data collection for this study and Gp was determined for each tree greater than 11.6 in dbh.

METHODS

The proportions of trees in each Gp category based on dbh and age were estimated by generalized logistic regression (GLR), as described by the CATMOD procedure of SAS (1985). With a discrete response variable and continuous predictor variables, the maximum likelihood procedure of logistic regression is indicated. Logistic regression is normally used with dichotomous response variables; however, GLR allows responses with more than two levels.

Let p_i denote the probability that the response equals i (i = 1, ..., r). A GLR model is of the form:

$$\ln(p_j/p_r) = f_j \qquad (1).$$

where:

$j = 1, \ldots, r-1$

f_j = a function of predictor varibles

It follows from (1) that:

$$p_j/p_r = \exp(f_j)$$

$$p_j = p_r * \exp(f_j) \qquad (2).$$

Note that the p_i's must sum to 1, therefore:

$$1 = \sum_{j=1}^{r-1} p_j + p_r = \sum_{j=1}^{r-1}(p_r * \exp(f_j)) + p_r$$

$$= p_r * (1 + \sum_{j=1}^{r-1}\exp(f_j))$$

and

$$p_r = 1/(1 + \sum_{j=1}^{r-1}\exp(f_j)). \qquad (3).$$

This implies, from (2) and (3), that:

$$p_j = \exp(f_j)/(1 + \sum_{j=1}^{r-1}\exp(f_j)).$$

In the case of Gp being the response variable and dbh and stand age being the predictor variables:

p_i = the probability that Gp equals i, i = 1, 2, 3, below grade.

$f_j = b_{j0} + b_{j1}*age + b_{j2}*dbh + b_{j3}*age*dbh.$

b_{jk} = regression coefficients to be determined.

j = 1, 2, 3.

RESULTS AND APPLICATION

Table 1 presents the coefficients for each of the three species groups by potential grade. Figure 1 illustrates the likelihood of white oaks in a 60 year old stand to be classified into each Gp category. When a tree has a dbh of at least 15.6", the equations are proportioning actual tree grade.

Table 1. Matrix of coefficients determined by generalized logistic regression for proportioning potential tree grades by species group, age, and dbh.

Species group	Potential grade	Predictor variables				MLR[a]
		Intercept	Age	Dbh	Age*Dbh	p-level
White oak (n=1226)	1	-17.4431	.1524	1.0168	-.00752	.0013
	2	-12.2802	.1202	.7776	-.00656	
	3	-4.7749	.0688	.2584	-.00316	
Black oak (n=583)	1	-13.7317	.0950	.6370	-.00353	.0014
	2	-8.4053	.0724	.3612	-.00258	
	3	-4.8954	.0597	.1822	-.00212	
Other trees (n=178)	1	-8.4628	-.0690	.3030	.00920	.0015
	2	-.3877	-.1414	-.1372	.01230	
	3	.1788	-.0771	-.0890	.00712	

[a] Maximum Likelihood Ratio, Chi-square Goodness-of-fit test.

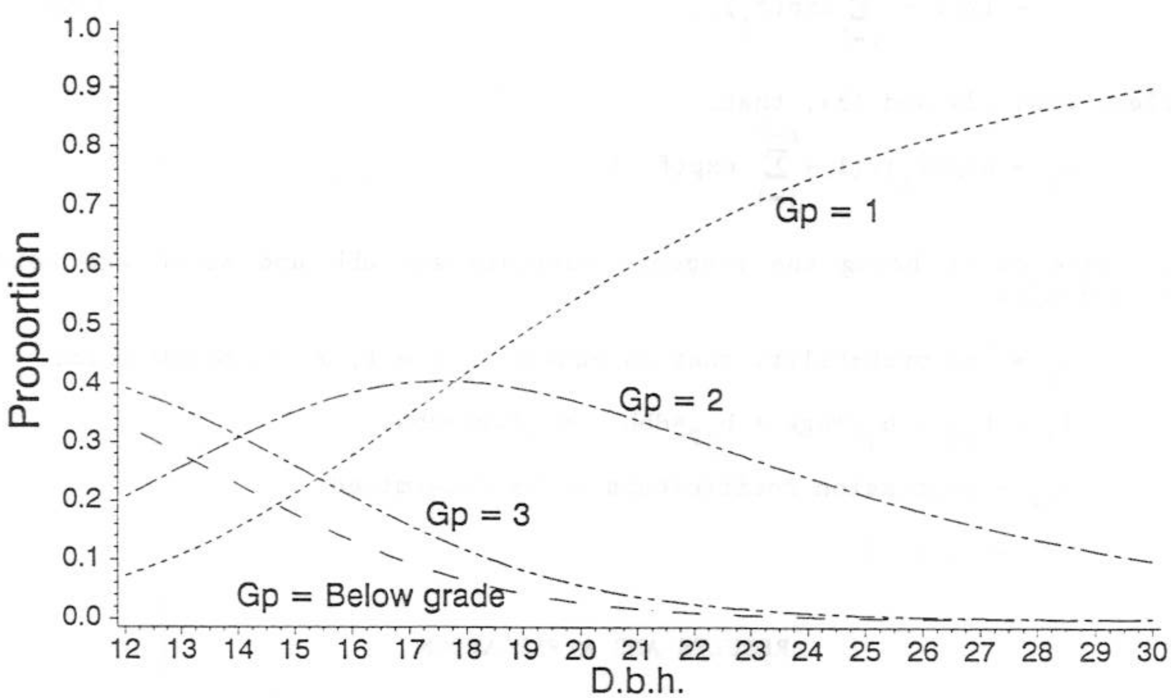

Figure 1. Proportion of trees by potential grade (Gp) over d.b.h. for the white oak species group at age 60, predicted by logistic regression.

The equations developed above were incorporated into OAKSIM. OAKSIM allows input to be a tree list from a 100 percent inventory of an acre (species, dbh) or a stand table (species, diameter class, number of trees per acre). When stand table data is used, OAKSIM creates a tree list by uniformly distributing individual tree dbh measurements to each tree in a diameter class. Species groups for Gp determination are assigned by the mortality group code specified by the user in the control information of OAKSIM (Hilt 1985b).

Temporary one-fifth acre plots were measured and marked for thinning in unmanaged stands in southern Ohio. Data from five of these plots, which had site index of 80 and stand age of 80, were entered into OAKSIM as a 100 percent cruise of an acre. Figure 2 compares the actual distribution of Gp on these plots to that estimated by the equations. The equations tend to overestimate the number of trees with Gp = 1, and underestimate the number of trees with Gp=3. After analysis of other data sets, it appears that the equations do not adequately account for differences in Gp for individual trees. The equations can accurately predict the Gp proportions for large numbers of trees (500 or more), but when used for a specific case, such as 65 sawlog trees per acre, the results can be logical but unnacceptable.

An arbitrary modification was made to the thinning rule such that a tree with Gp = 4 is more likely to be thinned than a tree with Gp = 3 within the same diameter class. This modification did not alter how many trees were cut in each diameter class, it allowed trees to be harvested based on a measure of their potential value. Spacing considerations sometimes require that high quality trees be thinned from certain areas and lower quality trees be left in other areas. Since the equations developed on managed stands did not work well with unmanaged stands, the actual measures of Gp from the unmanaged plots were used to test the OAKSIM thinning rule. Figure 3 is a comparison of the actual trees marked for cut in the unmanaged plots versus those chosen by the OAKSIM thinning routine. The original OAKSIM thinning rule determined in which diameter classes trees would be cut. This rule favors the larger diameter classes and failed to cut some of the larger, lower quality trees. Otherwise, the thinning pattern of the simulator is quite similar to the actual cut.

CONCLUSIONS

This study used logistic regression to distribute Gp over dbh and age. Gp, a measure of the potential quality of a tree, has the ability to account for hardwood tree quality changes over time, a requirement for use in individual-tree, growth and yield simulators. While the equations yield logical results for general application, the results may be unacceptable for specific trees. Although the results reported here cover managed stands of the upland oak cover type, the methodology developed can be applied to any hardwood species and incorporated into any individual-tree or stand level simulators of hardwood growth and yield. Work is planned to use the techniques described in this paper with data collected by the Forest Inventory and Analysis project of the Northeastern Forest Experiment Station. Updated equations will be integrated in the OAKSIM and NE-TWIGS simulators.

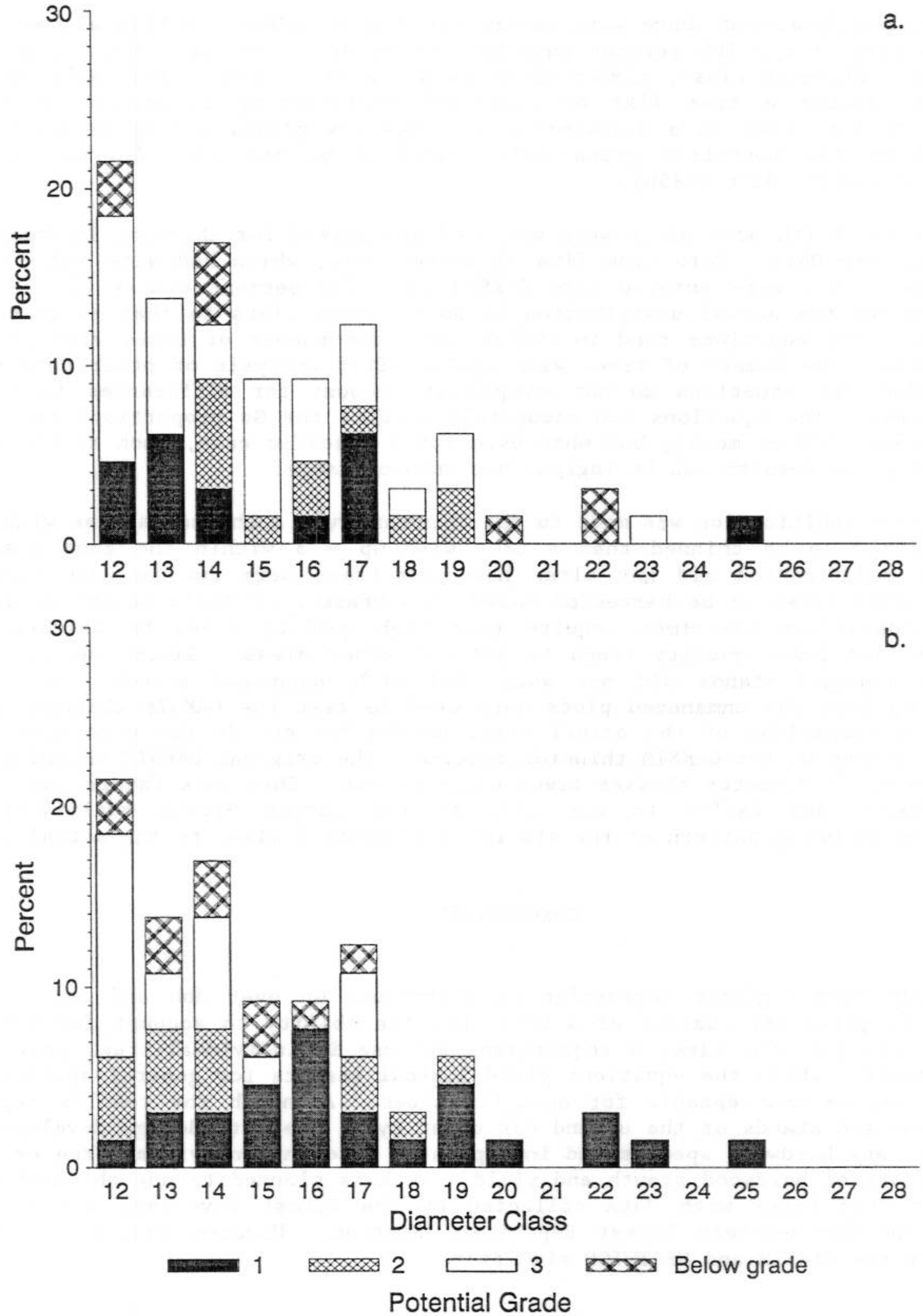

Figure 2. Comparison of actual (a) vs. predicted (b) distribution of potential grade over d.b.h.

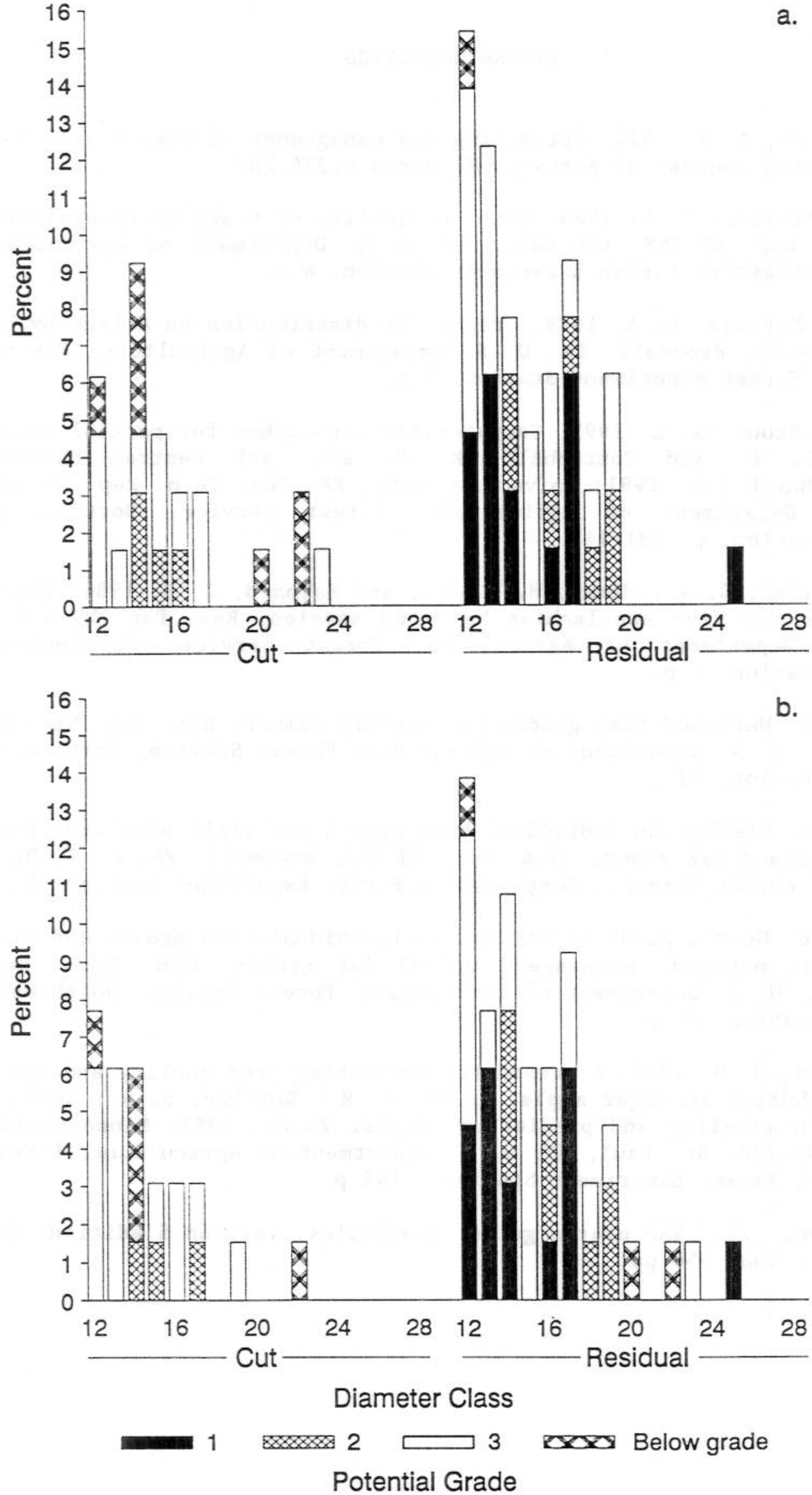

Figure 3. Comparison of actual (a) vs. predicted (b) distribution of potential grade of trees marked for thinning.

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Predicting forest growth and yield under climatic change conditions

H. Grewal

Abstract

According to most general circulation models the climate in west-central Canada is expected to change in the next 50-100 years. We need to consider such changes in our predictions of future growth and yield. The increase of greenhouse gases especially CO_2 will probably cause the temperature to rise and perhaps precipitation to some extent in the higher latitudes of the northern hemisphere. In west-central Canada boreal tree species are expected to be most affected by climate change. Present species ranges are expected to migrate northwards. Palaeobotanical studies indicated that similar climatic warming which occurred in west-central Canada about 6000 years ago resulted in similar shifts in species distribution. Transect studies along latitudinal north-south direction provided evidence of growth and yield variation along climatic gradients. As the most productive forest region in west-central Canada, research into the effects of climatic change on forest productivity in the boreal forest is urgently required. Ecosystem-based dynamic gap models may offer the means to study the effects of climate change induced by CO_2 increase on forest growth and yield.

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Introduction

In the foreseeable future, the air pollution due to anthropogenic effects and climatic change could modify the silvicultural practices in Canada. The effect of air pollution is studied intensively in Europe and eastern North America. These studies have demonstrated the detrimental effects of the air pollution on the functioning and structure of the forest ecosystem and the future forest growth and yield. This could be the case also with climatic change but the effects of the climatic change are much less known than those of the air pollution. It is expected that the climatic change is, in particular, inevitable in the high latitudes of the northern hemisphere which include the most productive forests in Canada. The climatic change at high latitudes is expected to result in higher temperatures with longer growing seasons but precipitation would increase only slightly or remain the same (Mitchell et al. 1990). The future forest growth and yield will be dependent on the structure and functioning of the forest ecosystem and the consequent patterns of silvicultural management. Therefore the interaction between the ecological processes and silvicultural practices is the basis for the analysis of the silvicultural implications of the climatic change. Consequently, the future forest yield is not predictable unless the silvicultural management of the forest ecosystem is outlined at the same time as the effect of climatic change on the structure and functioning of the forest ecosystem. This paper stresses the need to consider an "ecosystem" approach to modelling the future growth and yield in light of the increasing evidence of global warming and climatic change.

CO_2 increase and global warming

Rising CO_2 levels in the US will raise the temperature in US by 3.0 to 5.1 degrees within the next 50 to 100 years based on hypothetical climate change scenario using GCM's and historical climate data (Woodman 1990). Application of these scenarios to several forest succession models resulted in a northward shift in the ranges of northern hardwoods, boreal forest species (Botkin et al. 1989). In western Canada anticipated climate change within the next century, caused by anthropogenic actions (greenhouse gas emissions, etc) would result in a warmer climate with precipitation patterns similar to the present. The CCC GCM, Environment Canada, for example shows temperature changes in the order of +4 to +6 degrees for the region. Table 1 shows the comparison of 6 GCM models for projected global mean temperature and precipitation changes for the 2 X CO_2 or doubling of atmospheric carbon dioxide (occurring probably by 2050). Four of the six models including CCC indicate expected increased summer dryness for mid-continental North America.

Historical data

Interestingly enough, comparable conditions of anticipated climate change existed in western Canada during the post glacial "mid-Holocene" warm-dry period about 6000 years ago (Zoltai and Vitt 1990), then grasslands and aspen parklands occurred far north of their present extent. The anticipated climate change would cause increased drought conditions in the south and longer growing season in the north. For the southern boreal region, we may expect reduced growth rates, higher mortality and higher incidence of insect and disease infestations. The extent of wildfires will probably also increase. In the mid-range, forest tree species would benefit from the extended growing period with increased productivity. In the north, tree species would become more aggressive in extending their ranges.

Transect studies

Maini (1968) reported a strong effect of latitudinal change in the dominant height of mature aspen in Saskatchewan (Figure 1), based on measurements along a 1200 km N-S transect through grassland, grassland-forest , boreal forest, and into the edge of the forest tundra transition. Aspen trees attained maximum height in the main boreal forest but were considerably shorter northward near the tundra and southwards near the grasslands.

Similar trends were found in total biomass production (Johnstone and Peterson 1980) when stands from the grassland-forest transition, the main boreal zone and montane regions were examined. The montane stands were all from high elevation >1300 m above sea level, where climates are similar to a more northern forest-grassland ecotone location. Tree biomass components from stands of comparable age were always greater in the main boreal zone than in either the montane or aspen-grassland ecotone (Figure 2). Other productivity indicators including height, diameter at breast height, crown dimensions and leaf areas showed similar highly significant ($p<0.01$) differences.

These data indicate that aspen (and probably for other species), growth and productivity is sensitive to a climate gradient as reflected in regional latitudinal differences. Optimum conditions for aspen, and other boreal species for that matter, exist within the main boreal zone, with less suitable conditions near the southern and northern ecotones in response to climate-related environmental stresses. Should the projected climate changes occur the optimum conditions for aspen and other tree species will shift accordingly.

Ecoclimatic regions

Anthropogenic changes are expected to exceed natural climatic fluctuations by the end of

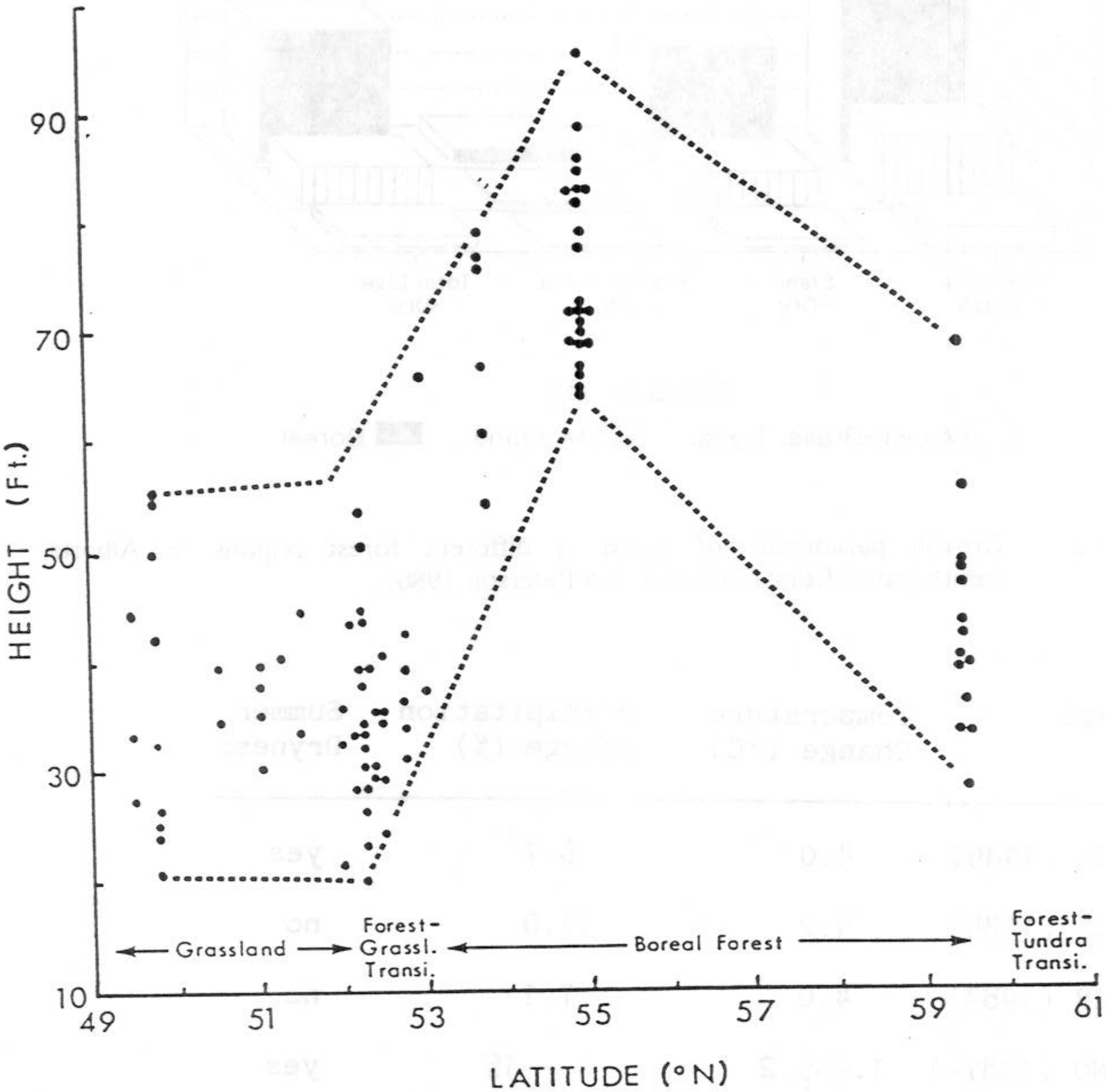

Figure 1. Height growth of mature aspen stands along a 1200 km N-S transect in Saskatchewan (Maini 1968)

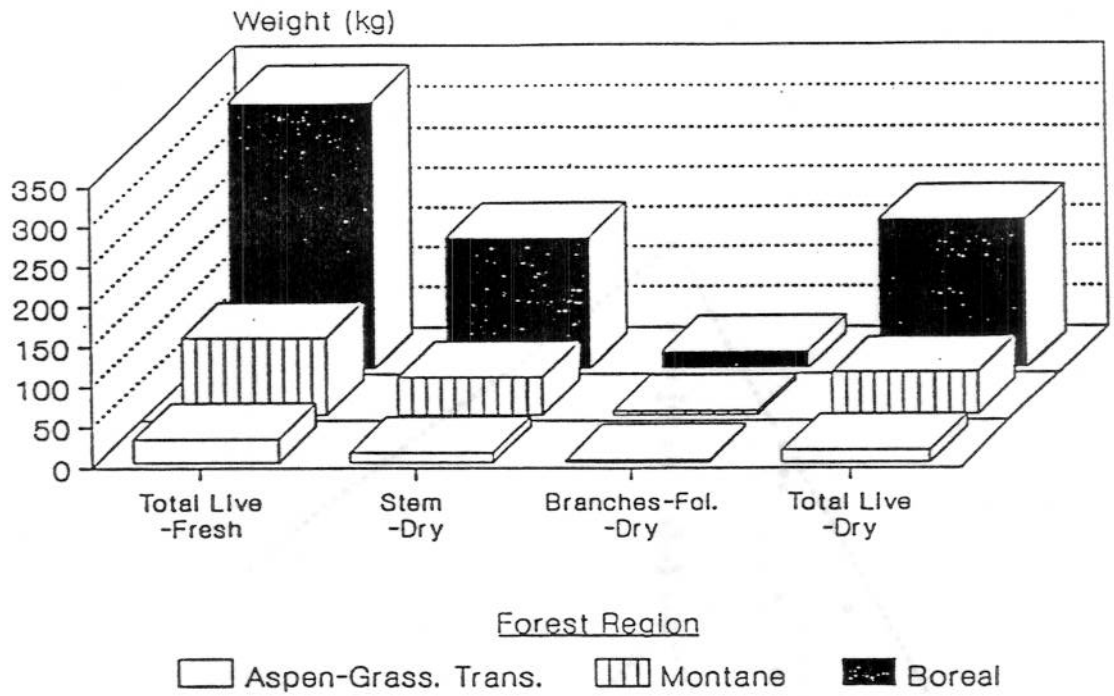

Figure 2. Growth parameters of aspen in different forest regions in Alberta (recalculated from Johnstone and Peterson 1980)

Model	Temperature Change (°C)	Precipitation Change (%)	Summer Dryness
GFDL (1989)	4.0	8.7	yes
CISS (1984)	4.2	11.0	no
NCAR (1984)	4.0	7.1	no
UKMO (1987+)	1.9-5.2	4 - 15	yes
OSU (1987)	2.8	7.8	yes
CCC (1990)	3.5	3.8	yes

Table 1. Comparison of CGM "$2xCO_2$" -"$1xCO_2$" experiment results (reproduced from Environment Canada 1990)

Boundary	Degree days
Arctic/Subarctic	500
Subarctic/Boreal	900
Boreal/Grassland	1350(west)-1600(east)
Arid Grassland/ Transitional Grassland	1500(west)-1900(east)
Boreal/Cool Temperate	1500
Cool Temperate/ Moderate Temperate	2250

Table 2. Approximate annual degree days (5 degree C base) at present boundaries of ecoclimatic provinces

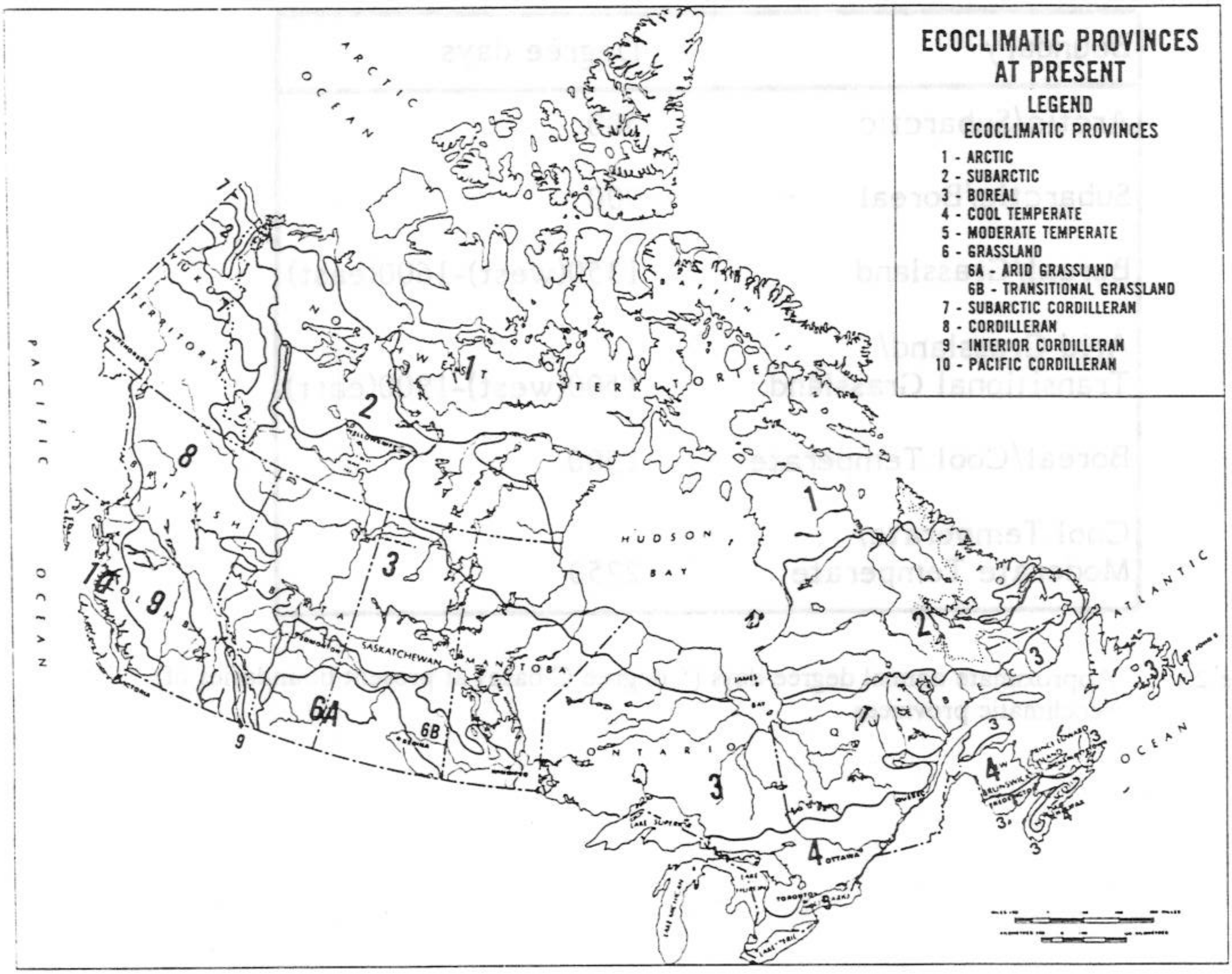

Figure 3. Ecoclimatic provinces at present

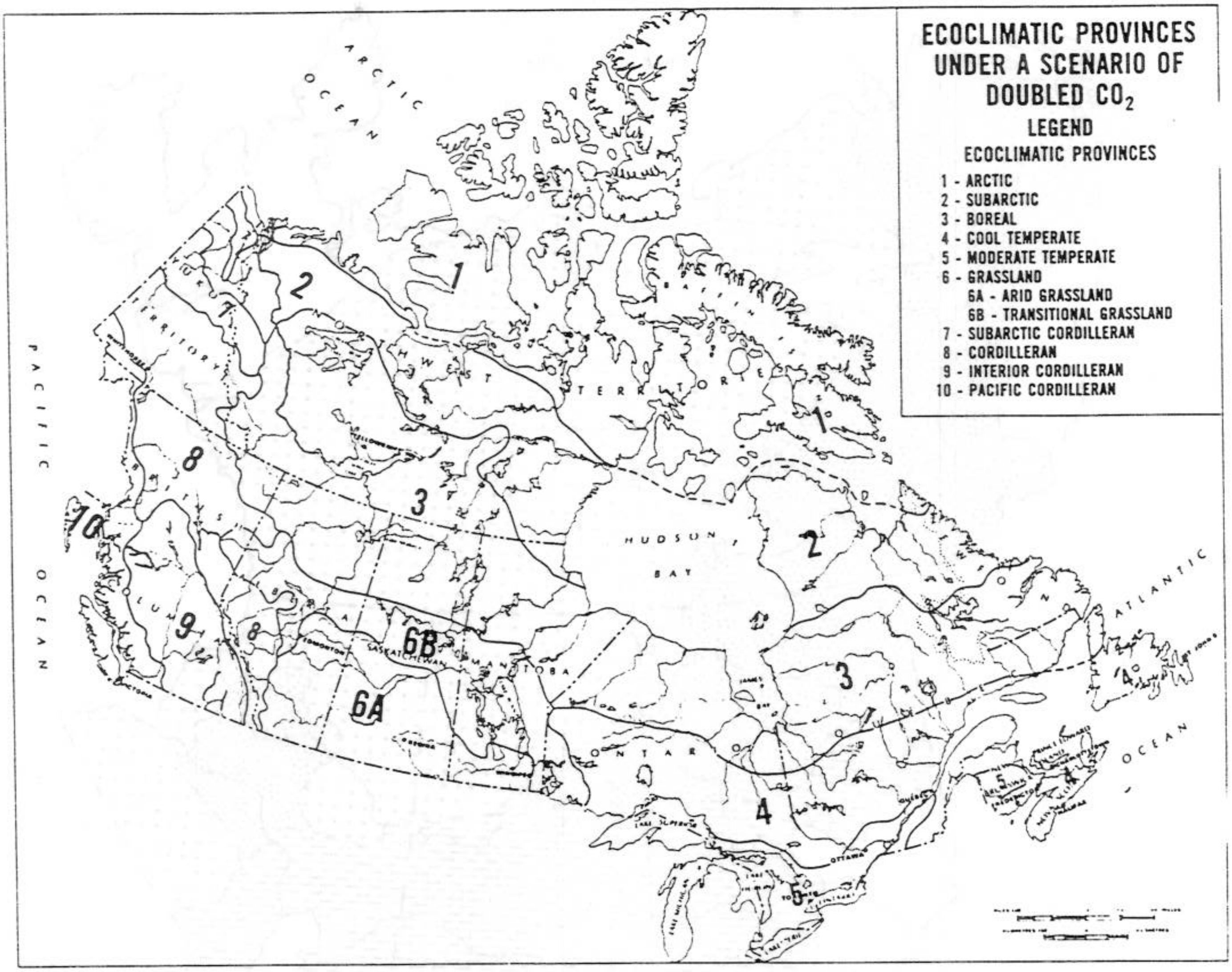

Figure 4. Ecoclimatic provinces under a scenario of doubled CO_2

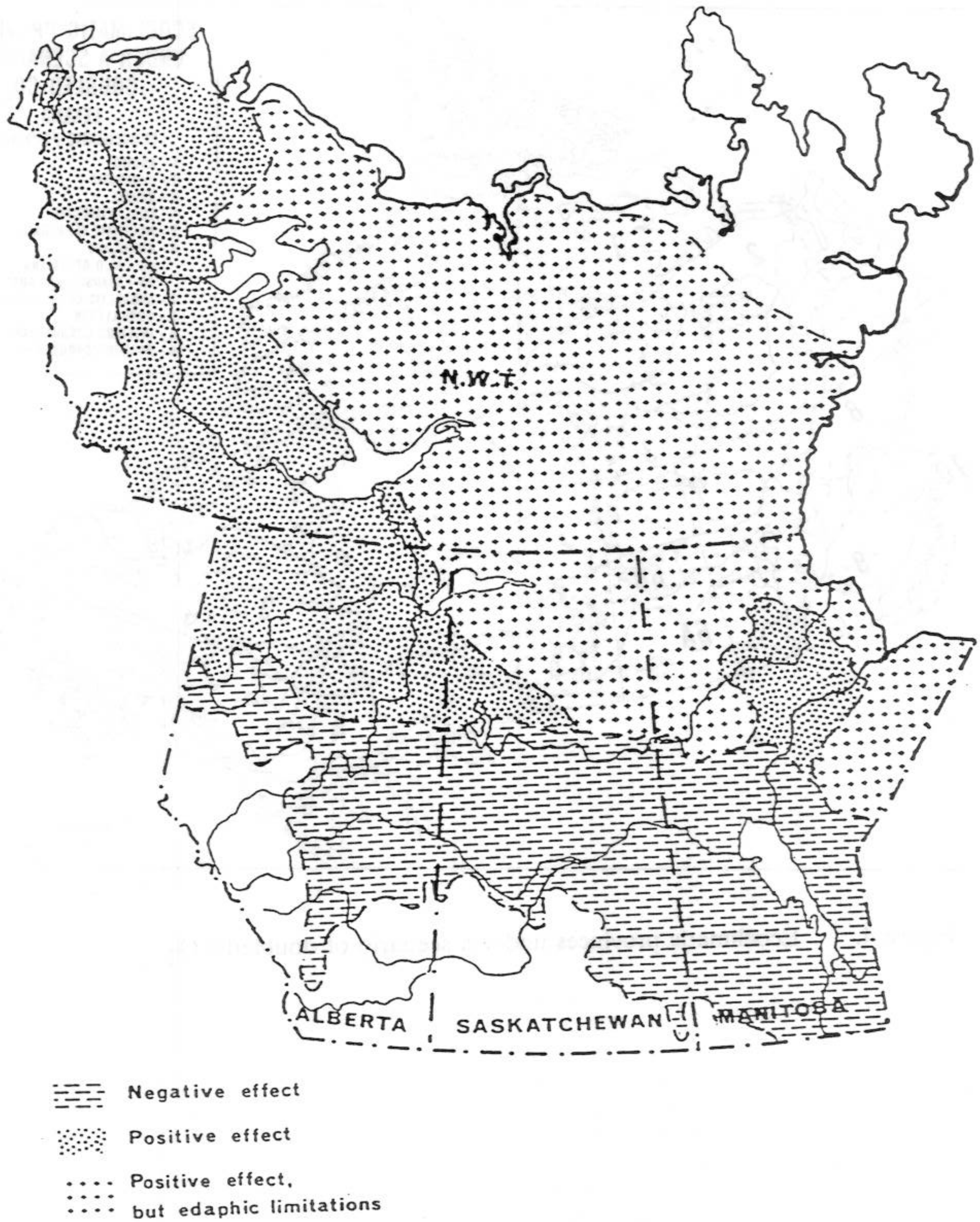

Figure 5. Projected impact of climate change at $2xCO_2$ levels on aspen growth in west-central Canada

the century. Table 2 shows the approximate annual degree days (5 degree C base) at the present boundaries of ecoclimatic provinces. Using degree days to locate the generalized position of ecotones shows promise. Zoltai (1988) used this approach to produce a map of Ecoclimatic Provinces of Canada (Figure 3) under current climate. The Goddard Institute for Space Sciences (GISS)'s model was used to predict climatic conditions under doubled CO_2 conditions. This general circulation model predicts mean monthly temperature and precipitation for points located every 5 deg longitude and 4 deg latitude apart. Using these projections Zoltai (1988) produces an ecoclimatic provinces map under a scenario of doubled CO_2 (Figure 4). Of particular interest to our region, the conditions favourable for coniferous boreal forests will exist some 300-450 km farther north than at the present. However, boreal forest conditions will be displaced along the southern boundary by about the same amount. Increase in sea level due to the melting of polar ice caps may flood large areas around Hudson and James bays. Figure 5 shows the likelihood of climatic change at 2 X CO_2 on aspen growth in west-central Canada (Zoltai et al. 1991).

The LINKAGES model

The challenge of predicting growth and yield, forest productivity under climatic change conditions forces us to look into new approaches of modelling our ecosystem relationships. We cannot simply look at a site and assume productivity to remain the same in the future. Processes such as carbon and nitrogen cycles, temperature (degree days) and water availability must be examined and projections made for the expected changing conditions. Admittedly it is difficult to include these complex relationships, however, we can no longer assume that climate will remain the same. Ecosystem dynamic gap models such as

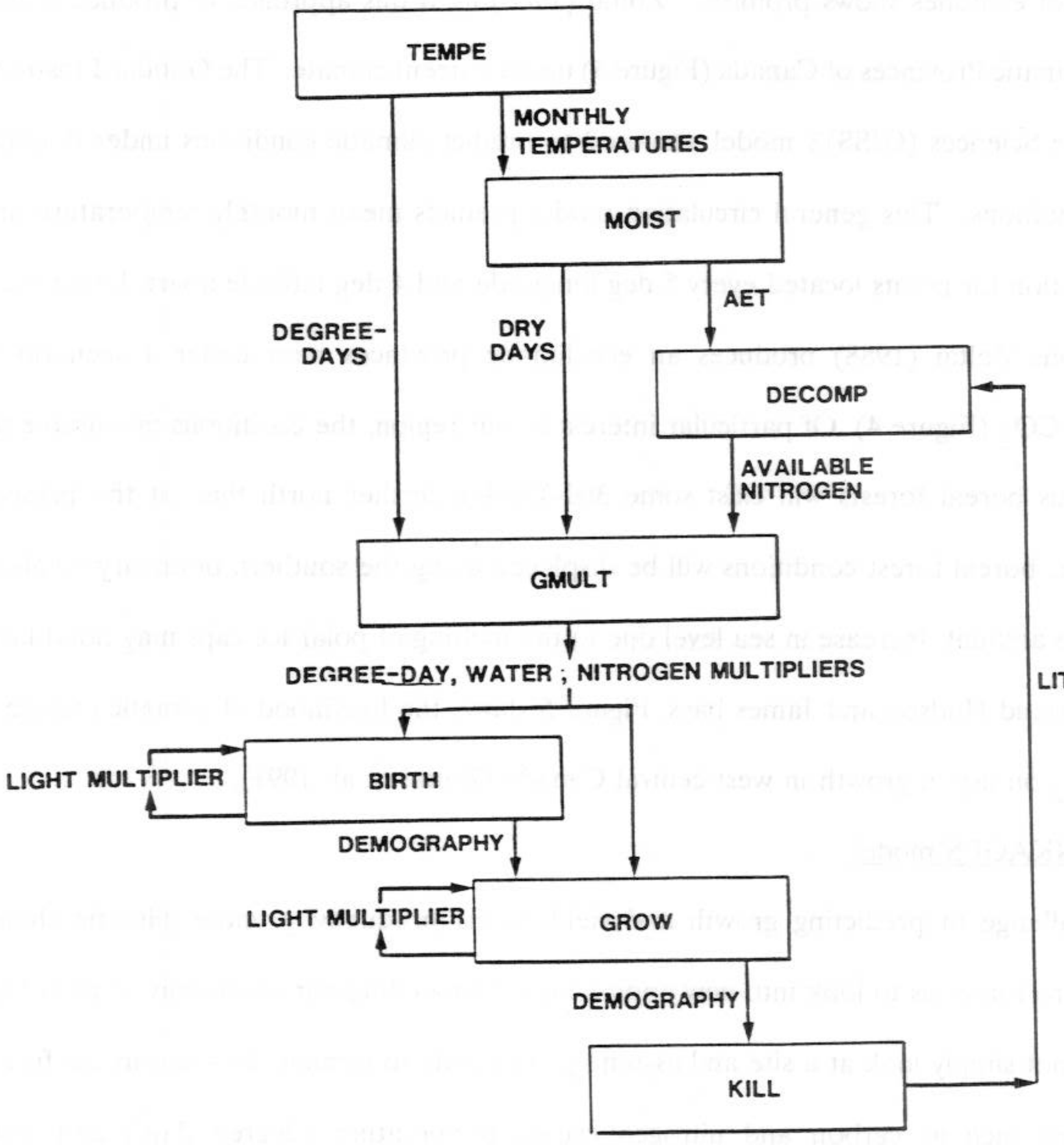

Figure 6. Structural and functional relationships in the forest ecosystem and the effects of climatic factors on productivity of the forest ecosystem according to Pastor and Post (1985)

LINKAGES (Pastor and Post 1985) are required to answer such questions as productivity changes under climatic change conditions. Figure 6 presents a schematic diagram of the hypothesis of the model. The ecosystem model considers the establishment and growth of individual trees in a 1/12 ha plot and their responses to degree days, soil water deficits, soil nitrogen availability, and light. The maximum and minimum growing season degree days a species can tolerate are assumed to coincide with the southern and northern limits of its range. Species are assumed to be either shade tolerant or intolerant and are assigned to appropriate photosynthetic response curves accordingly. The growth of each tree is limited by degree days, water deficits, light or nitrogen, whichever is most limiting in a given year. Different species in turn influence nitrogen availability through the chemical quality of their litter and influence light availability in all smaller trees through shading (Pastor and Post 1985). The assumption is made that the probability of mortality increases from about 10% to 30% upon two consecutive years of slow growth due to stress. In the model, changes in temperature affect tree growth directly through the degree-day response curves; indirectly through the increased evapotranspiration and hence drought stress; and through changes in decomposition rates, and hence nitrogen availability. Species biomass, total biomass, number of live stems, leaf area, and total woody production are calculated for the output interval. These, along with humus C:N, soil CO_2 evolution, soil organic matter, available nitrogen, and average evapotranspiration, are considered in the ecosystem simulation model.

Conclusion

Sceptics may say that the climate will not change but only fluctuates slightly. However palaeobotanical studies have shown that the range of boreal forests have shifted significantly in the past due to climate warming, it can happen again in the future. Increasingly we are seeing evidences from global warming that it will happen. We are driven to explore a more "global" approach to predicting (modelling) forest growth and yield that considers all the components of the ecosystem in an explicit manner. Forests take a long time to mature: in 80 years the climate is expected to undergo significant changes. It is to our benefit to anticipate the response of the forests, to take advantage of the changes, or at least to minimize the detrimental impact.

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AN ECOLOGICALLY BASED GROWTH MODEL FOR RED PINE EMPHASIZING CLIMATE AND SOIL MOISTURE INFLUENCES

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ABSTRACT:

Growing season duration for a red pine plantation was determined using bi-weekly dendrometer tape data. Stem analysis of 60 trees at age 40 allowed volume growth reconstruction. Daily weather records of the same time interval were run through a locally calibrated soil water transport model based on Darcy's approach and provided a daily soil moisture regime to a depth of 1.2 m.

Observations indicated diameter and volume growth was greater during years when growing season precipitation events occurred at shorter intervals than in years when the same amount fell during a few large events. These two extremes resulted in greater and lesser available soil water or lesser and greater soil water potential, respectively.

Analysis of relationships between the diameter/basal area/volume growth to such environmental characteristics as average air temperature, rainfall, potential evapotranspiration, and average amount of available soil water, produced net superior correlations between the later, and the growth variables. A preliminary growth model relating annual diameter, basal area and volume growth to soil moisture availability is outlined in this paper.

Mixedwood Yield Function Development for Crop Planning in Geraldton District

by Wayne A. Lewis and Mark G. Speers *

ABSTRACT

Preliminary mixedwood yield functions were derived for Geraldton District to assist in the preparation of future timber management and crop plans. Mixedwood stands were stratified prior to sampling with Ontario's Forest Resource Inventory map system. Stratification criteria used was a 70:30-30:70 conifer to hardwood species composition for three site classes up to one hundred years old, with five replicates of each stand stratification type. One hundred and six stands have been sampled to date. Temporary sample plots were established using probability proportional to size sampling. Honers' (1967) volume tables were used to estimate individual tree volume. Yield functions were derived using non-linear regression and the Chapman-Richards equation. The yield equations derived are preliminary with further sampling required in a number of age classes. Permanent sample plots will be established in the future to examine the successional dynamics of mixedwood stands. The forest level wood supply model FORMAN will be used to develop future crop plans for the Longlac and Nakina Forests.

INTRODUCTION

The purpose of this report is to present the results of a growth and yield project initiated to develop yield functions for the mixedwood forest unit in Geraldton District.

A technical report by Payandeh and Field (1986) entitled "Yield Functions and Tables for Mixedwood Stands in Northwestern Ontario" concentrated on mature stands with cover types ranging from pure conifer stands to various levels of mixedwoods. Their research derived yield functions which utilized data compiled by Evert (1975, 1976a) and includes data from all cover types (pure, mixed conifer, mixed hardwood and conifer and pure hardwood). The objective of this endeavor is to examine the yield of second growth mixed conifer/hardwood stands in Gerldton District.

The maximum allowable depletion calculations in the current Timber Management Plans (T.M.P.) for the Geraldton Management Unit and the Longlac and Nakina Forest Management Agreement areas were prepared with the yield curve dependent wood supply model FORMAN (Wang 1987). Three yield curves are required for each forest unit, they include: the natural forest, the future managed forest and the future unmanaged forest. The natural forest yield curves were developed by Kimberly-Clark Canada Inc. from the information contained in four thousand stand inventory cruise plots. The cruise information was overlain onto the F.R.I. mapsheets and volume over age curves were manually derived by forest unit.

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The future managed and unmanaged yield curves were developed based on best guess assumptions. The yield functions developed in this report will be applied to future unmanaged stands. The State of the Geraldton Forest (Jovic 1990) report indicates that a large portion of the future unmanaged and managed stands are regenerating to a mixedwood stand type. Therefore, the need for a mixedwood classification and associated yield curve information is of paramount importance to forest management in Geraldton District.

This report outlines the sampling methodology employed in data collection followed by an analysis of the results and a discussion of the management implications of this project. In addition, a series of conclusions and recommendations will be presented outlining future growth and yield strategies required for Geraldton District.

METHODS

With the initiation of the mixedwood study a reliable predictor of individual tree volume was required to estimate stand volume. Honers' (1967) Standard Volume Tables and Merchantable Conversion Factors for the Commercial Tree Species of Central and Eastern Canada were used to estimate individual tree volume and verified using a Tree Ring Increment Measurement (T.R.I.M.) unit. A total of fifteen white spruce (Picea glauca)[Moench] A. Voss, black spruce (Picea mariana)[Mill] BSP., balsam-fir (Abies balsamea) [L.] Mill and jack pine (Pinus banksiana) Lamb., were selected for T.R.I.M. analysis. A concious effort was made to select trees at all levels in the canopy to verify the applicability of the volume predictor across the complete range of possible mixedwood stand conditions. There was no significant difference between the predicted volume and the estimated volume at the 95% confidence level.

Stand Sampling Methods

The initial objective of this project was to sample mixedwood stands between 20 and 50 years old; however, since most of the older stands sampled were allowed to regenerate naturally, or with a minimum of silvicultural treatment, stands greater than 50 years were also selected.

The following stratification criteria was used to differentiate pure and mixedwood stands: the hardwood to conifer species composition was between 70:30 to 30:70, for Site Class 1, 2 and 3 as determined by F.R.I. Within each stratification five replicates were desired to reduce sampling variability. The number of plots required within each stand was dependent on stand size (Table 1). It was recognized by the authors that this method of determining sample size would not adequately account for within stand variability. An analysis of the data, based on the sampling protocol described will be completed and a statistically sound sampling regime based on the variability of the mixedwood condition will be developed.

Table 1. Number of temporary sample plots established per stand.

Stand area (ha)	Number of plots
8-25	2
26-50	3
51-75	4
each additional 75	add one plot

Cruising Methods

Probability proportional to size (P.P.S.) (BAF=2) sampling was employed to collect individual tree and stand data (Husch, Mueller and Beers 1982) (Grosenbaugh 1958). Plots were randomly located within each stand. At each plot the data collected included tree height, diameter at breast height (dbh) (at 1.35m above root collar) for all trees. DBH was measured and marked on every tree to allow the determination of tree height from dbh to the top of the tree using a Suunto clinometer. By using dbh rather than the base of the tree, data could be collected during the winter months in a more accurate manner. When data was entered into the database 1.35m was added to the measured height of each tree to determine total tree height. Tree age was collected at dbh and total age correction factors were determined for each species across the range of site classes available, to obtain an estimate of total tree age.

Permanent Sample Plots

Permanent sample plots (P.S.P.) will be established in a selected number of stands from which temporary sample plot data was collected. P.S.P. data will be collected using Provincial standards (Andison et al. 1990).

RESULTS AND DISCUSSION

A link between F.R.I. and the data collected was desired; therefore, a comparison of the stratified data and its correlation with F.R.I. was completed. The total sample to-date covered 106 F.R.I. stands. Of the 106 stands 84 were similarily stratified as mixedwood by the cruise data (79%). Of the 84 stands, 78 had the same hardwood:conifer ratio (93%). It is imperative that a strong correlation exist between the F.R.I. stratification and the stand stratification determined by field sampling.

Species composition was the primary stratification criteria used to select stands for sampling. From initial sampling results and from discussion with K-C representatives, it was precluded that age and site class information from F.R.I. does not accurately reflect present stand conditions. As such, site class and age were used as a guide for stand selection, but final stand stratification was completed with field data. While an attempt was made to select a minimum of stands within each stratification type, oversampling occurred due to discrepancies between F.R.I. and field sampling estimates of age and site class. Therefore, additional sampling within the 70 to 100 year old age classes for the three site classes and the desired replications shown in Table 2, is required to complete the sampling for this project.

Table 2. Summary of number of stands sampled by stratification type.

Age class	Site class 1		Site class 2		Site Class 3	
	Complete	Required	Complete	Required	Complete	Required
20-29	0	5	5	0	2	3
30-39	7	0	18	0	5	0
40-49	1	0	25	0	12	0
50-59	3	2	7	0	6	0
60-69	1	4	2	3	1	4

Data Analysis

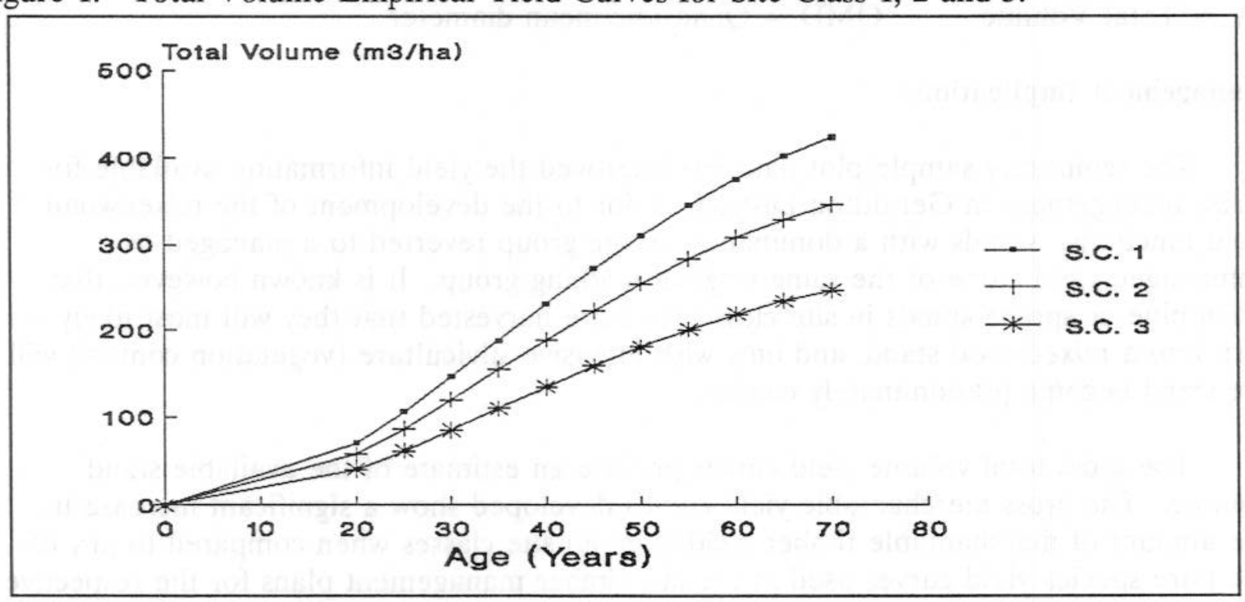
During the early data collection process it became clear that stands within the 20 to 60 year old age classes had a component of residual trees. Many of the residual trees were older than the regenerating stand, were widely scattered throughout the stand and generally did not reflect the structure of the regenerating stand. These trees were recorded in the database, but were excluded from the analysis. The criteria used for excluding residual trees from the database was: that any tree greater than 30 years older than the average plot age, or if the trees' dbh was 15cm greater than the average plot dbh.

The mixedwood yield data was examined using multiple-linear regression and non-linear regression. Multiple linear regression provided a poor estimate of volume with the available stand information (r^2 values $<.5$). Since F.R.I. is generally the only available source of stand information the variables that can be utilized in the yield function are limited to age, site class (which can be easily converted to site index) and stocking. Age and site class are useful stand parameters; however, stocking (which is based on the ratio between the actual basal area/acre and the normal basal area/acre) was not estimated.

The Chapman-Richards function has been employed in a number of forms to estimate stand volume (Clutter et al. 1983). Non-linear regression for the estimation of a mixedwood yield function was employed using the statistical package SYSTAT and two different minimization methods, Quasi-Newton and Simplex (Wilkerson 1958). The Chapman-Richards function allows for the production of a yield curve with a sigmoidal shape and one inflection point and as with most biologically based models the Chapman-Richards function is intrinsically non-linear (Draper and Smith 1966)(Pienaar and Turnbull 1973). The form of the Chapman-Richards function allows for an improved prediction of stand volume based on the variables available from F.R.I., being age and site class. The yield functions produced using the Chapman-Richards function are gross total volume and Honers' (1967) Merchantable Conversion factors were used to derive a set of gross merchantable volume yield functions.

The gross total volume yield curves produced (Figure 1) indicate a different pattern in yield curve development than those produced by Payendah and Field (1986) for naturally disturbed stands. The rate of yield accretion is less in early stand development with lower maximum values for current annual increment (CAI) and mean annual increment (MAI) for all site classes. The slower rate of growth found in the second growth mixed-wood stands results in the biological rotation age being longer than those found by Payendah and Field (1986), but shorter than the eighty year rotation age that is generally applied to these stands for timber management planning purposes.

Figure 1. Total Volume Empirical Yield Curves for Site Class 1, 2 and 3.



To complete the production of the empirical yield tables multiple linear regression was used to estimate stems per hectare, quadratic mean diameter, average height and basal area parameters, using sample data collected. Generally, a high correlation (Spearmans r^2 coefficient) was achieved between the dependent and independent variables used (Table 3).

Table 3. The Functions Used to Predict Mixed-wood Stand Yield Tables.

Stand Variable	Function	Correlation r^2	SEE
Total Volume	55.35*SI^.687*(1-e(-((.02*age)^2.02)))	.88	18.25
Merch. Volume	26.69*SI^.905*(1-e(-((.018*age)^2.506)))	.88	18.25
Basal Area/ha	28.93-.568*A+.003*A^2+.209*TV-.652*S	.85	4.17
QMD	-3.769+.334*A-.002*A^2+.004*TV-.135*B +.001*BA^2+.673*HT+.147*SI	.80	2.64
Tree Height	7.807+.04*A+.095*TV-.467*BA+.002*BA^2 +.098*SI	.92	1.33
Stems per ha	11717.36+12.957*A-.428*A^2+244.524*BA -1.993*BA^2-1210.265*QMD+26.607*QMD^2 -95.669*SI	.81	13.20

A = AGE SI = Site Index SEE = Standard Error of Estimate
BA = Basal area/hectare HT = Total Height
TV = Total Volume QMD = Quadratic mean diameter

Management Implications

The temporary sample plot data has improved the yield information available for forest management in Geraldton District. Prior to the development of the mixedwood yield functions, stands with a dominant working group reverted to a managed or unmanaged yield curve of the same original working group. It is known however, that when pine or spruce stands in site class 1 or 2 are harvested that they will most likely turn into a mixedwood stand, and only with intensive silviculture (vegetation control) will the stand become predominately conifer.

The gross total volume yield curves provide an estimate of the available stand volume. The gross merchantable yield curves developed show a significant increase in the amount of merchantable timber yield from all site classes when compared to any of the pure species yield curves used in the last timber management plans for the respective management units in Geraldton District. This will have a significant impact on crop planning in the future, as it is estimated that up to thirty-five percent of the stands in the Longlac Forest fall within the mixedwood stratification. Validation of the merchantable yield conversion factors will be required prior to using the merchantable yield functions in any future crop plans.

The yield tables produced are an average estimate of available volume from mixedwood stands in Geraldton district. While these tables provide an improvement in the prediction of future yields available from mixedwood stands, further information is required to properly interpret the volume available from the variety of species in the boreal mixedwood. From a timber planning perspective, mixedwood stands prove to be the most challenging. Mixedwood stands may be stratified into even-aged layers or they may be a collection of smaller pure species stands. Differentiating the type of mixedwood from F.R.I. is impossible, so no attempt was made to use them as a separate stratification.

Table 4 highlights the interpretation of the yield functions for the three site classes. The intersection of CAI and MAI indicates that the biological rotation age for mixedwood stands may be considerably younger than anticipated. There may be a significant ecological impact of lowering or raising the rotation age for stands in terms of long-term site productivity. In order to further understand this relationship a link will be made between this study and a project initiated by the Ontario Forest Research Institute to study the effects of mechanized full tree logging on site productivity in Geraldton district.

Table 4. Mixedwood Yield Function Interpretation.

Site Class	Maximum CAI (m3/ha/yr)	Maximum MAI (m3/ha/yr)	Biological Rotation Age (Years)
1	8.5	6.5	55
2	6.3	4.6	60
3	4.9	3.6	70

RECOMMENDATIONS AND CONCLUSIONS

The majority of nutrient rich sites in Geraldton district are regenerating as mixed hardwood and conifer stands. As such, the production of stand level management tools are required to allow the proper planning of the forest resources in Geraldton district.

Futher knowledge of mixedwood stand dynamcis will be attained through the establishment of district level permanent sample plots that will allow the refinement of the data collected from the temporary sample plots. Temporary sample plot information will be collected for pure hardwood/conifer stands and extensively managed conifer stands to produce a set of yield curves for the next T.M.P. using standardized methods, with fewer assumptions than the present set of yield curves.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the dedicated efforts of Geoff Mattiussi, Mark Judd, Frank Lennard, Jerry Reaume, Penny Ratusniak, Patrick Roy, Dave Barker, Debbie McEwen and Luc Alarie for their assistance in the collection of field data. The efforts of Fred Tittaferante in the preparation of the database management system for this project were greatly appreciated.

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The Role of Site in the Changing Composition of Mixed Softwood Stands

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Abstract

The black spruce content of mixed black spruce-jack pine stands is believed to increase over time which has important implications for stand management. The reasons for this increase are attributed to its shade tolerance, persistent height growth and ability to establish itself over a longer period of time than jack pine. Although the spruce content in mixed softwood stands has been observed to be greater on wetter sites, the question whether site in some way also regulates changes in spruce content once the stand is established has not been answered.

This study uses stand and soil data from 381 observations made on 68 PSPs located in the Longlac-Geraldton area of northern Ontario to determine whether a site-related equilibrium exists which influences trends in stand composition. A model relating spruce content to the first and third principal components of a

soil factor analysis was used to estimate the equilibrium composition for each plot in the study. The predicted equilibrium composition was then included in a stand composition model to determine whether or not changes in composition were site-related. Results were negative and it is concluded that the relatively minor increases in spruce content that occur throughout the life of these stands are related more to the physiological characteristics of the two species than to site.

Introduction

This study investigates the relative importance of site on the change in the black spruce (Picea mariana (Mill.) B.S.P.)) component in mixed black spruce - jack pine (Pinus banksiana Lamb.) stands growing in the boreal forest region of northern Ontario (Rowe, 1972) in the Longlac-Geraldton area. Both are commercially important species that occur in varying mixtures over a wide range of sites, including peatlands and dry sand flats.

Jack pine is a pioneer species that is shade intolerant and establishes itself only in short periods immediately after a fire due to the serotinous nature of its cones (Spurr and Barnes, 1980). Jack pine develops quickly but has asymptotic height tendencies (Wang, 1991).

Black spruce also tends to be a fire origin species, however its recruitment period is longer than that of jack pine because of its non-serotinous cones and its ability to regenerate through layering (Carleton, 1982). Black spruce is semi-shade tolerant and its height growth on a given site tends to be slower and more linear than that of jack pine (Smith, 1984). Both species are xerophytic, although jack pine seems to do better on dry sandy soils while spruce predominates on peatlands and treed swamps.

It is the purpose of this study to model the changes in spruce content of stands (expressed as percent spruce basal area of total softwood basal area) that reflect the aforementioned silvical characteristics of the two species growing on different sites in northern Ontario. This trend is important in making forest management decisions related to the preference of pine or spruce in determining rotation ages and allowable annual cuts.

Based on the foregoing, one would expect the spruce component to increase as a stand develops because of:

i) it's relative competitive advantage due to its shade tolerance;

ii) it's longer recruitment period;

iii) it's sustained steady height growth rate.

On the other hand, it may be that an equilibrium mixture of spruce and jack pine exists for a given site as demonstrated by the fact that spruce can occur in pure stands on swamp sites while jack pine commonly occurs in pure stands on dry sandy flats. Thus the spruce content can be determined by the amount of moisture present on a site. If this is true, one might expect spruce content to either increase or decrease toward some equilibrium level as determined by soil moisture. This is the hypothesis to be tested.

Work on this subject has been done by Nigh (1990) who developed a species composition model (Table 3,c-1) based data from permanent sample plots (PSP) that were originally established by the Kimberly-Clark Corporation in the Longlac-Geraldton area. Nigh's prediction equation relates change in spruce content to initial stand composition. This model, with the inclusion of a site related equilibrium composition ratio, was used to determine if the rate of change in spruce content could also be related to site.

Procedure

Data used in this analysis were obtained from the Kimberly-Clark Corporation and the Ontario Ministry of Natural Resources. They include 381 records from 68 PSPs ranging in age from 35 to 150 years. All plots contained at least 85% spruce and/or jack pine. Table 1 presents the summary statistics. Soil pits were dug in each plot and various data by horizons as well as ten general descriptive variables were recorded.

Analysis of the massive collection of soil data presented a problem which was partially overcome by using only the ten descriptive variables which were then re-coded on a "present-absent" basis (Table 2). Soil data were then further condensed by doing a principal component analysis (Johnson and Wichern, 1988) and using the first three (significant) components for further model development and testing. Table 3a displays the equations for the three components which were used to generate component values for each of the 68 plots.

Regression analysis was done to develop an equation relating stand composition to the principal components. A general positive bias was detected and corrected by making an appropriate minor adjustment to the intercept term. This equation was used to estimate the "equilibrium" composition for stands growing on sites with given soil characteristics (Table 3b). Finally, an equilibrium function was derived which compared the actual composition of a plot to its equilibrium composition. This function was incorporated into Nigh's equation to test whether there was a tendency for individual stands to move towards a site-related equilibrium composition or not. If such a tendency existed, one would expect that Nigh's modified equation would fit the data better than the unmodified equation.

Observations

A general sense of how the spruce content in a mixed softwood stand changes over time can be obtained by examining Figures 1 which summarizes the distribution of changes in percent spruce over a twenty year period on 67 PSPs. It is clear that the changes are not dramatic, with most of the plots showing very little change at all (within+/- 2.5%). There is some tendency for a small positive increase, i.e. 5%, however in a surprising number of stands there was an actual decrease in spruce content which could support the equilibrium theory. Correlations between annual change in spruce content and both stand age and stand composition were non-significant (i.e. -.05 and -.11 respectively). A good correlation was found between the first principal component of the soil data and spruce content (i.e. -0.75), indicating a strong relationship between soil moisture and jack pine content with no pure jack pine stands on wet sites but being more prevalent on dry sites, black spruce was prevalent on both wet and dry sites. The role of the first principal component as a measure of soil moisture in soil analyses has previously been noted by Jones et al. (1983).

The second and third principal components can be associated with other soil properties that may be nutrient related. Of the three principal components considered in this study, the first and third appeared to be significantly correlated with spruce content in the mixed spruce-pine stands. These components were used in Equation b, (Table 3), to predict the average (equilibrium) spruce content for stands in the data set. The correlation coefficient associated with this equilibrium composition equation (R Squared = .60) indicates that much variation remains unexplained.

The equations predicting future (i.e. 5 years) jackpine content in these plots are shown in Table 3 part c. The parameter estimates for Equation c-1 (Nigh's Equation) agree with Nigh's original estimates even though the data set was expanded to include stands with between 85 and 90% softwoods for this study. Equation c-2 which includes the equilibrium function has resulted in a residual mean square error (RMSE) slightly larger than the one for Equation c-1. When the difference in residual sums of squares between the two equations are tested (Table 4) there is no significant difference, and we conclude that spruce composition in these stands is not tending to some site-related equilibrium.

Discussion

Although this study supports the general observation that the species composition of stands occupying a particular site is site-related, it does not support the concept that the composition of a stand will shift to a site-related equilibrium composition. It would seem that stand composition is determined by the set of site and seed-source conditions that exist at the time of stand establishment and that any change in composition after that is determined by the inherent growth characteristics of the two species.

For spruce and jack pine in particular, it would seem that such shifts in species composition, which favour spruce, are relatively minor over the life of the stand. Nigh's model adequately describes the trends to be expected (Figure 2) although there is still a large amount of variation yet to be explained,(i.e. the root mean square error for five year change is 1.6%).

The fact that spruce content can be expected to increase marginally over time in mixed spruce-jack pine stands has certain implications for successional development. Although spruce does make up a higher proportion of the basal area in older stands, it does not usually carry on to form a significant second growth stand. Rather, the pattern seems to be that either the pine or spruce component collapses and in the process the other species succumbs to windthrow or exposure leaving a sparse understory of spruce that was established through layering to form an open, full-crowned stand of poor quality trees.

The fact that the minor increases in spruce content over time are not site-related simplifies the modelling process since this means that site does not have to be taken into consideration in modelling growth and yield in mixed spruce-jack pine stands.

Acknowledgements

This study was funded as part of a contract with the Ontario Ministry of Natural Resources. Earlier logistical support and access to PSP data by The Kimberly-Clark Corporation is also acknowledged. Mr. Gordon Nigh's contribution was supported through a much appreciated NSERC fellowship. Mr. James Maclellan, a student at the Faculty of Forestry, University of Toronto also made a major contribution in the efficient collection of field data.

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Table 1. Data Summary - Kimberly-Clark PSPs.					
Variable	Count	Mean	Std. Dev.	Min.	Max.
Age (years)	381	92.06	30.85	34	166
% Spruce	381	0.39	0.35	0	1.0
Basal Area sq.m/.08 ha	381	2.78	0.54	1.27	4.1
Spruce Volume cu.m/.08 ha	381	7.90	7.63	0	26.8
Jack Pine Volume cu.m/.08 ha	381	13.85	8.51	0	34.3
Spruce Height (m)	381	13.72	4.93	0	23.7
Jack Pine Height (m)	381	17.60	4.25	0	26.8
1st Principal Comp.	381	0.077	1.682	-4.62	1.86
2nd Principal Comp.	381	-0.046	1.316	-1.843	3.34
3rd Principal Comp.	381	-0.083	1.089	-1.261	6.65
5 year change in % spruce	313	0.001	0.003	-0.018	0.02

Table 2. Standardized Soil Variables						
Variable	<	X1	X2	≥	Y1	Y2
Glei (gl)	<100cm	1	-2.95	≥1.0m	10	0.334
Calcium (Ca)	<50cm	1	-1.61	≥50cm	10	0.612
PSD1	<50cm	1	-0.77	≥50cm	10	1.277
PSD2	<72cm	1	-1.50	≥72cm	10	0.627
Bedrock (r)	<62cm	1	-3.55	≥62cm	10	0.277
Distinct Mottling (dm)	<100cm	1	-2.06	≥1.0m	10	0.478
Prominent Mottling (pm)	<100cm	1	-0.74	≥1.0m	10	1.317
Seepage (sp)	<100cm	1	-0.17	≥1.0m	10	5.75
Humus Form (fm)	≠8	1	-2.56	= 8	10	0.38
Water Table (w)	<100cm	1	-1.81	≥1.0m	10	0.55

X1: Assigned value for variables "less than",
X2: Standard value for the "less than" variables.

Y1: Assigned value for the variables "greater than",
Y2: Standard value for the "greater than" variables.

Table 3. Equations Derived in the Study			
a) Principle Components Analysis			
Variable	1st Component	2nd Component	3rd Component
gl	0.478	-0.189	0.148
ca	0.416	-0.055	-0.031
psd1	0.051	0.491	-0.091
psd2	-0.136	0.446	0.146
r	-0.063	-0.294	-0.603
dm	-0.249	-0.482	0.170
pm	0.217	0.418	-0.277
sp	-0.028	0.071	0.674
hf	0.494	-0.153	0.148
w	0.469	-0.005	-0.053
proportion	0.315	0.180	0.171

b) <u>Equilibrium % Spruce - (ES)</u>

ES = 0.3439 - 0.1518*1stPC + 0.0637*3rdPC

RMSE = 0.218   R sq = 0.598

c) <u>Jack Pine Component Prediction Equations</u>

1. Site Independent

$C_p = C_{p0} 0.9965^{5a}$, where $a = C_{s0}^{0.2501}$,   (Nigh, 1991)

RMSE = 0.01563

2. Site Dependent

$C_p = C_{p0}\{(0.5(EC - C_{s0} + 2))^{-0.0071}\}0.9963^{5b}$,

RMSE = 0.01565

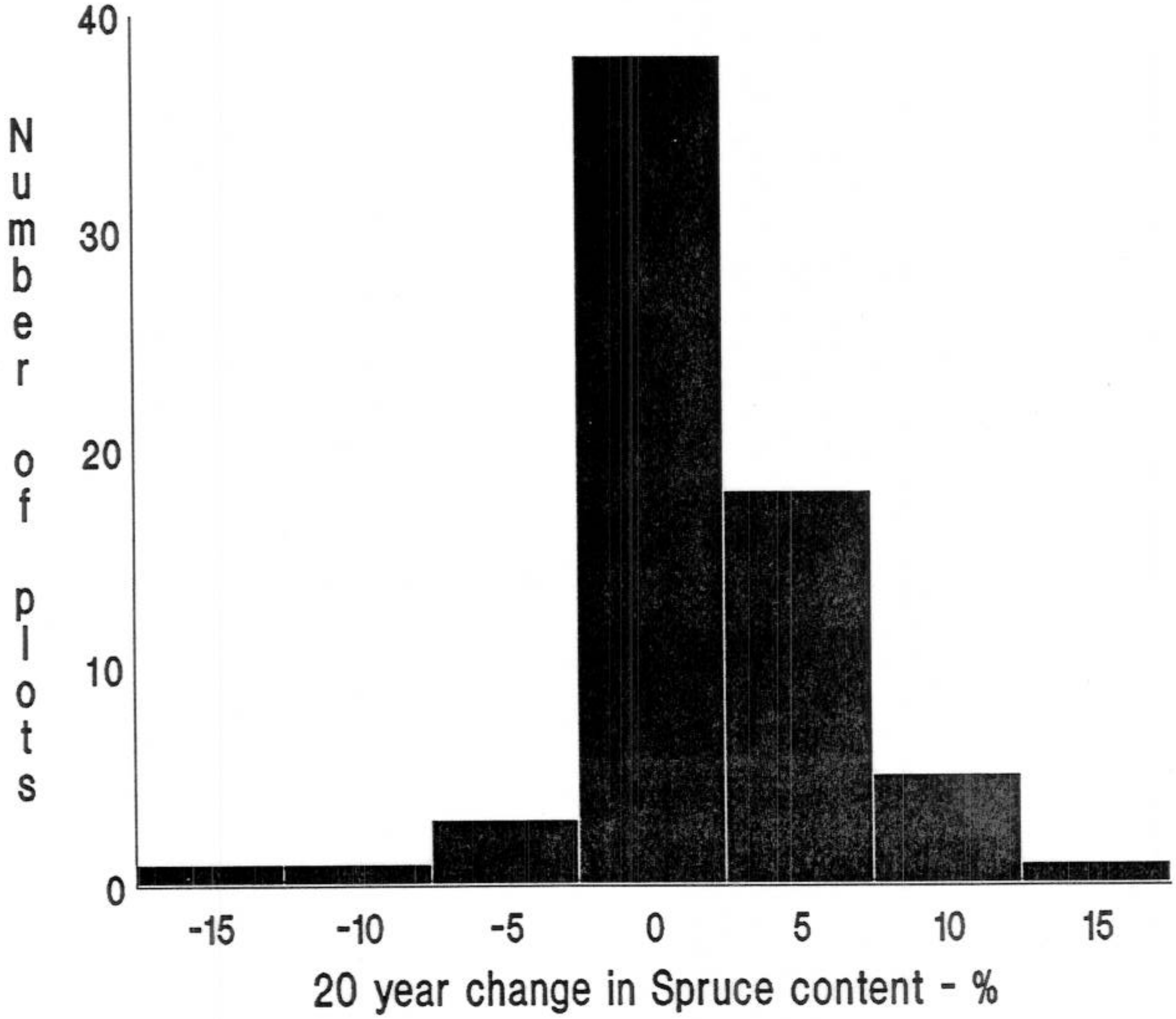
where $b = C_{s0}^{0.2829}$

<u>Note:</u>

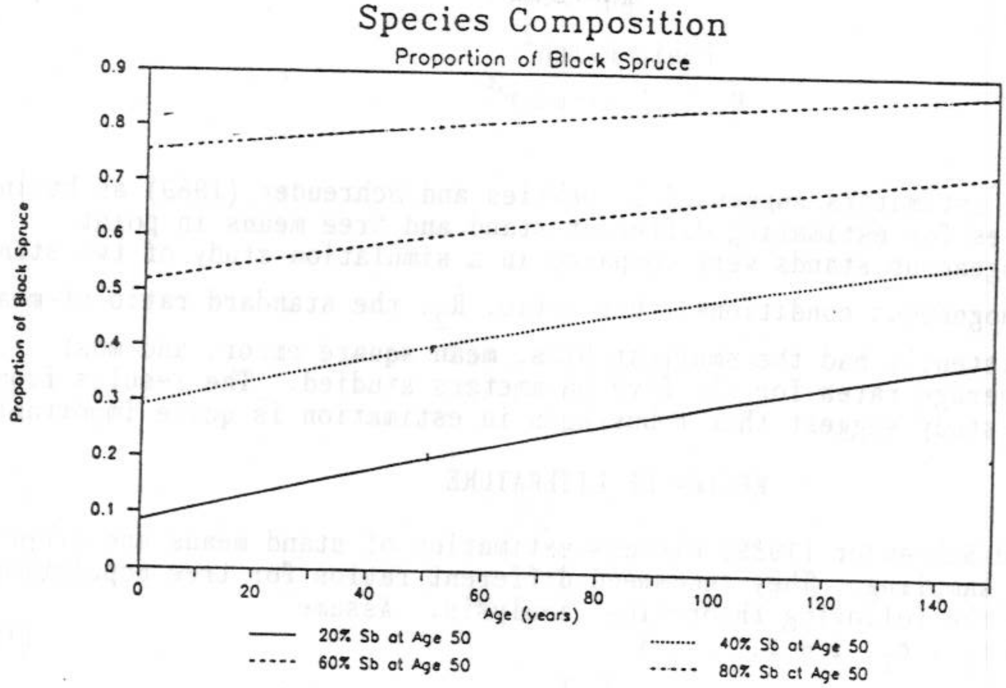
C_p is predicted jack pine content,
C_{p0} is current jack pine content,
C_{s0} is current spruce content,
All the above are fractional values.

Table 4. Analysis of Variance			
Source	d f	Res. SS	Res. MS
Site Independent	311	0.075950	0.0002442
Site Dependent	310	0.075921	0.0002449
Difference	1	0.000029	
F(1,310) = 0.000029/0.0002449 = 0.1184 ns			

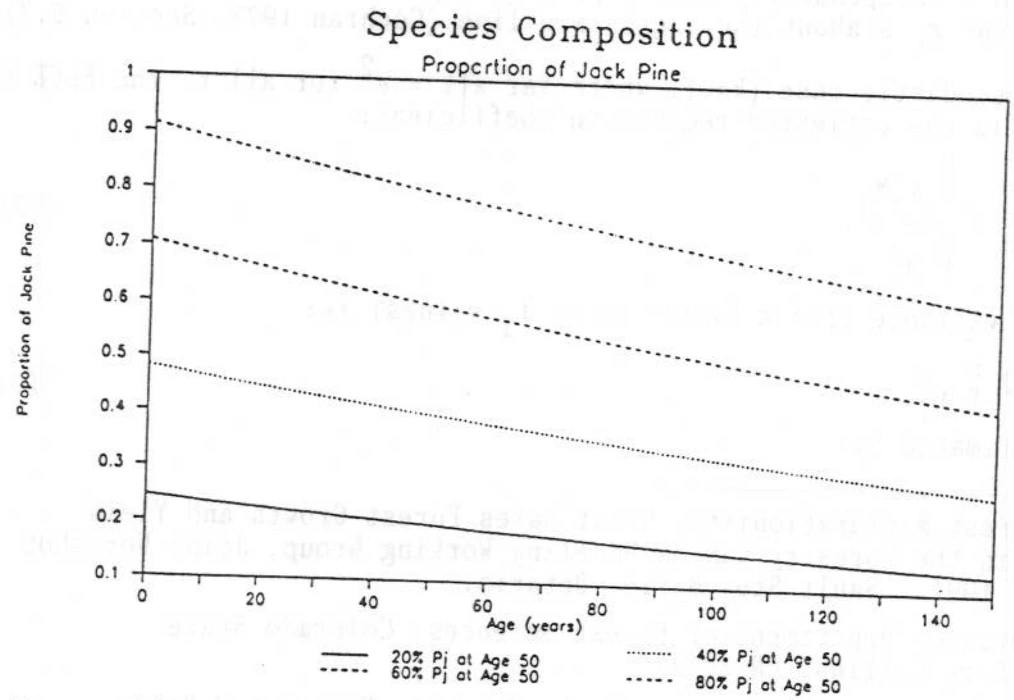
Figure 1: Change in % Spruce on Kimberly-Clark permanent sample plots over a 20 year period - 67 plots.



average change: 1.76%
standard deviation: 4.45%
standard error: 0.54%
15 plots showed exactly 0 change.



a) Proportion of Black Spruce



b) Proportion of Jack Pine

Figure 2. Changes in Species Composition over Time

ESTIMATION OF STAND MEANS AND OTHER RATIOS IN POINT SAMPLING – A SIMULATION STUDY[1]

By

Robin Reich[2]

H. T. Schreuder[3]

Abstract.

Three ratio estimators suggested in DeVries and Schreuder (1989) as having optimal properties for estimating different stand and tree means in point sampling in homogeneous stands were compared in a simulation study of two stands representing homogeneous conditions. One ratio, $\hat{R}_2$, the standard ratio-of-means estimator, consistently had the smallest bias, mean square error, and most reliable 95% coverage rates for all five parameters studied. The results from this simulation study suggest that robustness in estimation is quite important.

REVIEW OF LITERATURE

DeVries and Schreuder (1989) discuss estimation of stand means and other ratios in point sampling. They recommend different ratios for tree population ratios based on the following theoretical analysis. Assume

$$z_i = \alpha + \beta t_i + e_i, \; i = 1, \ldots, N \qquad (1)$$

where the e_i have 0 mean and variance $\sigma^2 . t_i^k$ with k specified.

If $\alpha = 0$, then the best linear unbiased estimator (BLUE) of R, based on data collected on n independently-chosen points, depends on the nature of the distribution of the z_i's about the regression line (Cochran 1977, Section 6.7).

In the homoscedastic case (k=0), where Var $z|t = \sigma^2$ for all t, the BLUE for R (Royall 1970) is the estimated regression coefficient:

$$\hat{R}_1 = \frac{\sum^n z_i t_i}{\sum^n t_i^2} = \frac{\sum^n y_i M_i}{\sum^n M_i^2}. \qquad (2)$$

Its conditional variance (for a fixed set of t_i-values) is:

$$\text{Var } \hat{R}_1 = \sigma^2 / \sum^n t_i^2, \qquad (3)$$

which can be estimated by:

---

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$$\text{var } \hat{R}_1 = s^2/\sum^n t_i^2, \text{ where } s^2 = (\sum^n z_i^2 - \hat{R}_1^2 \cdot \sum^n t_i^2)/(n-1). \quad (4)$$

Expression (4) also may be used as an approximation of the estimated unconditional variance.

If the bivariate distribution of z and t is heteroscedastic in z, with variance proportional to t (k=1), i.e., $\text{Var } z|t = \sigma^2.t$, the BLUE for R (Royall 1970) is the ratio of means:

$$\hat{R}_2 = \bar{z}/\bar{t} = \frac{\sum^n z_i}{\sum^n t_i} = \frac{\sum^n y_i}{\sum^n M_i}, \quad (5)$$

with unconditional variance:

$$\text{Var } \hat{R}_2 \doteq (1/M)^2(1/n)(\sum^N y_i^2 + R^2 \cdot \sum^N M_i^2 - 2 \cdot R \cdot \sum^N M_i y_i)/(N-1), \quad (6)$$

and estimated variance:

$$\text{var } \hat{R}_2 \doteq n \cdot (\sum^n t_i)^{-2}(\sum^n z_i^2 + \hat{R}_2^2 \cdot \sum^n t_i^2 - 2 \cdot \hat{R}_2 \cdot \sum^n z_i t_i)/(n-1) \quad (7)$$

where for lack of knowledge of M, or R, we substituted $\hat{M} = \sum^n M_i/n = AK.\sum^n t_i/n$, and $\hat{R}_2$.

If (k=2) the heteroscedasticity is characterized by $\text{Var } z|t = \sigma^2.t^2$, the BLUE for R (Royall 1970) is the mean of ratios:

$$\hat{R}_3 = \frac{\sum^n (z_i/t_i)}{n} = \frac{\sum^n (y_i/M_i)}{n} = \frac{\sum^n r_i}{n} = \bar{r}. \quad (8)$$

As $\hat{R}_3$ is the mean of a simple random sample of size n, its unconditional variance is:

$$\text{Var } \hat{R}_3 = S^2/n = (1/n).\sum^N (r_i - \sum^N r_i/N)^2/(N-1), \quad (9)$$

which can be estimated as:

$$\text{var } \hat{R}_3 = s^2/n = (1/n).\sum^n (r_i - \bar{r})^2/(n-1). \quad (10)$$

Bootstrap or jackknife variance estimation can easily be implemented as estimators of (3), (6), and (9), as alternatives to (4), (7), and (10). Both techniques are described in Schreuder and Ouyang (1991).

For the general model (1) with $\alpha \neq 0$, it is not clear what the best ratio estimator is. Presumably one would use the most robust estimator of R_1, R_2, and R_3. This is likely to be $\hat{R}_2$ but this needs to be verified empirically.

OBJECTIVES

1. Assess the gain in efficiency in using the appropriate estimator $\hat{R}_1$ in (2), $\hat{R}_2$ in (5), or $\hat{R}_3$ in (8) for estimating average tree basal area ($\overline{BA}$) $\overline{BA}$ = average tree basal area; $\overline{D}$ = average tree diameter; $\overline{H}$ = average tree height; $\overline{V}$ = average tree volume; and $\overline{LH}$ = Lorey height (DeVries and Schreuder 1989). Different sample sizes n = 10 - 50 will be used.
2. Assess classical variance estimators as in (4), (7), and (10) and compare to bootstrap and jackknife variance estimates in terms of unbiased estimation of the empirical variance and stability (variance).
3. Determine the relative frequency of containing the true parameter of interest in 95% constructed confidence intervals for each parameter estimate with confidence intervals constructed using the classical, bootstrap, and jackknife standard error for each estimate.
4. For the general model (1) with $\alpha \neq 0$, attempt to determine what ratio estimator might be best for k = 0, 1, or 2. If successful, the gain in efficiency using various ratio estimators might be evaluated with simulation.

Data

1. 902 clusters of 5-point plots consisting of pure loblolly pine with site classes 1-5 (most 3, 4), age from 13-22, and growing stock levels from 10-160 trees/acre (mostly in the 71-130 range) were used (DeVries and Schreuder 1989). An expansion factor for number of trees per acre is $NTPA_{ij}$ = 6875.5 /(number of inventory points (DBH_{ij}^2)) for trees greater than or equal to 5 inches in diameter; and NTPA = 300.00 / (number of inventory points) for trees less than 5 inches. For those clusters we have for cluster i:

$$\hat{BA}_i = \sum_{i=1}^{m_i} NTPA_{ij} \cdot \frac{\pi D_{ij}^2}{4}$$

$$\hat{N}_i = \sum_{i=1}^{m_i} NTPA_{ij}$$

$$\hat{D}_i = \sum_{i=1}^{m_i} NTPA_{ij}\, D_{ij}$$

$$\hat{H}_i = \sum_{i=1}^{m_i} NTPA_{ij}\, H_{ij}$$

$$\hat{V}_i = \sum_{i=1}^{m_i} NTPA_{ij}\, \beta . D^2 H_{ij},$$

where β = 0.0018 obtained from fitting $V_{ij} = \alpha + \beta D^2 H_{ij} + \epsilon$ using simple linear regression. This population will be referred to as N902.
2. A subset of 428 clusters out of the 902 clusters of 5-point plots above which is more homogeneous in the sense that site class is 3 or 4, age 15-20 years, and growing stock levels from 71-130 trees/acre with the same

information as above. This will be denoted by population N428.

Methods

2000 samples of 10, 20, 30, 40, and 50 clusters were drawn by simple random sampling from each population using a multiple linear congruential random sampling generator (L'Ecuyer 1988).

For each sample estimates $\hat{R}_1$, $\hat{R}_2$, and $\hat{R}_3$ for each of the parameters $\overline{BA}$, $\overline{D}$, $\overline{H}$, $\overline{V}$, and $\overline{LH}$ were computed. Also their classical, jackknife, and bootstrap variance estimates were computed (see Schreuder and Ouyang 1991 on how to compute jackknife and bootstrap variance estimates). The 95% confidence intervals for each estimate with its appropriate standard error estimates were computed and the proportion of confidence intervals containing the true parameter was determined.

The average variance and variance of the mean over the 2000 simulations was computed. The average variance was computed to be the variance between the 2000 estimates. This latter variance is called the simulation variance and is the best estimate of the variability of the estimates generated.

Results and discussion

As indicated in DeVries and Schreuder (1989), scatter diagrams of fairly homogeneous loblolly pine plot data indicated that for average basal area/tree ($\overline{BA}$) and arithmetic mean tree diameter ($\overline{D}$), $\hat{R}_1$ appeared to be the most suitable ratio estimator and $\hat{R}_2$ might be preferred for arithmetic mean tree height ($\overline{H}$), average volume per tree ($\overline{V}$), and the Lorey mean stand height ($\overline{LH}$). The results for N428 are discussed but not shown since they are similar to those for N902.

The simulation results only confirm these expectations for $\overline{H}$, $\overline{V}$, and $\overline{LH}$. These results show that $\hat{R}_1$ and $\hat{R}_3$ are seriously biased for N902 clusters (Table 1) and for N428, whereas the bias of $\hat{R}_2$ is always considerably less. As expected, $\hat{R}_2$ is consistent (which means that the bias decreases with increasing sample size), but the bias of $\hat{R}_1$ and $\hat{R}_3$ is independent of sample size. The bias of $\hat{R}_1$ ranges from about -2% (for $\overline{LH}$) to about 15% (for $\overline{V}$) and for $\hat{R}_3$ from about 3.5% (for $\overline{LH}$) to -40% (for $\overline{V}$) for N902. For N428 the corresponding biases are about -1% (for $\overline{LH}$) to about 15% (for $\overline{V}$) for $\hat{R}_1$, and about 1.9% (for $\overline{LH}$) to about -37% (for $\overline{V}$) for $\hat{R}_3$. That is, the bias for the two estimators is somewhat less for the more homogeneous populations (N428), but still substantial. For $\hat{R}_2$ the biases range from about -0.20 ($\bar{H}$) to -1.80 ($\bar{V}$) with n=10 for N902, and from 0.20 ($\overline{LH}$) to -2.45 ($\bar{V}$) with n = 10 for N428. The corresponding ranges of bias are about 0.04 ($\bar{D}$) to 0.18 ($\overline{LH}$) with n = 50 for N902, and -0.02 ($\bar{H}$) to -0.34 ($\overline{BA}$) for N428. The biases for $\hat{R}_2$ do not seem to be less for the more homogeneous population.

From the point of view of estimation bias, $\hat{R}_2$ definitely seems to be the best ratio estimator. It has the smallest bias in all cases and the bias decreases with increasing sample size.

In terms of mean square error efficiency, $\hat{R}_2$ is always the best estimator. This is true for N902 (Table 1) and N428. $\hat{R}_3$ is never competitive with $\hat{R}_2$, and $\hat{R}_1$ is only reasonably competitive for $\bar{H}$ and $\overline{LH}$. This is true for both N902 and N428. Apparently the conditions for which $\hat{R}_1$ and $\hat{R}_3$ would be better than $\hat{R}_2$ are simply not well approximated with these data sets despite speculations to that effect in DeVries and Schreuder (1989). Note that the mean square error for $\hat{R}_2$ decreases approximately proportional to sample size as we go from n = 10 to n = 50. This is not true for $\hat{R}_1$ and $\hat{R}_3$ because for those two estimators, the contribution of the bias component to the mean square error is substantial and does not decrease with sample size.

The classical, jackknife, and bootstrap variance estimators expressed as percent of the simulation variances of $\hat{R}_1$, $\hat{R}_2$, and $\hat{R}_3$ are shown in Table 2 for n=10 and n=50. For $\hat{R}_2$ the classical variance estimator is consistently best, followed by the bootstrap variance estimator. The jackknife variance estimator always overestimates the true variance of $\hat{R}_2$. The jackknife variance estimator needs a finite population correction but no satisfactory expression for this has yet been found.

For $\hat{R}_3$, too, the classical variance estimator is best, jackknifing seems second best for the smaller sample sizes and bootstrapping seems second best for the larger sample sizes.

For $\hat{R}_1$ the classical variance estimator is clearly unsatisfactory; it always seriously underestimates the true variance. The bootstrap and, to a lesser extent, the jackknife variance estimator give substantially better estimates of the true variance even though they are seriously biased in some cases.

The 95% coverage rates for $\hat{R}_1$, $\hat{R}_2$, and $\hat{R}_3$ are shown in Table 3 for n=10 and n=50 with the classical, jackknife and bootstrap variance estimators. The coverage rates for $\hat{R}_2$ seem quite acceptable especially for the larger sample sizes. Coverage rates for the classical variance are about the same as with the bootstrap and jackknife variance estimates.

Recommendations

1. The standard ratio-of-means estimator, $\hat{R}_2$, should be used for estimating different stand and tree means in preference to $\hat{R}_1$ and $\hat{R}_3$ unless there is strong evidence to the contrary.
2. The confidence intervals for the classical variance estimates should be used with $\hat{R}_2$.
3. Robust estimators such as $\hat{R}_2$ should be used unless the optimality of such estimators as $\hat{R}_1$ and $\hat{R}_3$ has been clearly demonstrated.

Table 1. Bias and mean square error of the estimate for the three ratios as a percentage of the true means for N902.

	TRUE	BIAS			MSE		
	VALUE	R1	R2	R3	R1	R2	R3
SAMPLE SIZE = 10							
BASAL AREA	12.26	12.18	-1.53	-32.88	21.73	16.54	35.04
DIAMETER	3.18	5.93	-0.82	-14.76	10.66	8.62	17.79
HEIGHT	27.01	2.14	-0.20	- 5.20	7.62	6.74	9.60
VOLUME	1.19	14.11	-1.76	-39.79	27.30	21.04	42.60
LOREY HEIGHT	42.25	-1.82	0.40	3.65	6.69	6.07	7.53
SAMPLE SIZE = 20							
BASAL AREA	12.25	13.64	-1.01	-35.02	19.72	11.53	31.47
DIAMETER	3.18	6.75	-0.54	-15.71	9.45	6.02	16.18
HEIGHT	27.01	2.31	-0.14	-5.60	5.83	4.83	7.98
VOLUME	1.19	15.87	-1.16	-42.37	24.29	14.74	37.57
LOREY HEIGHT	42.25	-2.22	0.17	3.55	5.23	4.44	5.98
SAMPLE SIZE = 30							
BASAL AREA	12.26	14.38	-0.58	-35.11	19.38	9.45	29.87
DIAMETER	3.18	7.20	-0.23	-15.63	9.24	4.94	15.36
HEIGHT	27.01	2.44	-0.04	-5.57	4.96	3.84	7.20
VOLUME	1.19	16.59	-0.76	-42.69	23.39	11.89	35.42
LOREY HEIGHT	42.25	-2.46	0.01	3.45	4.39	3.46	5.23
SAMPLE SIZE = 40							
BASAL AREA	12.26	14.72	-0.30	-34.65	19.10	7.81	28.44
DIAMETER	3.18	7.38	-0.11	-15.50	9.02	4.09	14.69
HEIGHT	27.01	2.61	0.09	-5.44	4.58	3.32	6.55
VOLUME	1.19	17.14	-0.29	-41.83	23.22	9.94	33.31
LOREY HEIGHT	42.25	-2.33	0.15	3.61	3.96	3.04	5.00
SAMPLE SIZE = 50							
BASAL AREA	12.26	15.04	0.10	-34.27	19.13	6.92	27.78
DIAMETER	3.18	7.51	0.04	-15.35	8.95	3.61	14.35
HEIGHT	27.01	2.51	0.06	-5.42	4.20	2.93	6.31
VOLUME	1.19	17.44	0.16	-41.42	23.11	8.87	32.55
LOREY HEIGHT	42.25	-2.29	0.18	3.66	3.65	2.75	4.83

Table 2. Average variance estimates expressed as a percentage of the simulation variance of three estimators for N902.

	MEAN	CLASSICAL	JACKKNIFE	BOOTSTRAP
n = 10				
BASAL AREA				
R1	3.271292	85.4928	118.0630	97.1887
R2	4.202632	99.4748	107.3555	103.6644
R3	16.321724	102.1289	102.1288	92.0648
DIAMETER				
R1	0.065816	77.0144	120.3672	95.8269
R2	0.075456	98.7275	107.8514	100.2167
R3	0.200736	100.9763	100.9760	90.2454
HEIGHT				
R1	3.718422	66.7334	113.4649	86.4715
R2	3.328289	99.3125	106.7927	95.2889
R3	5.476488	102.8119	102.8110	92.4354
VOLUME				
R1	0.049600	88.2273	114.4613	96.0368
R2	0.064420	99.3933	105.8235	103.5395
R3	0.277698	102.9880	102.9880	93.1130
LOREY HEIGHT				
R1	7.680965	69.8243	104.6234	83.5879
R2	6.492871	99.0492	104.4426	91.9482
R3	7.025888	105.7743	105.7743	95.7456
n = 50				
BASAL AREA				
R1	0.572185	86.8875	103.2159	95.4346
R2	0.718813	103.6911	104.9475	104.2886
R3	3.258661	101.4629	101.4591	99.6930
DIAMETER				
R1	0.012137	76.0464	104.2624	95.4276
R2	0.013103	104.3679	105.9718	104.6237
R3	0.038863	103.1967	103.2048	100.9972
HEIGHT				
R1	0.762069	61.3657	100.9309	90.6492
R2	0.624125	100.7210	102.1217	99.1492
R3	1.083792	101.0415	101.0051	99.0400
VOLUME				
R1	0.008456	91.4806	101.7515	95.7126
R2	0.011096	102.1020	103.0450	102.6035
R3	0.057093	99.2211	99.2212	96.9962
LOREY HEIGHT				
R1	1.554152	67.9430	97.8327	92.8138
R2	1.335293	94.8666	95.8913	93.4224
R3	1.477864	95.7096	95.7118	93.8600

Table 3. 95% coverage rates for the three ratios using the three variance estimates for N902.

	CLASSICAL	JACKKNIFE	BOOTSTRAP
n = 10			
BASAL AREA			
R1	80.80	81.90	80.45
R2	93.85	94.30	93.20
R3	94.60	94.60	92.05

DIAMETER			
R1	82.05	84.50	83.55
R2	93.75	94.20	93.70
R3	92.95	92.95	89.90
HEIGHT			
R1	87.20	89.50	89.20
R2	95.00	95.25	94.25
R3	94.95	94.95	93.60
VOLUME			
R1	82.00	81.30	80.35
R2	93.25	93.40	93.20
R3	94.95	94.95	93.65
LOREY HEIGHT			
R1	90.60	92.45	91.15
R2	94.05	94.45	93.20
R3	91.30	91.30	90.10
n = 50			
R1	29.50	33.00	30.90
R2	94.55	94.70	94.90
R3	29.65	29.65	28.60
DIAMETER			
R1	33.40	42.15	38.90
R2	94.85	94.95	95.00
R3	27.35	27.40	26.65
HEIGHT			
R1	76.40	84.30	83.20
R2	94.95	95.10	94.25
R3	76.35	76.60	75.20
VOLUME			
R1	35.50	38.95	37.10
R2	94.70	94.75	94.45
R3	41.80	41.80	40.40
LOREY HEIGHT			
R1	80.50	87.90	86.60
R2	93.80	94.15	93.45
R3	73.55	73.40	72.90

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GIP: Growth Implementation Package and things to come

by

David K. Walters and Alan Ek

ABSTRACT. GIP uses models developed for 14 cover types in Minnesota providing per acre estimates of basal area, number of stems, quadratic mean diameter, and volumes to specified top diameters. The equations were developed from linear and nonlinear least squares analyses using USDA Forest Service Forest Inventory and Analysis project data. They are intended for projecting future forest characteristics including yield on a statewide basis assuming the continuation of the level of management inherent in the data. A brief description and example of model implementation procedures and important considerations in applications are provided. Future enhancements to the model include the development of growth models from the remeasurement of the FIA data and improvement of mortality and regeneration models.

INTRODUCTION

Data from Forest Inventory and Analysis (FIA) plots are becoming more and more readily available (Hansen 1990, Hansen et al. 1990), however, little has been done, at least outside of the FIA project, to summarize these data through the use of mathematical models. Traditionally, these data are presented in a tabular form (Hahn and Raile 1982, Essex and Hahn 1976). While offering valuable information concerning the current regional timber supply, these tables are difficult to integrate into planning efforts for predicting present and future yields. Through modeling techniques, equations have been developed for the data from Minnesota which *smooth* the values found in these tables and facilitate application. The equations developed relate basal area, number of stems, quadratic mean diameter, volumes and biomass to age and site index.

The equation forms used here are similar to those described in numerous forestry texts and articles (e.g., Husch et al. 1982, Bruce and Schumacher 1950, Schumacher 1939, MacKinney and Chaiken 1939). A recent publication by Walters et al. (1990) has also illustrated the construction of similar equations from an industrial forest inventory data set. A key to their successful usage is understanding their shortcomings (Leary and Smith, 1990; Davis and Johnson, 1986) and appropriate applications. The specific equations used in GIP can be found in Walters et.al (1991).

DATA

The data for this study were obtained from the North Central FIA data base collection for the 1977-78 Minnesota survey (Jakes, 1980) using the Scientific Information Retrieval (SIR) system (Robinson et al. 1980) and procedures documented by Hahn and Hansen (1985). After eliminating certain plots because of suspect data points (outliers) or because they were otherwise not pertinent to this study, 8856 FIA 10-point clusters (hereafter called plots) were available for analysis. For further details of measurement procedures, consult Doman et al. (1981).

To obtain per acre estimates of the various dependent variables, the individual tree values were summed using appropriate per tree expansion factors.

MODEL FITTING AND RESULTS

In order to provide a complete set of equations, several different dependent variables had to be modeled. In some cases, the optimal means of predicting variables were not possible because of limitations of the data. As an example, there was no plot remeasurement data available. Consequently basal area <u>growth</u> and <u>mortality</u> models[1] could not be developed directly. The following basic models[2] were initially hypothesized and subsequently fitted:

$$B = a_1 S^{a_2} A^{a_3} \qquad [1]$$

$$D = b_0 + b_1 A^{b_2} + b_3 S \qquad [2]$$

$$N = \exp(c_0 + c_1 lnD) \qquad [3]$$

$$V = d_1 B^{d_2} H^{d_3} \qquad [4]$$

$$PV_T = V\exp(e_1 T^{e_2} + e_3(\frac{T}{1+D})) \qquad [5]$$

$$SV_T = PV_T(f_1 + f_2 A^{f_3}) \; /98.484 \qquad [6]$$

where,

A = stand age (years)
S = site index (feet)
B = basal area (ft^2/acre) for all trees greater than or equal to 0.95 inches dbh
D = quadratic mean diameter (inches) of the stand
N = number of trees per acre
H = average total height of dominant/codominant trees
V = gross volume (ft^3/acre) for all trees greater than or equal to 4.95 inches dbh above a 1 foot stump

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1. Upon completion of the second measurement of these data, a basal area <u>growth</u> model will also be fitted.

2. In addition, the stand height equation provided in Hahn and Carmean, 1982 is used to provide an estimate of stand height.

$PV_T=$ gross merchantable volume (ft^3/acre) for all trees greater than T+2 inches dbh and classified[3] as pulpwood material above a 1-foot stump and below a top diameter outside bark (dob) of T inches

$SV_T=$ gross volume (MBF/acre[4]) for all trees greater than T+2 inches in dbh and classified[2] as sawtimber material above a 1-foot stump and below a top diameter outside bark (dob) of T inches

and a_i, b_i, c_i, d_i, e_i, and f_i are forest type dependent parameters.

Each of these models, and numerous variants to each of them, were fitted using the SYSTAT statistical package (Wilkinson 1988). Model selection was based on a number of different criteria. Goodness of fit statistics including mean absolute deviation from the known value (MAD), mean deviation (ME), and mean squared deviation or error (MSE)
were calculated. R^2 was also calculated using a formulation presented by Ksvaleth, 1985 even though it cannot strictly be applied to these nonlinear models. In addition, extensive use was made of residual plots and other graphical techniques to evaluate model form and adequacy. The final coefficient estimates are provided in Walters et.al. (1991). As an example a graph of the volume equation for the Aspen cover type is provided in Figure [1].

Comparison of empirical yield equation to remeasured data

Preliminary results from aspen plots in the 1990 measurement of survey unit 1 (Aspen-Birch unit) of the Minnesota statewide inventory[5] were used to examine equation [1]. Only those plots which were visited twice, forested, undisturbed, and had a stand age and a basal area recorded at both measurements were included in this analysis. Basal area at the second (1990) measurement was then predicted using the age and site index from the first (1977) measurement using equation [1] and a ratio adjustment to initial basal area. This predicted basal area was compared with the actual, observed basal area at the time of the second measurement. As a point of comparison, basal area was also predicted using the GROW (Brand, 1981) subroutine which is used in the STEMS forest tree growth model (Belcher, 1981). Table 2 contains mean error and mean absolute error (percent) for these two predictions of 121 Aspen plots meeting the above criteria. Figure 2 shows the relationship of mean error (%) versus stand age for equation [1] and the GROW estimates of basal area for the aspen cover type. Aspen is the only type for which an adequate sample size exists to make these calculations. It is expected that equation [1] would appear much better when evaluated with data from across the state (which is the geographic range of the model). More detailed evaluation of the models will be conducted after the data for the statewide inventory is released.

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[3] Using USDA Forest Service FIA size class codes. Size class codes are:
1) saplings and seedlings
2) poletimber
3) sawtimber

[4] International 1/4 inch rule

[5] M. Hansen, personal communication.

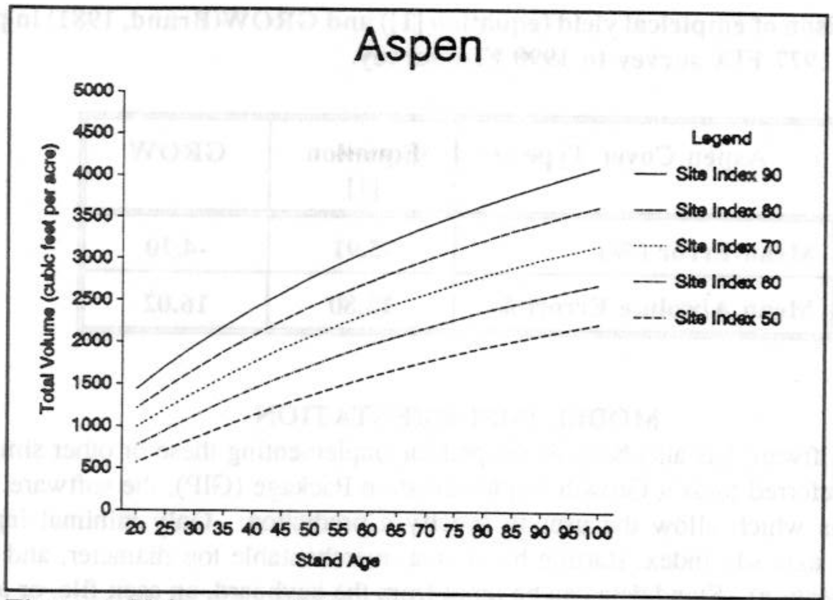

Figure 1. Volume predictions from equation [4] for Aspen cover type.

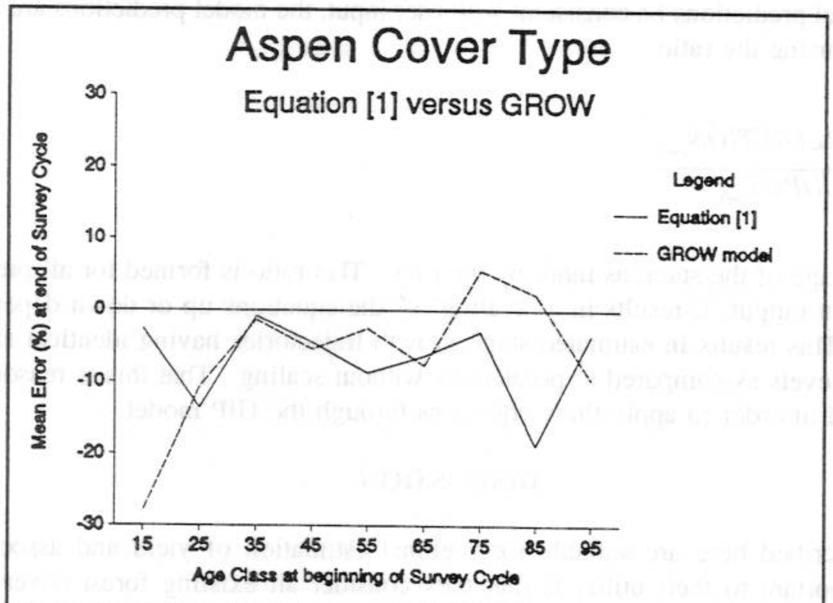

Figure 2. Comparison of mean error (%) of basal area prediction from equation [1] and the GROW model (Brand, 1981) as a function of stand age at beginning of updating cycle.

Table 2. **Comparison of empirical yield (equation [1]) and GROW(Brand, 1981) in predicting basal area from 1977 FIA survey to 1990 FIA survey.**

Aspen Cover Type	Equation [1]	GROW
Mean Error (%)	-5.91	-4.70
Mean Absolute Error(%)	12.80	16.02

MODEL IMPLEMENTATION

Microcomputer software has also been developed for implementing these or other similar, stand-level models[6]. Referred to as a Growth Implementation Package (GIP), the software consists of a series of menus which allow the user to specify a prediction. Only minimal input data is required (starting age, site index, starting basal area, merchantable top diameter, and length and frequency of projection). Stand data can be input from the keyboard, an ascii file, or an R:BASE (Microrim, 1990) database table and can be output to the monitor, an ascii file, or an R:BASE database table.

Scaling Density and Volume Input

In order that model predictions be consistent with user input, the model predictions are also scaled by stand density using the ratio

$$R=\frac{MODEL\ PREDICTION_{t=0}}{USER\ INPUT_{t=0}} \qquad [7]$$

where t=0 is the age of the stand as input by the user. This ratio is formed for all predictions to provide consistent output. It results in a "scaling" of the equations up or down dependent upon the input data. This results in estimated stand growth trajectories having identical shape but at higher or lower levels as compared to predictions without scaling. That this is reasonable to do must be assumed in order to apply these equations through the GIP model.

DISCUSSION

The models described here are suitable for regional estimation of yield and associated stand conditions. Important to their utility is that they consider all existing forest cover types with identical data input and output standards. The models provide an important tool for rapid yield prediction with minimal software and hardware requirements.

Many efforts involving predicting growth, yield, and stand conditions need only average estimates by cover type. Our experience has been that such efforts frequently use crude percentage or per

[6]Lime, S. D., D. K. Walters, and A. R. Ek. 1990. GIP: Software for implementing stand-level yield equations. MANUSCRIPT IN PREPARATION. This implementation software and documentation can be obtained upon request at nominal cost from the authors.

cord growth rates obtained from permanent plot data. A significant improvement would be to use an individual tree growth model, such as the regional model STEMS (Belcher, 1981). A second alternative is the equations given. The resulting predictions provide an empirical, data-based estimate of future stand conditions. The equations are also easily used and require only stand-level input information. These are some of the strengths of these models. Hence, for updating timber inventories and making projections for short time periods, these models should have very important utility. While predictions for selected or managed stands will likely be underestimated, preliminary information from the 1990 measurement of the Minnesota statewide inventory show relatively minor differences in predicting stand basal area between STEMS and these empirical yield estimates (Table 2, Figure 2)[7].

The planned addition of growth information to GIP (these data will soon be available) will improve several aspects of these models. Specifically, the ability to predict yields for managed stands will be improved. Still, the difference between empirical yield models and estimates from improved growth models or STEMS are important as they describe the gains possible from forest protection and management investments.

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Forest Area Estimation - Calibrating Remote Sensing Estimates.

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ABSTRACT

Forestry applications utilizing calibration procedures for improving areal cover type estimates have typically included what are commonly called the classical and inverse methods. Both methods, as traditionally applied in forestry, require that the reference data arise from a simple random sample of pixels, even though simple random sampling is not necessarily the most efficient means of gathering information from the reference data. A simulation study was conducted which compared the classical and inverse techniques across a range of cover type distributions, classification accuracies, and reference sample sizes. The two methods were compared on the basis of bias, accuracy, and feasibility. Variance estimates for the two methods were also compared. Results of the simulation study are discussed. In addition, cluster sampling is discussed as an alternative sampling scheme for the reference data. Possible methods of calibrating areal estimates with clustered data are reviewed.

INTRODUCTION

The challenge of combining relatively inexpensive, biased estimates with expensive, unbiased estimates has been addressed repeatedly over the years. Much debate has focused on the most appropriate method of linear calibration. Most of the literature has concentrated on choosing between the classical and inverse methods, based on direct and indirect regression respectively. (Eisenhart, 1939; Krutchkoff, 1967; Williams, 1969). Theoretical foundations for the two methods are generally provided by the likelihood principle and Bayesian reasoning, respectively (Lwin and Maritz, 1982, Hunter and Lamboy, 1981). Interestingly, the inverse method was also shown to be the maximum likelihood method by Tenenbein (1972); the classical method was derived as an asymptotic maximum likelihood estimate by Grassia and Sundberg (1982).

Both the classical and inverse methods can be obtained from regression techniques. Let X denote reference classification data and Y satellite classification data. Both are observed on the reference data sample units while only Y is available for the remaining units in the population. Adjustment of satellite data normally proceeds by regressing Y on X for the reference data sample units:

$$Y = \hat{b}_0 + \hat{b}_1 X + \text{error} \quad [1]$$

and using the estimator $\hat{X}(\text{whole}) = [Y(\text{whole}) - \hat{b}_0] / \hat{b}_1$ where Y(whole) is the satellite classification for the whole area (it is most clear here if X and Y are assumed to be percent acreages for a cover type). This is referred to as the classical method. The inverse method regresses X on Y:

$$X = \hat{\partial}_0 + \hat{\partial}_1 Y + \text{error} \quad [2]$$

with the estimator for the whole obtained in the obvious way.

Until Brown's (1982) paper, the main statistical body of literature treated the univariate, normal variables case. Brown reviewed multivariate calibration in detail and dealt with the case where X and Y are normally distributed, but states that normality is not necessary. He cites an article (Grassia and Sundberg, 1982) where the columns in a contingency table are multinomial conditional on X and the rows are multinomial conditional on Y, which is exactly the case when interest lies in area estimation for multiple cover types. Often in remote sensing applications an individual pixel is assigned one classification type; it can represent only one cover type. For these cases, the data can be thought of as arising from a multinomial distribution, although for certain sampling situations this is not necessarily so. For example, Chhikara et al. (1986) and Heydorn and Takacs (1986) sample (from this type of classification data) a population of heterogeneous clusters and obtain crop acreage estimates for each sample based on ground truth and remote sensing data. The acreage (proportion) estimates from the samples are assumed to come from a normally distributed population.

The classical and inverse methods have been derived for multinomial variables (Grassia and Sundberg, 1982 and Tenenbein, 1972). Both methods use the confusion matrix for correcting misclassification errors in data. The confusion matrix is an error matrix of counts where the individual cells represent units which are truly class i (rows), but are classified as class j (columns). Estimates are calibrated by both the omission and commission errors that have occurred during classification. Classification accuracy is presumed to depend solely on the true class of the unit. Of course factors such as where in a classification interval the unit lies or the values of adjacent units or even the prevalence of the unit itself may contribute to classification accuracy. Neither the classical nor the inverse estimator account for such possible dependencies. A benefit of both the classical and inverse methods is that they insure the calibrated total will equal the true total. In addition, the inverse proportion estimates are bounded by zero and one; the classical method can produce negative estimates and estimates greater than one.

A comparison of the classical and inverse methods was performed. Percent of land in various cover types was estimated with reference data arising from a simple random sample. In order for either estimator to be theoretically sound, data sets for calibrating the estimators and training the classifier must be independent. Extensions to this work will include evaluations of different reference sampling designs specifically, cluster sampling.

METHODS

DATA

Itasca State Park which contains mixed species forest and is located in northern Minnesota provided the simulation base for the study. The original satellite imagery data set covering the park represented an area approximately 1950 acres in size or 512 by 512 pixels (1 pixel ≈ 900 square meters). Within the park boundaries 158,693 pixels or approximately 1175 acres were available for study.

The reference data map was originally constructed from aerial photos flown in 1966; these were updated with photos flown in 1985. This provided complete reference coverage of the park. Reference data were digitized and converted from vector to raster format, then registered identically to Landsat Thematic Mapper (TM) data (Moore, 1987).

A supervised classification with 7 classes, from mid-May 1985 Landsat flights was available for study. The classes were combined post-classification from a more detailed 14-class system. Each class represented a unique cover type. The cover types identified were:

7-class data set
upland hardwood (uh)
upland conifer (uc)
water (w)
field and grass (fg)
marsh and bog (mb)
lowland conifer (lc)
cutover (c)

The original 7-class population data matrix was not used for conducting the simulation experiments. The only information retained from the original population matrix was total number of pixels in the population, number of classes, and distribution of the misclassified pixels.

In order to allow a more thorough comparison of the calibration methods being studied, the population data matrix was altered to reflect a range of possible population structures. Two components of the population structure were allowed to vary, the cover type distribution and the classification accuracy. Distributions where cover types occupied similar amounts of ground acreages were considered well-distributed, while those in which many of the cover types were rare were considered poorly distributed.

A maximum of three rare (2% or less of the total population) cover types was set. A total of eight cover type distributions were tested in the simulation (Table 1).

Five classification accuracy configurations were tested with each of the cover type distributions listed in Table 1:

- •All of the cover types were well classified (90% accuracy).
- •All of the cover types were moderately classified (60% accuracy).
- •All of the cover types were poorly classified (30% accuracy).
- •Common cover types were well classified while rare cover types were poorly classified[1].
- •Common cover types were poorly classified while rare cover types were well classified.

Classification accuracy in conjunction with the cover type distribution determines how many pixels are assigned to the diagonal elements of the error matrices. In addition the off-diagonal elements or misclassified pixels must somehow be apportioned to the different cover types. To accomplish this the simulation used the percentages implied by the original population data matrix (Table 2). By using the percent misclassified pixels from the original population for all population structures, the percent of misclassified pixels assigned to each cover type is independent of the actual number of pixels in that cover type as well as the classification accuracy of that cover type.

The combinations of cover type distributions and classification accuracies resulted in a total of 40 population structures. An example population data matrix is shown in table 3. It represents the population structure determined by cover type distribution one (see Table 1) and classification accuracy where all cover types are well classified. Once one of the population data matrices was constructed, a simple random sample was generated to determine which pixels would be included in the reference sample (i.e. which pixels would have both a ground and a remotely sensed classification associated with them). Probabilities were calculated for each cell of the population data matrix based on the proportion of pixels in the cell given the total number of pixels in the population. A uniform (pseudo) random number generator which uses a multiplicative-congruential method was invoked to allocate the sample. Sample sizes ranging from 100 to 1000 were tested for each of the population structures.

THE SIMULATION

Previous findings from simulation studies are not consistent as to which calibration method is best (Brown, 1982). Selection of the best method appears to depend heavily on the specific application, both in use of the calibration method and judgement of its performance. In our study a simulation was conducted to evaluate performance of the methods when Landsat TM data for an entire area and reference data for a subset of that area are available. Conclusions were made on the basis of overall bias, accuracy, and feasibility of the estimates themselves.

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[1]Cover types which represented more than 2% of the land area were considered common; 2% or less were considered rare.

Table 1. Cover type distributions for 7-class data set. % = percent of total Itasca State Park acreage represented by the indicated cover type. See text for definition of classes.

Cover type distribution	% uh	% uc	% w	% fg	% mb	% lc	% c
1	25	25	24	24	.7	.7	.6
2[a]	40	20	19	19	.7	.7	.6
3	17	17	17	16	16	16	1
4	34	25	10	10	10	10	1
5	40	30	10	5	5	5	5
6[a]	30	20	10	10	10	10	10
7	20	20	15	15	10	10	10
8	15	15	14	14	14	14	14

[a]Not all simulation experiments included this cover type distribution since initial simulation results indicated that it was similar to at least one other cover type distribution being studied.

Table 2. Allocation of misclassified pixels within each cover type for the 7-class data set obtained from the mid-May, 1985 Landsat TM imagery. For example 63 percent of the misclassified lowland conifer pixels were assigned to the upland conifer type. See text for definition of classes.

true\classified	%uh	%uc	%w	%fg	%mb	%lc	%c
%uh	-	72	02	04	08	03	11
%uc	67	-	02	03	11	12	05
%w	20	31	-	02	42	02	03
%fg	16	14	05	-	39	05	21
%mb	33	38	10	06	-	05	08
%lc	17	63	02	02	12	-	03
%c	59	11	01	20	08	01	-

Table 3. Population data matrix for 7-class system. Cover type distribution = 25%, 25%, 24%, 24%, .7%, .7%, .6%; classification accuracy = well classified. Elements represent pixel counts which are truly class i, but are classified as type j. See text for definition of classes.

true\classified	uh	uc	w	fg	mb	lc	c
uh	35706	2860	72	143	336	116	439
uc	2659	35706	83	118	433	483	191
w	764	1171	34277	61	1590	90	133
fg	598	538	189	34277	1484	197	803
mb	36	43	11	7	1000	5	9
lc	19	70	1	3	14	1000	3
c	56	11	1	19	8	1	857

The simulation was developed in GAUSS386 on a Northgate Elegance 486i. GAUSS386 is a matrix level language. The program has also been coded in Fortran, making use of the IMSL subroutines where possible.

Inverting the transition matrix as is required with the classical approach can lead to problems. The greater ill-conditioned the matrix, the greater the likelihood that infeasible proportion estimates will result. By varying the population structure we can determine if the presence of rare cover types contribute to the infeasibility problem of the classical estimator. In addition, looking at the correlation between condition number of the transition matrix and the error of the estimate associated with the most reference samples (presumably the most stable estimate) will suggest whether the condition number is related to the magnitude of the errors in the proportion estimates (whether positive or negative).

The performance of both methods was evaluated in part by calculating a bias and accuracy statistic for each method (equation [9]).

$$\% \text{ bias} = [\sum_{i=1}^{m} (\hat{\pi}_i - \pi_i) / m] / \pi_i * 100 \qquad [9]$$

where:

$\hat{\pi}$ = vector of estimated proportions
π = vector of actual proportions
m = number of simulation repetitions

Since there were multiple cover types, the average bias was represented by a vector (equation [10]).

$$\% \text{ accuracy} = [\sum_{i=1}^{m} |\hat{\pi}_i - \pi_i | / m] / \pi_i * 100 \qquad [10]$$

RESULTS and DISCUSSION

Without exception the inverse method outperformed the classical method in terms of accuracy and bias. However, for the situation where cover types were well-classified and equally distributed, both methods performed equally well (Figure 1). Under the conditions of a well-classified, equally distributed population, bias of both the classical and the inverse method were insensitive to reference sample size. Accuracy of the estimates was slightly affected. For example, a decrease in reference sample size from 1000 to 200 for cover type distribution 7 with 90% classification accuracy caused about a three to seven percent change in accuracy. With a reference sample size of 1000, percent accuracy ranged from two to five percent; with a reference sample size of 200, percent accuracy ranged from five to twelve percent (Figures 1 and 2).

For the inverse estimates the differences between the classification schemes is slight. For the classical method the differences are much more pronounced. As size of the reference sample increases, the differences become negligible. For situations where the common cover types were well-classified, but the rare cover types were not well-classified, the classical estimator was obviously adversely affected (Figure 3). In fact it performed worse than if all cover types were poorly classified. Misclassifying the common cover types while accurately classifying the rare cover types produced more accurate estimates than those generated by the poorly classified populations. This finding suggests that if rare cover types are included in the classification process, then accurately classifying them is more important than accurately classifying the common cover types. Although there is some evidence to indicate the same sensitivity in the inverse estimator, it is not as convincing as the data associated with the classical estimator.

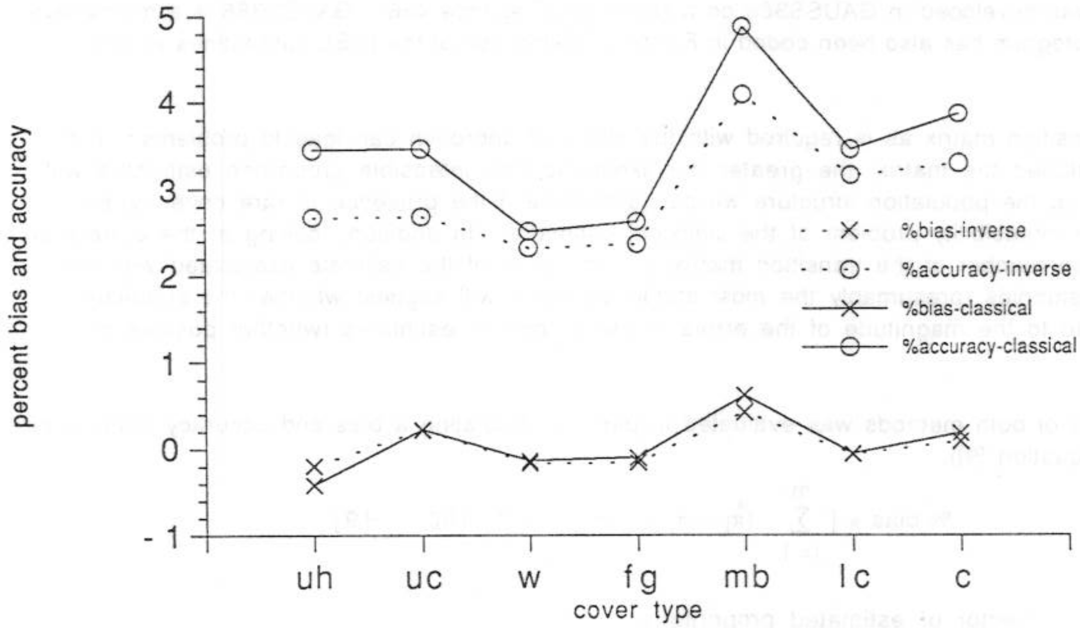

Figure 1. Average (based on 500 simulation repetitions) percent bias and accuracy values for both the inverse and classical methods. Cover type distribution=7, classification accuracy=well, reference sample size=1000. See text for definition of cover types.

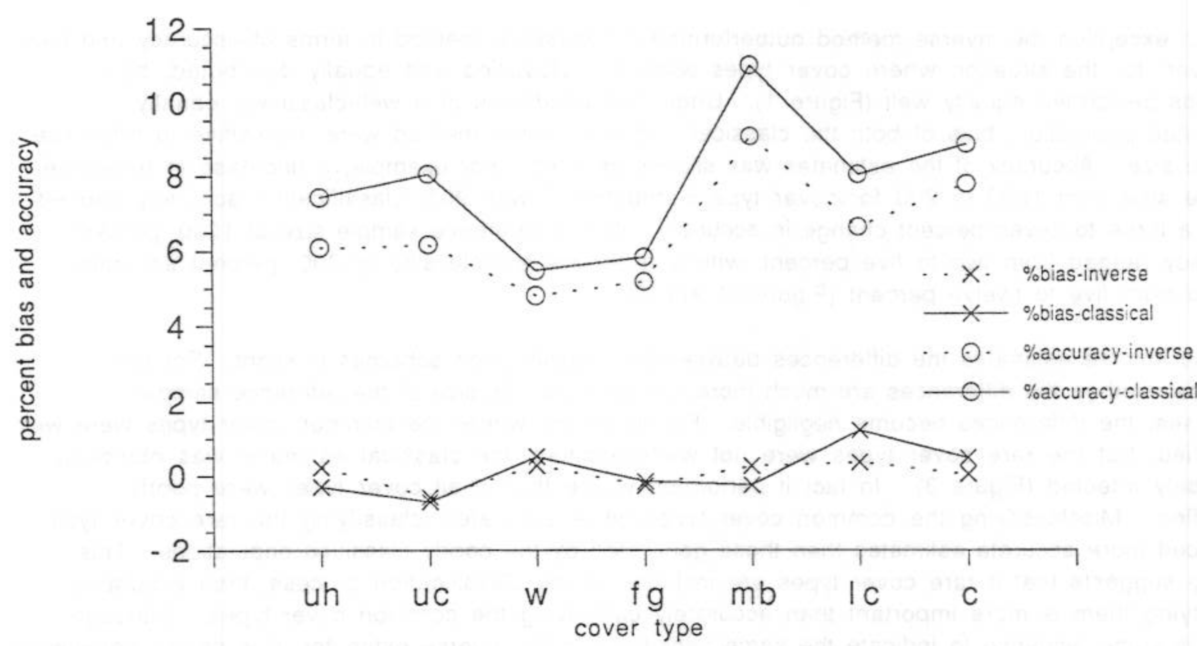

Figure 2. Average (based on 500 simulation repetitions) percent bias and accuracy values for both the inverse and classical methods. Cover type distribution=7, classification accuracy=well, reference sample size=200. See text for definition of cover types.

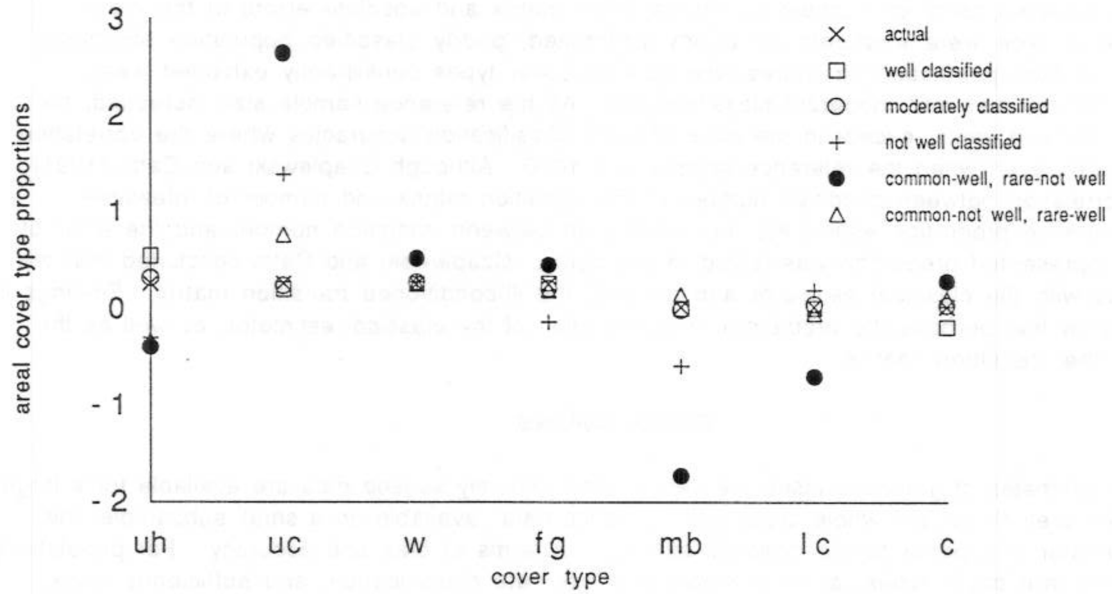

Figure 3. Comparison of classification accuracies for cover type distribution 1, reference=200, method=classical. See text for definition of cover types.

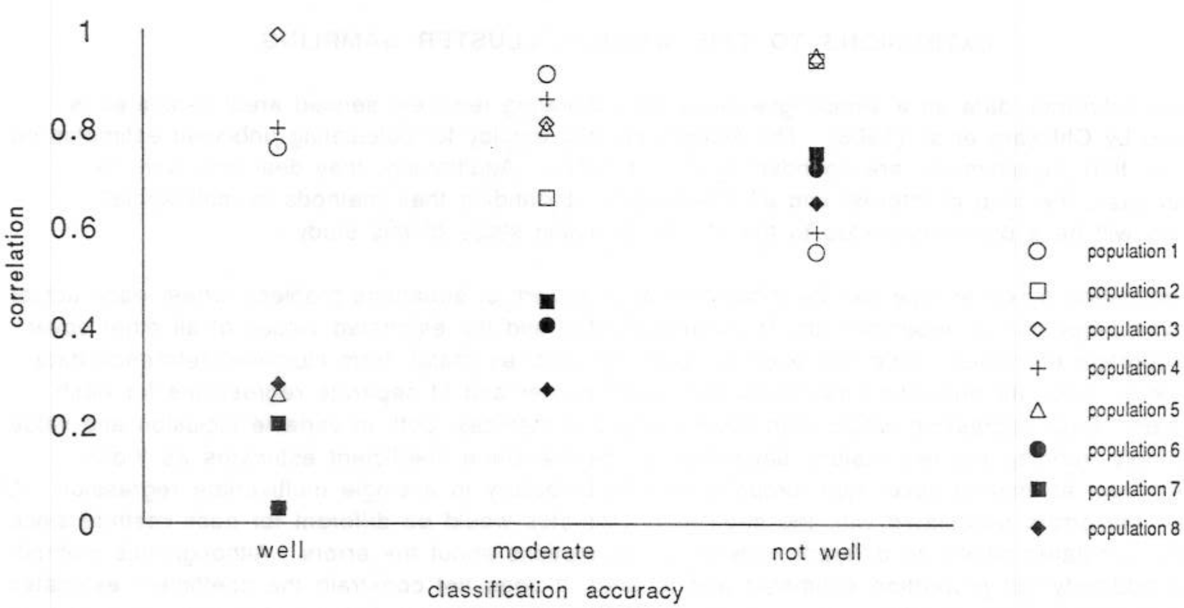

Figure 4. Classification accuracy vs correlation between condition number of the transition matrix and absolute errors of most prevalent cover type for reference sample of size 300, classical method.

Correlations between condition number of the transition matrix and absolute errors of the most prevalent cover type were strongest for poorly distributed, poorly classified population structures (Figure 4). In fact, population structures with no rare cover types consistently exhibited weak correlations for the well and moderate classifications. As the reference sample size increased, the correlations became weak, except in the case of poor classification accuracies where the correlation remained strong even when the reference sample was 1000. Although Czaplewski and Catts (1991) found no correlation between condition number of the transition matrix and number of infeasible solutions (negative proportion estimates), the correlation between condition number and the error of the largest represented proportion was tested in this study. Czaplewski and Catts concluded that the problem was with the classical estimator and not with the ill-conditioned transition matrix. Findings in this study show that perhaps the problem is a combination of the classical estimator, as well as the stability of the transition matrix.

CONCLUSIONS

When areal estimates of ground classes are desired and remotely sensed data are available for a large portion of the area (if not the whole area) with reference data available on a small subsample, the inverse estimator is superior to the classical estimator in terms of bias and accuracy. For populations containing no rare cover types, at least moderately accurate classification, and sufficiently large sample size (greater than 200) the classical estimator is comparable to the inverse estimator.

The ability of the classical estimator to yield reasonable estimates is at least partially dependent on the population structure from which the samples are drawn, as well as the classification accuracy of the samples and the size of the reference sample. The inverse estimator does not exhibit the same sensitivity to variations in the population or reference sample, making it a more practical estimator for everyday use. Constraining the classical estimate to be non-negative might improve its usability, but the inverse estimator will still be the best least squares estimator since it estimates directly the quantity of interest.

EXTENSIONS TO THIS WORK -- CLUSTER SAMPLING

Clustered reference data as a sampling scheme for calibrating remotely sensed areal estimates is discussed by Chhikara et al. (1986). The techniques they employ for calculating unbiased estimates do not insure that the estimates are bounded by zero and one. Additionally, they deal only with the binomial case, the crop of interest and all other crops. Extending their methods to multinomial situations will be a preliminary step to the cluster sampling stage of this study.

Areal estimation by cover type can be thought of as a system of equations problem, where each actual cover type proportion is dependent on its estimated value and the estimated values of all other cover type proportion estimates. One approach to obtaining areal estimates from clustered reference data would be to calculate proportion estimates from each cluster and fit separate regressions for each cover type. Each regression would then have identical X matrices, both in variable inclusion and value. Interestingly, running the regressions separately yields the same coefficient estimates as those obtained from estimating cover type proportions simultaneously in a single multivariate regression. Of course, the errors associated with the coefficient estimates would be different for each method since they are calculated based on different underlying assumptions about the errors. Although this method insures additivity (all proportion estimates add to one), it does not constrain the coefficient estimates to be bounded by zero and one. We suggest constraining the aforementioned multivariate regression to yield coefficient estimates that are additive and bounded by zero and one as one method of obtaining parsimonious equations which are statistically valid and intuitively appealing. A simulation will be conducted to determine what number of clusters gives as good a results as if the pixels were randomly selected.

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Sampling Schemes for Estimating Total-Tree Photosynthesis in Populus Clones - A Modeling Approach.

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ABSTRACT

The ecophysiological growth-process model ECOPHYS was used to evaluate several sampling schemes for estimating total-tree photosynthesis of first-year Populus clones. Growth of two clones was simulated under varying weather conditions providing photosynthesis data on a leaf-by-leaf basis throughout the growing season. Both whole-leaf photosynthesis and photosynthetic rate (i.e per unit leaf area) were sampled. Simple random sampling, stratified random sampling and a series of physiologically-based sampling schemes were evaluated as well as a ratio estimator, where leaf area is used as an auxiliary variable. Estimators are compared on the basis of their bias and accuracy in estimating the total photosynthesis (mg CO2) of the tree at an instant in time. Elements of extending the sampling process to estimate daily and yearly photosynthesis will also be elaborated.

Introduction

Current efforts to understand the affects of anthropogenic stresses, such as ozone and acid deposition, on tree growth and development require meaningful and reliable assessment techniques (Coleman et al. 1991). Traditionally, an integrative approach has been applied to the problem of detecting properties that effectively measure growth. Both morphological and physiological characteristics have been used. One of the most common physiological variables used to predict performance in young trees is photosynthetic rate and more recently total-tree photosynthesis. Because total-tree photosynthesis is a more direct measurement of the growth process, it is believed to be a better indicator of tree growth than traditional mensurational variables such as height and diameter. However, measuring photosynthesis on a leaf-by-leaf basis is very time consuming, expensive and more sensitive to weather conditions than measuring traditional morphological variables. Therefore, it is necessary to develop methods of obtaining reliable estimates of total-tree photosynthesis that are inexpensive, less time consuming and practical.

This paper discusses the development of a sampling methodology to estimate total-tree photosynthesis in the establishment year of Populus clones. A modeling approach was used and we outline three stages of this approach. The first stage involves estimating instantaneous total-tree photosynthesis. To accomplish this, several sampling designs are evaluated and compared on the basis of their relative average errors (i.e error is expressed as a percent of the average instantaneous total-tree photosynthesis). The second addresses when and how often samples should be taken during the day to estimate total daily photosynthesis. The third and final stage considers seasonal patterns of photosynthesis to determine when and how often samples should be taken to estimate total growing season photosynthesis. Different clones and different weather scenarios are evaluated to determine if either of these factors impacts the properties of particular sampling designs.

Materials and Methods

The ecophysiological growth process model ECOPHYS (Rauscher et al. 1990) was used to simulate the growth of two Populus clones under two varying weather conditions. ECOPHYS uses the individual leaf as the primary biological unit and simulates growth by modeling the actual growth processes rather than growth as expressed by dimensional change. Incident solar radiation is converted to photosynthate according to leaf-specific photosynthetic production functions and then the photosynthate is transported throughout the tree for use in maintenance and growth. Factors affecting the amount of solar radiation received by each leaf include clone-specific variables such as leaf size and orientation and mutual shading. Other clonal characteristics that influence photosynthetic rate are timing of bud-set, bud-break and leaf senescence. The clones used in this study differ with respect to these traits; they were Populus euramericana cv. 'Eugenei' and 'Illinois5', a Populus deltoides clone. Clones were "grown" with ECOPHYS using weather data from Rhinelander, Wisconsin (1979) and East Lansing, Michigan (1987). Weather data included solar radiation (photosynthetically active photon flux density of PPFD) and air temperature. The data from East Lansing, Michigan represents a warmer, sunnier growing season than the Wisconsin season.

Combinations of two clones and two weather conditions comprised a set four initial conditions for which hourly whole-leaf photosynthesis (mg Co_2/second) and individual leaf areas were generated for each leaf. Photosynthetic rate (mg Co_2/second/m^2) was then calculated for each leaf. Hourly, daily and total growing season photosynthesis and photosynthetic rate were calculated for each of the four initial conditions and could then be compared to estimates as 'true' values.

Stage I - Estimating Whole-Tree Instantaneous Photosynthesis

Several approaches were used for estimating instantaneous whole-tree photosynthesis including 1.) simple and 2.) stratified random sampling estimators, 3.) a ratio estimator with leaf area as the auxiliary variable, 4.) a combined stratified ratio estimator with leaf area as the auxiliary variable, and 5.) a series of "adhoc" methods in which two standard leaves were always sampled and successive leaves were added in proportion to the size of the tree. All of the sampling schemes, except the ratio estimators, were applied in two ways with the variable of interest either

"A" - the whole-leaf photosynthesis of the sampled leaf or

"B" - the photosynthetic rate (photosynthesis per unit leaf area of the sampled leaf.

A more detailed description of the sampling schemes follows :

1.) Simple Random Sampling (srs)- leaves are selected at random from the entire tree; sample size = 1, 2, 3 or 4 where the average number of leaves on a clone in mid-season is 40.

2.) Stratified Random Sampling (strat) - ECOPHYS divides the tree into four leaf maturity classes : immature (expanding), recently mature, mature and overmature. Production of photosynthate differs between classes and thus stratification by maturity class was used as a means to reduce the error of the simple random sampling estimator. Stratification was done in three ways: the first divided the tree in half with immature (expanding) and recently mature leaves in one strata and mature and overmature leaves in another (strat2); the second differentiated between immature and recently mature leaves as separate strata but left mature and overmature leaves in the same stratum (strat3). The third used each of the four maturity classes as four separate strata (strat4). In all cases, a sample size of one was drawn from each stratum.

3.) A Ratio Estimator (ratio) - both whole-leaf photosynthesis and leaf area of the sampled leaves are measured and the ratio of the sample means ($\bar{y}/\bar{x}$) is multiplied by total-tree leaf area to obtain an estimate of total-tree photosynthesis. Sample size = 1, 2, 3 or 4.

The goal was to increase precision by taking advantage of the correlation between whole-leaf photosynthesis and its area. The ratio estimate of Y, total-tree photosynthesis, is

$$\hat{Y}_R = (\bar{y}/\bar{x}) * X$$

where X is the total leaf area of the tree. There is a bias of order 1/n associated with the ratio estimator due to deviations from a straight line regression through the origin. Formulas used to calculate both the variance and the bias of the ratio estimator are first order approximations only. (Cochran 1977)

4.) A Combined Stratified Ratio Estimator (combined ratio)- the same three stratification methods as described above are used to obtain sample estimates of both Y and X, the population totals of photosynthesis and leaf area, respectively, and then find their ratio ($\hat{Y}_{st} / \hat{X}_{st}$). The combined ratio estimate of Y is

$$\hat{Y}_{Rc} = (\hat{Y}_{st} / \hat{X}_{st}) * X$$

and there is an associated bias for this estimator as well. A separate stratified ratio estimator was not included as strong evidence suggesting the ratio differed between strata was lacking. Also, Cochran advises against using this estimator with small sample size as the risk of bias is much greater than with the combined ratio estimator (Cochran 1977).

5.) Adhoc Estimators - three adhoc schemes are used to estimate whole-tree photosynthesis by finding the mean of the sample and multiplying by the total number of leaves on the tree in method "A" or by total leaf area of the tree in method "B". The three schemes are referred to as "adhoc + n" where n is the average sample size taken with that estimator. In "adhoc2", the second leaf from the top in maturity class two (i.e - recently mature leaves) and the fourth leaf from the bottom of the tree are always chosen and are referred to as the "standard'"leaves. In "adhoc3" the two standard leaves are chosen plus every tenth leaf between them for an average sample size of three. In "adhoc6", the two standard leaves are chosen plus every fifth leaf between them for an average sample size of six. The "adhoc2" method is currently being used in the field based on physiological considerations (Coleman et al. 1991). Recently mature leaves are the most stable and productive leaves on the plant and a leaf chosen from the middle of this class would therefore be a stable indicator of high-level photosynthesis production. The fourth leaf from the bottom is a senescing leaf and is chosen to "balance out" the estimator for whole-tree photosynthesis.

The mean squared errors of the first four estimators were calculated at each hour using the variances of the whole-leaf photosynthesis and leaf areas of the individual leaves at that hour. The root mean squared error was used as a basis of comparison and the average over the entire growing season was found for each hour in the day as well as across all hours. For the adhoc methods, estimates were compared to the known total-tree photosynthesis and the bias and accuracy were then calculated. Bias is defined as the difference between the estimated and true total-tree photosynthesis values, accuracy is the absolute value of the difference. Averages were calculated for every hour across the growing season and then across all hours to get **overall** averages. Mean squared errors were then expressed as percent values by dividing by the average instantaneous whole-tree photosynthesis for the entire growing season. The $\sqrt{\text{average bias}^2}$ of the "adhoc" methods were also calculated, expressed as percent values and then compared to the percent root mean squared errors of the other estimators.

Results and Discussion for Stage I

Method "B", measuring photosynthetic rate gave better overall estimates than method "A", measuring whole-leaf photosynthesis, for every estimator with each set of initial conditions. This finding was expected as method "B" utilizes information about the size of the leaf while method "A" does not make use of leaf area. The difference between these methods is greatest in the simple and stratified random estimators but does not become clear with the adhoc estimators until sample size is at least equal to three. (see fig. 1)

Overall, the adhoc estimators did better than expected, out-performing the simple and stratified random estimators in about 75% of the cases. The differences between the adhoc and the random estimators were much greater for method "A" than for method "B". (see Fig. 1) Interestingly, the adhoc estimator with an average sample size of six did not do as well as the simple random sampling estimator with n equal four for two of the four sets of initial conditions and were only slightly better for the other two sets.

For method "A", the ratio and the stratified combined ratio tended to be the best estimators with average percent error equal to about 23%, 30% and 38% for two, three, and four strata, respectively. For method "B", "adhoc2" and "adhoc3" tended to be the best for sample sizes two and three. However, the stratified estimator with n equal four gave consistently better estimates than the adhoc estimator with an average sample size of six for every set of initial conditions.

For the adhoc procedures, adding every tenth leaf to the original standard leaves tended to decrease the error of the adhoc2 estimator by about 20% , whereas sampling every fifth leaf in addition tended to further decrease the error by only about 5%. Because the average sample sizes of adhoc3 and adhoc6 were three and six respectively, sampling every fifth leaf did not improve the estimate sufficiently in terms of increasing accuracy to recommend it in practice.

The overall percent averages tended to be lower for the clone Eugenei at both locations and were lower for both clones at Rhinelander, WI. Results were otherwise consistent across clones and weather conditions (see Fig. 2).

Stages II and III - Extending the sampling strategies to estimate daily and yearly photosynthesis.

Because interest lies in obtaining estimates of total growing season photosynthesis rather than at an instant in time, the variance of photosynthesis across leaves versus time of day and time of year was evaluated As samples will most likely be taken between the hours of 10:00 a.m. and 2:00 p.m. in the field for practical purposes, the variance of whole-leaf photosynthesis was compared at each hour within this window for several typical days. As can be seen in Fig. 4, photosynthesis appears to be the most stable at 11:00 a.m.. If this proves to be a trend throughout the entire growing season , it would be necessary to take more samples at 10:00 a.m. ,12:00 p.m, 1:00 p.m and 2:00 p.m. than at 11:00 a.m. in order to obtain estimates of similar accuracy for each hour.

Of equal importance is the question of how often during the growing season daily totals should be estimated in order to obtain accurate estimates of total growing season photosynthesis. Preliminary studies indicate that taking samples every two weeks gives estimates nearly equivalent in accuracy to estimates found by sampling every week.

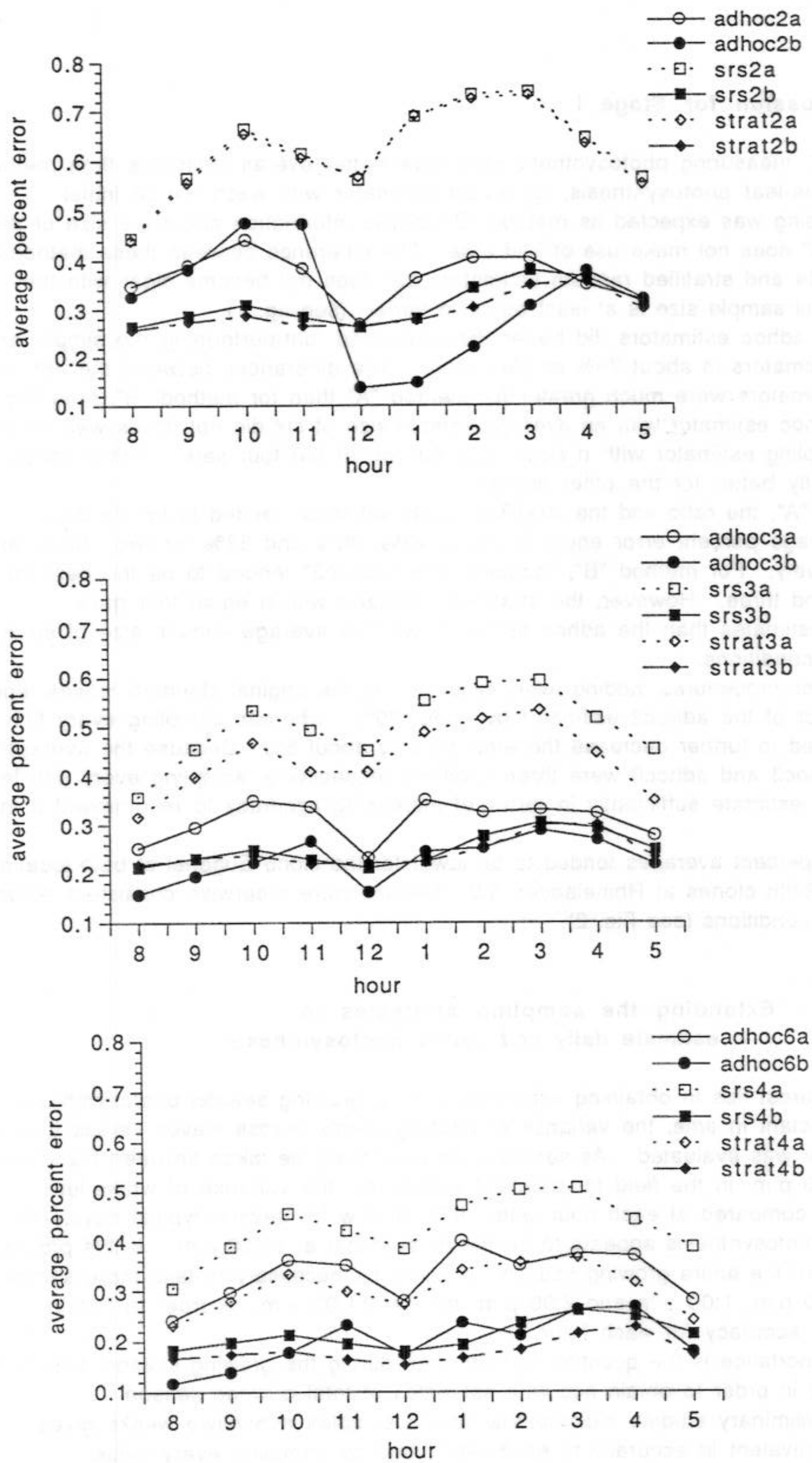

Fig. 1 - Average percent error at each hour of simple random, stratified random and "adhoc" estimators for sample sizes 2, 3 and 4 (avg n=6 for "adhoc6") for Eugenei at Rhinelander, WI.

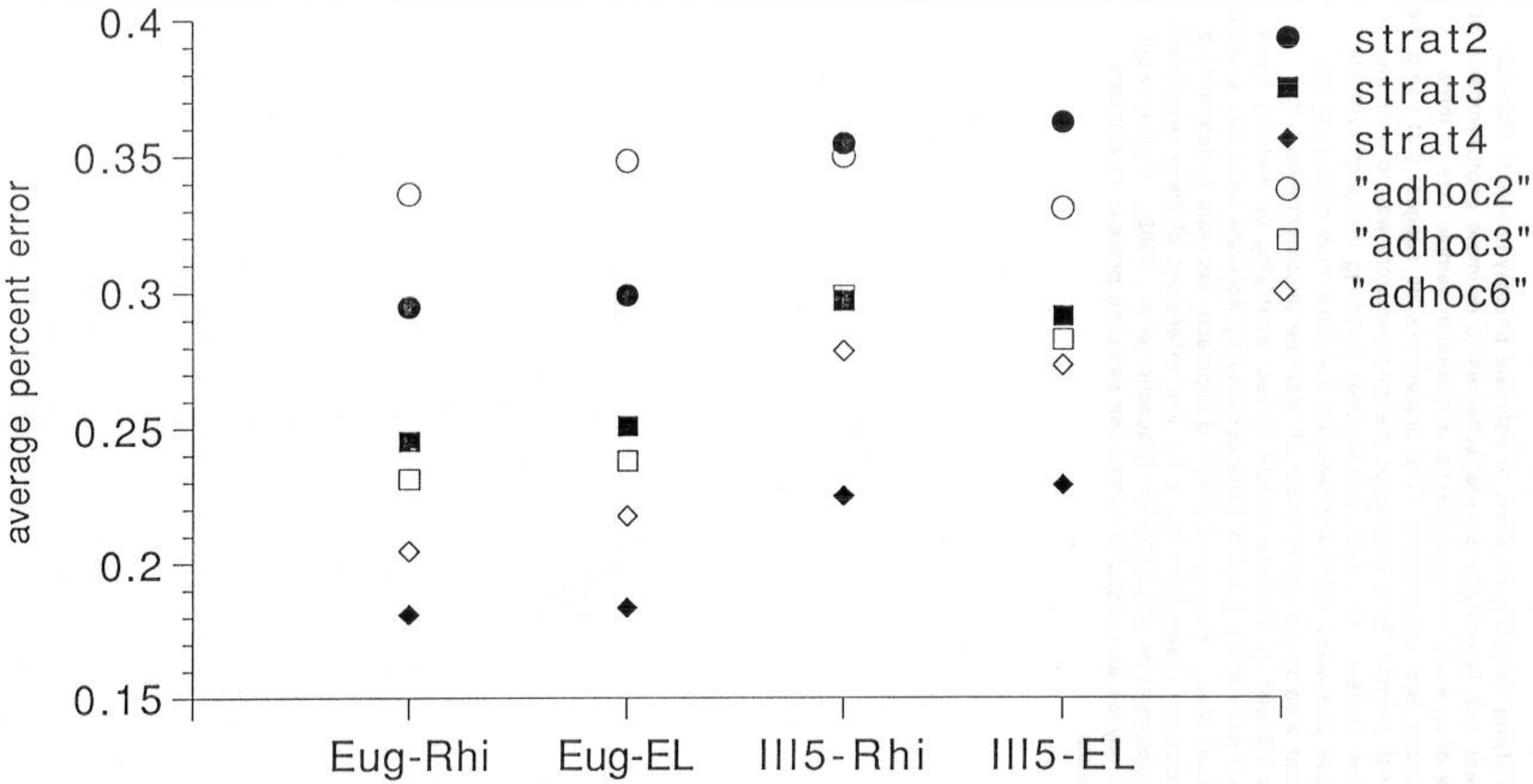

Fig. 2 - Overall average percent error of the stratified random and "Adhoc" estimators using method "B" for sample sizes 2, 3, and 4 (avg. n=6 for "Adhoc6") for all four sets of initial conditions:
Eugenei at Rhinelander, WI; Eugenei at East Lansing, MI;
Illinois-5 at Rhinelander, WI; and Illinois-5 at East Lansing, MI.

Conclusions

The first step in identifying sampling schemes to estimate photosynthesis in Populus trees in the establishment year was to evaluate several schemes to estimate photosynthesis at an instant in time. Because of time and cost constraints, a maximum sample size of three leaves is most practical for many field researchers. The present results suggest that using the "adhoc3" sampling scheme with method "B" seems to be the most accurate way to estimate instantaneous total-tree photosynthesis. This approach includes sampling the photosynthetic rate of the two standard leaves and every tenth leaf between them and then multiplying the sample mean by total-tree leaf area to get an estimate of total-tree photosynthesis. If, however, the sample size is allowed to increase to four leaves, stratifying by maturity class and drawing one sample from each strata gives a more consistently accurate estimate, at least among the estimators discussed here. Because a modeling approach was used to determine a sampling methodology, conclusions drawn from this study and extensions of these results are restricted by the underlying assumptions of ECOPHYS (Rauscher et al., 1988). Further work will include more extensive analyses as needed to extend the sampling process to estimate daily and yearly photosynthesis.

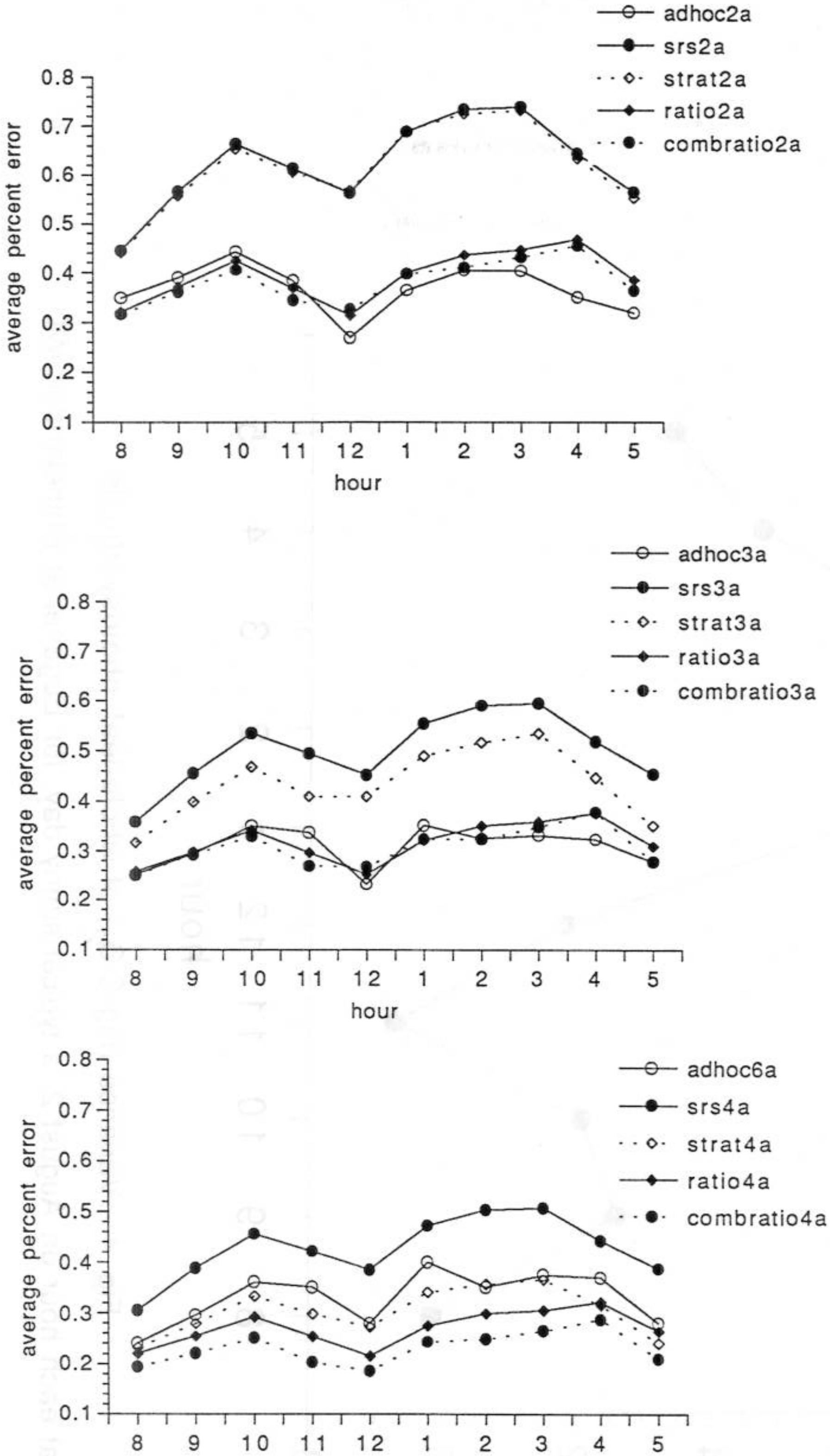

Fig. 3 - Average percent error of the "adhoc", simple random, stratified, ratio, and stratified combined ratio estimators using method "A" with sample sizes equal to 2, 3 and 4 (avg n = 6 for"adhoc6") for Eugenei at Rhinelander, WI.

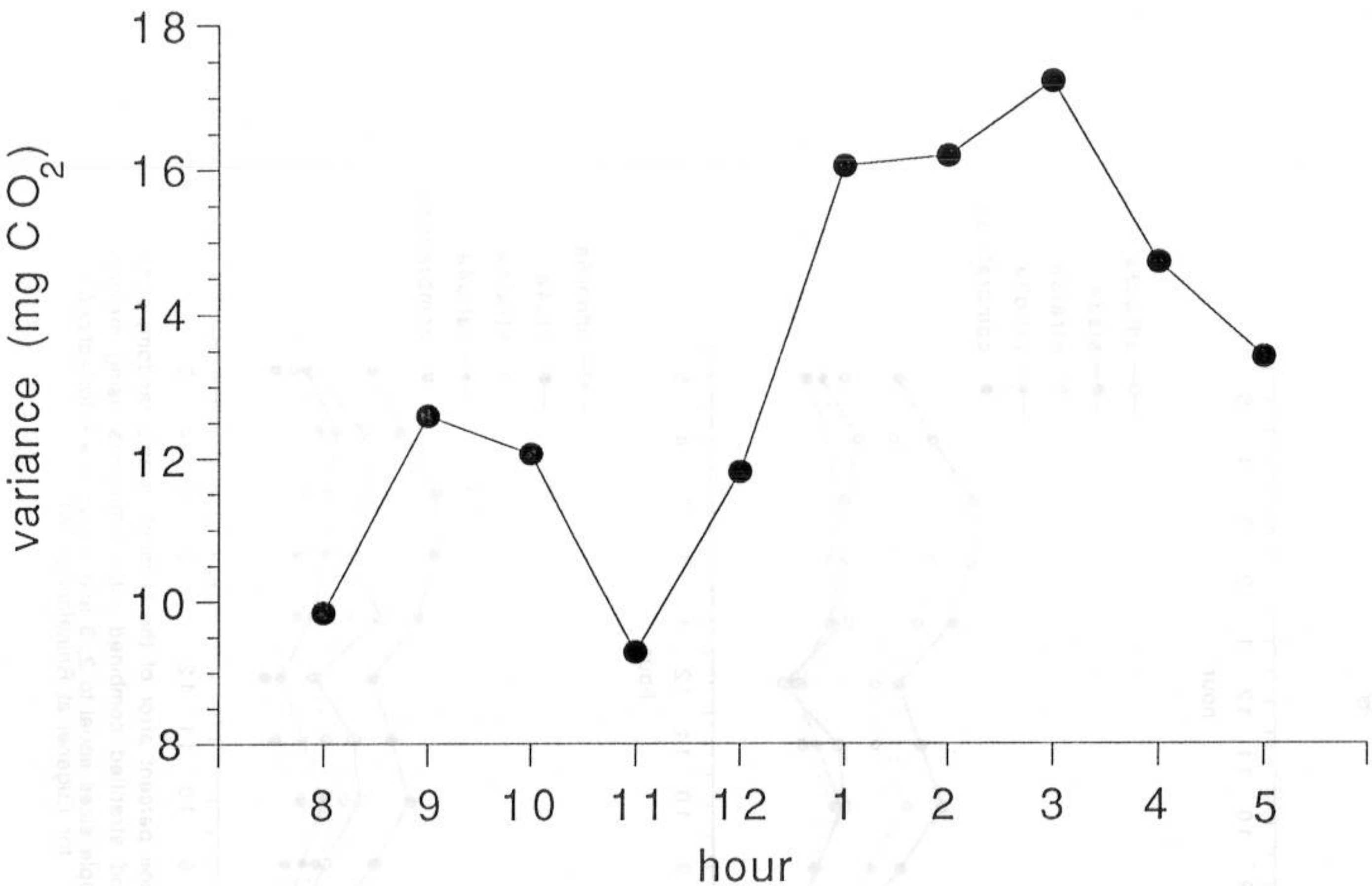

Fig. 4 - Variance (mg CO_2) of whole-leaf photosynthesis at each hour on August 2, a typical sunny day, for Eugenei at Rhinelander, WI.

Acknowledgements

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NONTRADITIONAL USES OF FOREST INVENTORY DATA IN THE NORTH CENTRAL REGION

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ABSTRACT:

USDA, Forest Service conducts periodic inventories of the nation's forest resources through the Forest Inventory and Analysis (FIA) program. Data from these inventories have traditionally been used to assess current timber supplies, to make future projections of future timber supplies, to develop and test growth and yield models, and for a number of other information needs primarily related to commercial timber production. The data collected by FIA can and is being used in a variety of ways. In this paper a number of these other uses that have been made of FIA data in the North Central Region are described. Possible other uses that could be made of the current FIA data base are discussed. Changes that could be made in FIA inventories that would enable wider use of this inventory information are also discussed.

POLYMORPHIC SITE INDEX CURVES FOR BLACK SPRUCE STANDS OF THE CLAY BELT REGION IN NORTHERN ONTARIO

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Abstract

Site index curves were derived for black spruce (*Picea mariana* (Mill.) B.S.P.) stands using data from permanent sample plots located in the Clay Belt region of Northern Ontario. These plots were recently classified according to the Ontario Forest Ecosystem Classification system (FEC); it was possible, therefore, to relate long-term height growth to the operational groups as defined by the FEC. Each operational group was characterized by a specific height growth pattern.

Introduction

Site index curves are now commonly accepted for estimating site productivity. In recent years a major development has consisted of deriving polymorphic site index curves (e.g., Alemdag 1988, Biging 1985, Borders *et al.* 1984, Cao and Durand 1991, Cieszewski and Bella 1989, Newnham 1988, Payandeh 1978, 1991, Quenet and Manning 1990, Ray *et al.*, undated). The transition from anamorphic curves to polymorphic curves constitutes an improvement because polymorphic curves are considered more realistic and representative of height development than anamorphic curves (Daniel *et al.* 1979, Monserud 1984a, Smith 1984). Other developments have consisted of relating site index values to environmental factors such as soil nutrient content or drainage conditions (e.g., Klinka and Carter 1990, Monserud *et al.* 1990, Payandeh 1986), to ecological classes derived from ecological classification systems (e.g., Green *et al.* 1989), or to major soil groups (e.g., Steinbrenner 1979; Schmoldt *et al.* 1985). Finally, there were studies that focused on deriving anamorphic or polymorphic site index curves for different habitat types and soil groups (e.g., Amateis and Burkhart 1985, Golden *et al.* 1981, Monserud 1984b, 1985, Zahner 1962). These approaches used data from temporary sample plots of different ages or from stem analysis. Less common in North America has been the derivation of site productivity curves from remeasurement data.

The main objective of the present study was to derive site index curves for black spruce (*Picea mariana* (Mill.) B.S.P.) with remeasurement data obtained from permanent sample plots. As the sample plots studied were classified according to the Ontario Forest Ecosystem Classification system (FEC), it was possible to relate long-term height growth to the operational groups as defined by the FEC. This approach was based on the premise that the operational groups are characterized by specific site conditions affecting the long-term pattern of height development. Site productivity functions that can predict long-term height growth with greater accuracy better meets one of the objectives of the use of site index curves, which is to determine the height development pattern that a stand might achieve for the rest of its life (Clutter *et al.* 1983). The hypothesis was that the shape of the height growth curves could be related to the ecological characteristics of the operational groups.

Methods

The black spruce stands are located in the Clay Belt region of Northern Ontario. While black spruce is the dominant species, the most common associated species are jack pine (*Pinus banksiana* Lamb.), balsam fir (*Abies balsamea* (L.) Mill.), white spruce (*Picea glauca* (Moench) Voss), tamarack (*Laric laricina* (Du Roi) K. Koch), white birch (*Betula papyrifera* Marsh.), balsam poplar (*Populus balsamifera* L.), white cedar (*Thuja occidentalis* L.), and trembling aspen (*Populus tremuloides* Michx.). Data were obtained from remeasured permanent sample plots established by the Spruce Falls Power and Paper Co. (Table 1), and were recently classified according to the FEC. The different classes consist of operational groups characterized by specific species composition and soil conditions. The main characteristics of the operational groups studied are summarized on Table 2.

The scope of this study was limited to naturally regenerated stands originating from fire or harvesting with no post-establishement treatments. As indicated in Table 1, there were wide ranges of age, DBH, and height. The number of measurements for individual plots varied between one and

Table 1: Summary statistics for the database.

	Minimum	Mean	Maximum	SD
Age	9	75	175	40.38
DBH (cm)	0	14.75	58.4	6.37
Height (m)	1.22	11.37	28.58	5.34

Observations: 684

Number of permanent sample plots: 86

	Frequency of measurements											
	1	2	3	4	5	6	7	8	9	10	11	12
Number of plots:	3	2	5	3	6	5	9	14	8	17	6	8

Table 2: Summary characteristics for the operational groups covered in this study. (Adapted from Jones *et al.* 1983).

Operational group	Common forest cover type[a]	Common soil texture	Common moisture regime[b]
5- Feathermoss-fine soil	Sb, Sb-Pj, Pj	fine loamy, clayey	3-6
7- Mixewood-herb rich	Po, Po-B-Sw, Po-Sb, Po-Bw	clayey, fine loamy	2-4
8- Feathermoss-spagnum	Sb	fine loamy, clayey	5-6
9- Conifer-herb/moss rich	Sb, Sw-B,Sw-Ce	Fine loamy, clayey	4-6
10- Hardwood-alnus	Po, Sb-Po, Po-B-Sw	Fine loamy, clayey	4-6
11- Ledum	Sb	Organic soil	7-8
12- Alnus-herb poor	Sb, Sb-Ce	Organic soil	7-8
13- Alnus-herb rich	Sb,Sb-L-Ce, Ce-L	Organic soil	7-8
14- Chamaedaphne	Sb, Treed bog	Organic soil	8

[a] Abbreviations for tree species:

Sb - black spruce	B - Balsam fir	Bw - White birch
Ce - Eastern white cedar	L - Larch	Po - Trembling aspen or Balsam poplar

[b] Moisture regime codes:

2 - fresh	4 Moderate moist	6 - very moist	8 Very wet
3 - very fresh	5 - Moist	7 - moderate wet	

twelve (Table 1). More than half of the plots were measured at least seven times. Site index was based on the mean height of the largest 100 trees/ha (top height) at stand age 50. Stand age was estimated as the number of years since harvesting or fire. The inventory procedures only involved measuring DBH of the trees present in the sample plots and tallying them by 1 inch (2.54 cm) classes. Height was measured only on subsample trees. Therefore, the following relationship was derived for each operational group:

$$(Height - 1.3) = b_1(Age) + b_2(DBH) \quad [1]$$

This relationship was used to estimate the top height of every sample plot studied. It differs from the usual sigmoidal shape that characterizes this type of relationship (Zedaker *et al.* 1987). However, for this set of data, the addition of exponential terms or the use of a sigmoidal function did not result in a better relationship than equation [1]. As there were no great differences among the operational groups, the data were merged and a single equation calculated:

$$(Height - 1.3) = 0.045679 \times Age + 0.546371 \times DBH \quad [2]$$

$$R^2 = 0.97$$
$$SE_E = 2.15 \text{ m}$$

The Weibull function was used to derive top height vs. age equations because it adapts easily to different growth forms (Yang *et al.* 1978). Furthermore, preliminary observations strongly suggested that it would better fit the observations than a function based on the Chapman-Richards model. The basic form of the Weibull equation is:

$$H = b_0 \left(1 - e^{-(b_1 \times Age)^{b_2}}\right) \quad [3]$$

This equation was fitted to top height data within each operational group, which resulted in the derivation of individual guide curves. That step became necessary in order to estimate the site index of individual plots because not all plots had measurements taken at the reference age (50). Within every operational group, the proportionality assumption precluding the use of an anamorphic approach was reasonably met for most of the plots.

Equation [3] was used to estimate site index at age 50:

$$SI = b_0 \left(1 - e^{-(b_1 \times 50)^{b_2}}\right) \quad [4]$$

Combining equations [3] and [4] resulted in the following function:

$$SI = H \frac{\left(1 - e^{-(b_4 \times 50)^{b_5}}\right)}{\left(1 - e^{-(b_4 \times Age)^{b_5}}\right)} \quad [5]$$

This approach is identical to that of Smith and Watts (1987) and Cieszewski and Bella (1989). As suggested by Curtis *et al.* (1974), the problem of minimizing two different sums of square was avoided. Therefore, instead of performing an algebraic transformation of equation [5], the following model was derived :

$$H = SI \frac{\left(1 - e^{-(B_6 \times Age)^{B_7}}\right)}{\left(1 - e^{-(B_6 \times 50)^{B_7}}\right)} \quad [6]$$

Equation [6] was used to derive the site index curves. Equation [5] can be used to estimate the site index of a stand when the operational group, top height, and age are known.

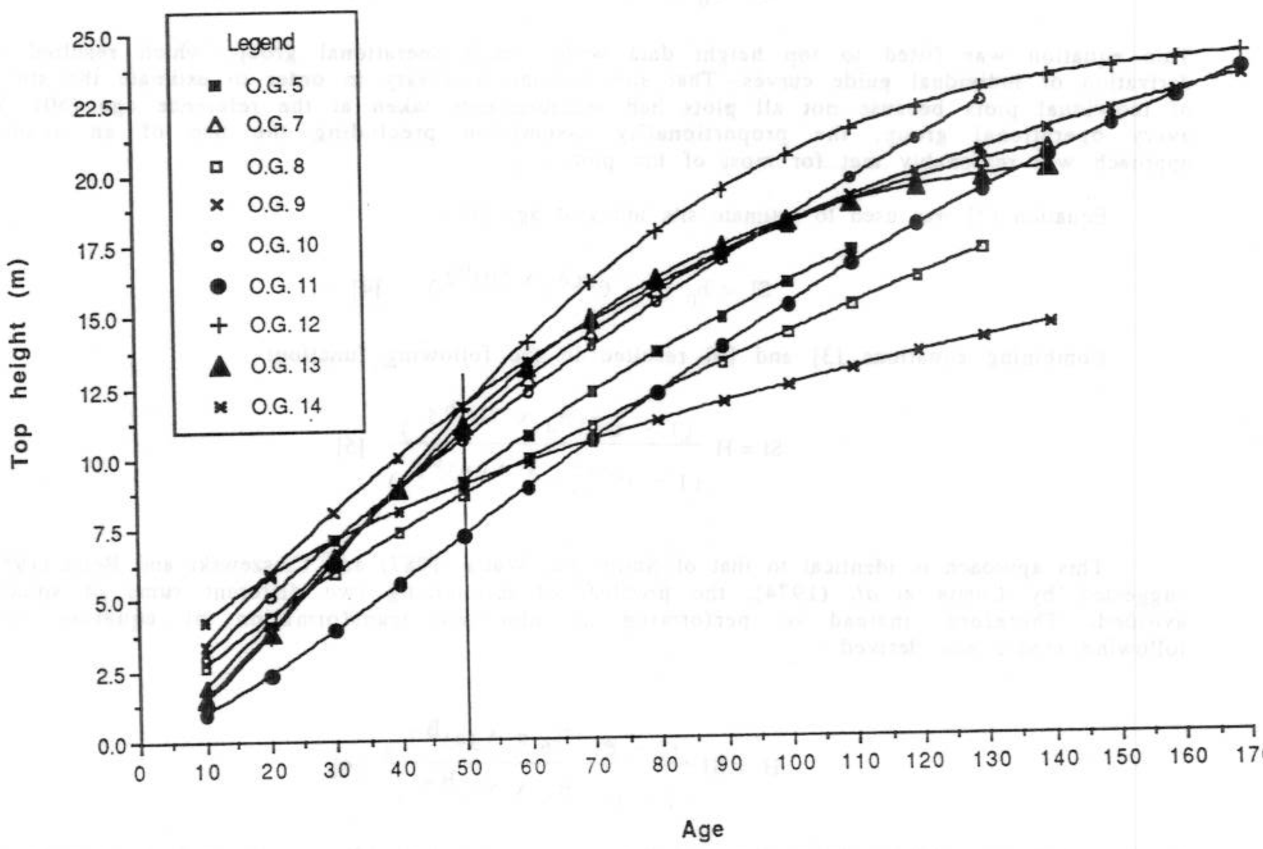
Results and discussion

The Weibull function fitted the observations within each operational group very well, as indicated by the high coefficients of determination and the relatively low standard errors of estimate (Table 3). The comparison of the long-term height growth pattern between the operational groups suggests a polymorphic pattern (Figure 1). Even though some operational groups can have very close site index values at age 50, they can have different productivities beyond this reference age. Therefore, there was a good reason to incorporate the operational groups to define site productivity. Because operational groups 7, 9, and 10 had very close top heights for virtually all ages and their soil characteristics and species composition were similar, it was concluded that, in practice, they could be merged. They will be designated as operational group 7c.

Table 3: Coefficients of the Weibull function derived for every operational group.

Operational group	n	B_0	B_1	B_2	R^2	SE_E
5	15	28.31213	0.00844	1.09233	0.9976	0.7003
7	265	23.02043	0.01393	1.24887	0.9804	2.0868
8	45	105.47375	0.00079	0.76041	0.9852	1.7756
9	65	30.00672	0.00911	0.89224	0.9775	2.1240
10	54	560.30897	0.00014	0.79418	0.9651	2.0848
11	86	32.38561	0.00709	1.32856	0.9566	2.9854
12	65	24.36510	0.01498	1.49497	0.9244	3.9245
13	60	20.63444	0.01675	1.44224	0.9722	2.1769
14	28	520.60064	0.00003	0.46841	0.9846	1.3612

Figure 1: Guide curves for each operational group.



The integration of operational groups within the site index equation involved use of dummy variables:

$$SI = H\frac{(1 - e^{-(0.00842 \times 50)^b})}{(1 - e^{-(0.00842 \times Age)^b})} \quad [7]$$

$R^2 = 0.9898$
$SE_E = 1.1052$

$$H = SI \frac{(1 - e^{-(0.00919 \times Age)^c})}{(1 - e^{-(0.00919 \times 50)^c})} \quad [8]$$

$$R^2 = 0.9971$$
$$SE_E = 0.7558$$

where

b = 0.98023xZ5 + 0.99397xZ7 + 0.95443xZ8 + 1.29446xZ11 + 1.08408xZ12+ 1.05938xZ13 + 0.67619xZ14),

c = 0.98637xZ5 + 0.99557xZ7 + 1.01151xZ8 + 1.48209xZ11 + 1.07505xZ12 + 0.98875xZ13 + 0.74827xZ14),

Z5 = 1 if operational group is 5, 0 otherwise,

Z7 = 1 if operational group is 7, 0 otherwise,

Z8 = 1 if operational group is 8, 0 otherwise,

Z11 = 1 if operational group is 11, 0 otherwise,

Z12 = 1 if operational group is 12, 0 otherwise,

Z13 = 1 if operational group is 13, 0 otherwise,

Z14 = 1 if operational group is 14, 0 otherwise.

This approach constitutes a practical way of integrating ecological characteristics in the site index equation. Compared to anamorphic curves, the only additional requirement consists of identifying the operational group of the stand under investigation. It is a much more practical approach than measuring several environmental parameters on the field (e.g., soil nutrient content, drainage, climate) and then relating them to productivity.

Equation [8] was used to redraw the guide curve of every operational group (Figure 2). It was not surprising to obtain good productivity in operational group 7c because its ecological characteristics coincide with optimum growing conditions for black spruce (Viereck and Johnson 1990). Furthermore, the seepage of water and nutrients on this site contributes to maintenance of high productivity.

The relatively high productivity of operational groups 12 and 13 may appear surprising because they both consist of organic soil. According to Jeglum (1974) and Payandeh (1978), black spruce grows slower on organic soil than on mineral soil because of poor drainage, low aeration, and poor nutrient supply. These two operational groups have a high productivity in terms of height growth because of the movement of water in the ecosystem (Maurer*, personal communication). Water flow provides high influx of nutrients and offers good aerobic growing conditions. However, their total productivity (e.g., biomass or volume) may be lower than operational group 7c because of lower stocking in those stands.

Although operational group 5 showed ecological characteristics similar to operational group 7c, it had lower productivity. This is probably related to poorer soil drainage and aeration on account of the soil having a greater proportion of fine material than in operational group 7c. Operational groups 8 and 14 consist of organic soils with poor to very poor drainage, and probably also with low water flow, considering their relatively lower productivity. The height development of operational group 11 follows one of the patterns mentioned by Spurr and Barnes (1980): poor growing conditions on the surface horizons, but with rich horizons below. The following scenario may be suggested. First, the roots grow on poorly decomposed and poorly drained organic soil, which results in relatively slow height development. Then, the roots meet rich mineral soil horizons, which results in accelerated height growth.

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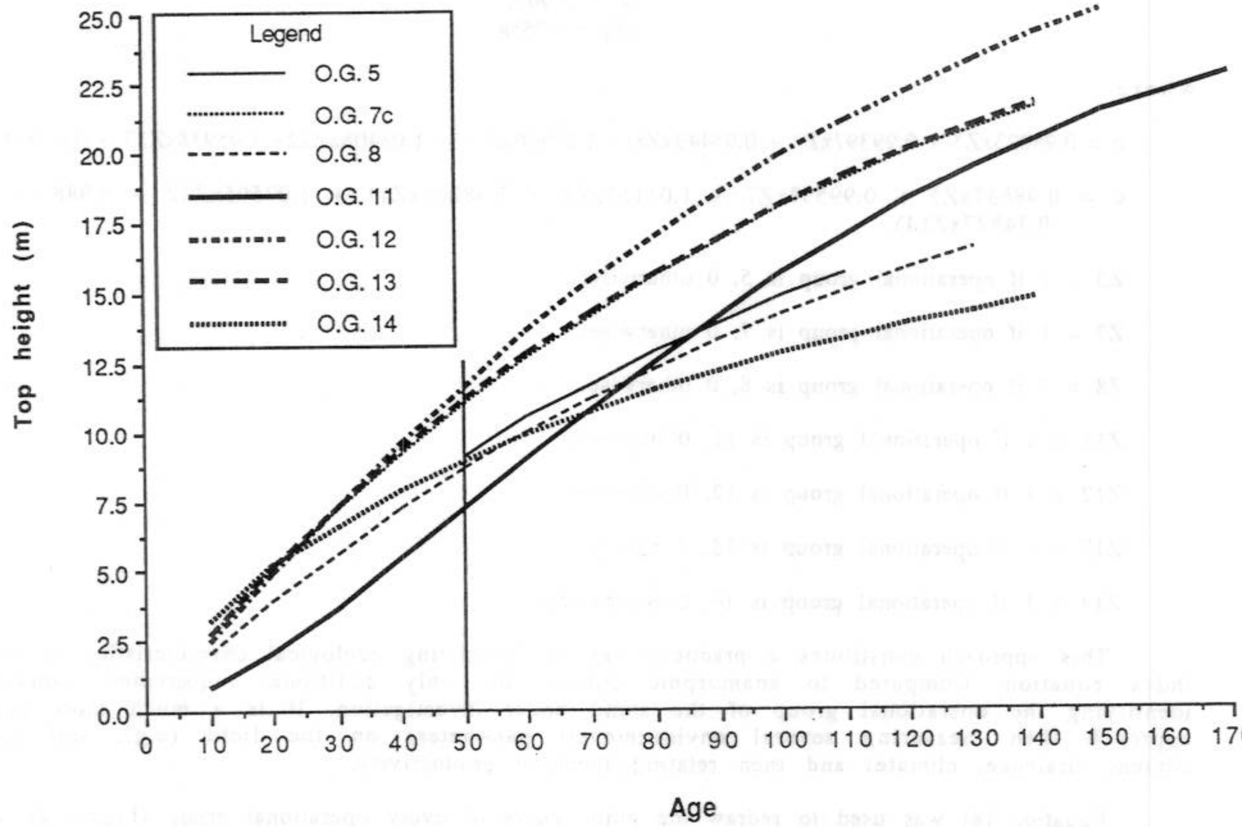
Figure 2: Guide curves for each operational group after merging



Within every operational group there was variation. As previously mentioned, the proportionality assumption was reasonably met for the majority of the sample plots. Therefore, equations [7] and [8] integrate both a polymorphic approach to explain the variability between the operational groups and an anamorphic approach to explain the variability within every operational group. This approach was also used successfully by Monserud (1984b, 1985) for inland Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands classified according to habitat type, and by Zahner (1962) for loblolly pine (*Pinus taeda* L.) classified according to soil groups. Site index curves of operational group 7c were superimposed on observed top height to illustrate the range of variation (Figure 3). However, the derivation of these curves was limited to the range covered by the observed values in order to avoid exaggerated extrapolation, thereby predicting unrealistic height development. For instance, the extrapolation of equation [8] for site indexes 16 and 18 of operational group 7c resulted in height growth that appeared too high for these sites. This suggests that the proportionality assumption does not apply for these highly productive sites. Therefore, future studies should focus on determining not only the long-term growth pattern of these stands, but also whether the stratification of the operational groups in vegetation types is necessary.

The residual values (observed values minus predicted values) of equation [7] for different ages are shown on Figure 4. Eighty-nine percent of the residuals were less than 1 m, and only two percent were greater than 3 m. High residuals occurred mostly before age 30. Even though the proportionality assumption was reasonably met for most of the plots, there were always some fluctuations in mean top height within individual plots probably caused by mortality among dominants and codominant trees. This fact can explain the small residual values. As for high residual values, the following trend was observed in some of the plots: mean top height followed the same site index curve for several ages, except for one or two young ages. The differences between the site index values at young ages and the site index values at older ages for the same plot probably relate to brush competition at young ages, which can have a significant influence on seedling development. For this reason, Monserud (1984a) suggested to use breast height age for site index curves.

Figure 3: Site index curves superposed on observed top heights for operational group 7c

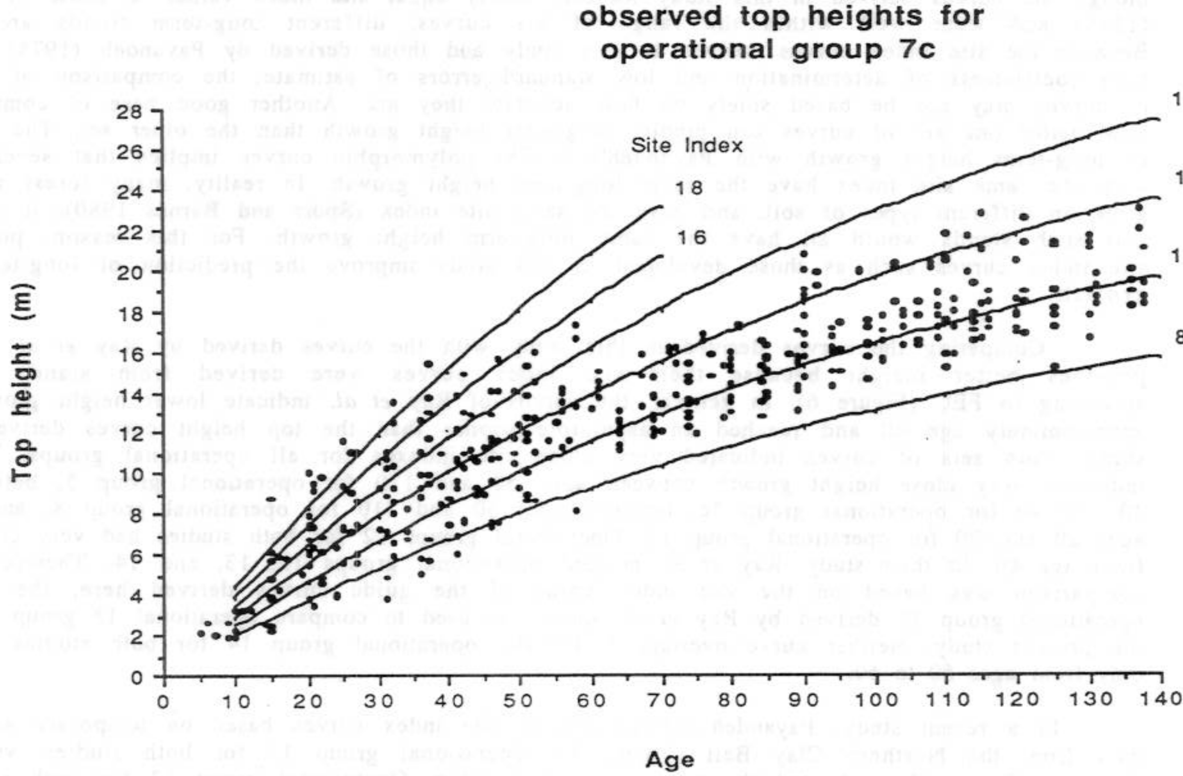
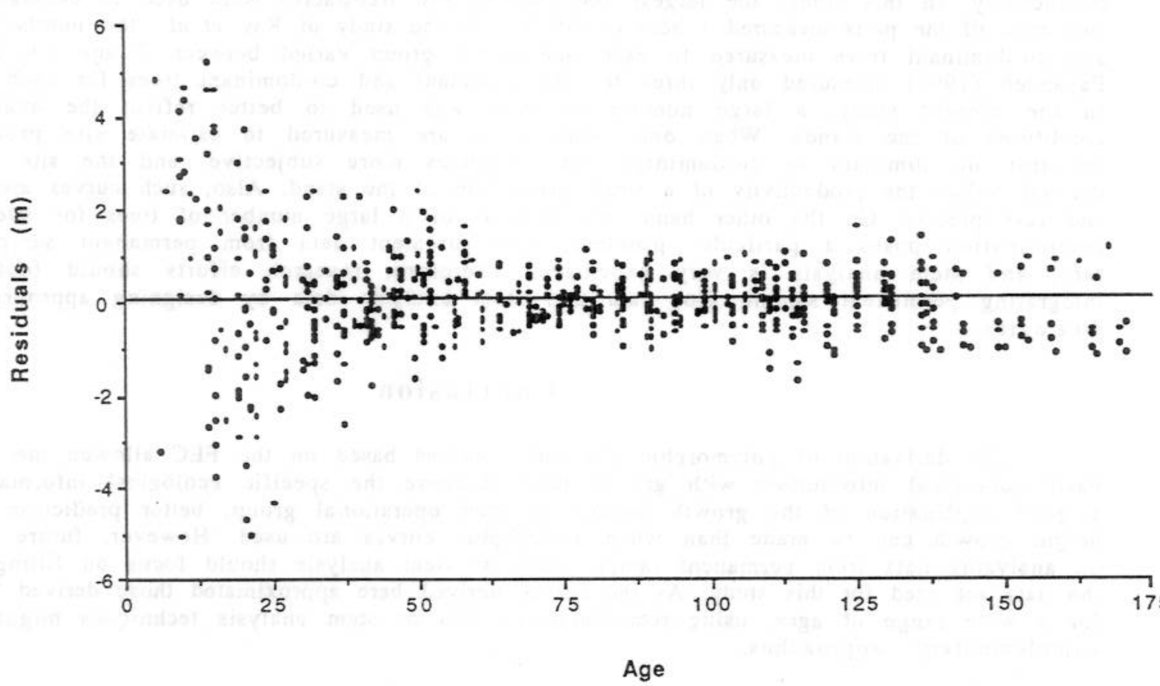


Figure 4: Residual errors of site index prediction for different stand ages



The guide curves derived for each operational group were compared with site index curves derived by Payandeh (1978) (Figure 5), Ray *et al.* (Figure 6), and Payandeh (1991) (Figure 7). These three studies involved the development of site index curves for black spruce in the Clay Belt area. Even though the curves derived in this study indicate nearly equal site index values to those of Payandeh (1978) and were well within the range of his curves, different long-term trends are evident. Because the site index curves derived in this study and those derived by Payandeh (1978) had very high coefficients of determination and low standard errors of estimate, the comparison of both sets of curves may not be based solely on how accurate they are. Another good base of comparison is how better one set of curves can predict long-term height growth than the other set. The prediction of long-term height growth with Payandeh's (1978) polymorphic curves implies that several stands with the same site index have the same long-term height growth. In reality, many forest stands can grow on different types of soil, and have the same site index (Spurr and Barnes 1980); it is unlikely that such stands would all have the same long-term height growth. For this reason, polymorphic site index curves such as those developed in this study improve the prediction of long-term height growth.

Comparing the curves derived in this study with the curves derived by Ray *et al.* (undated) provides better insight because their site index curves were derived from stands classified according to FEC (Figure 6). In general, the curves of Ray *et al.* indicate lower height growth up to approximately age 40 and reached an asymptote sooner than the top height curves derived in this study. Both sets of curves indicated very close site indexes for all operational groups. They also indicated very close height growth between ages 50 and 110 for operational group 5, between ages 40 and 90 for operational group 7c, between ages 30 and 110 for operational group 8, and between ages 20 and 70 for operational group 11. Operational groups 12 for both studies had very close values from age 40. In their study, Ray *et al.* merged operational groups 12, 13, and 14. Therefore, as the comparison was based on the site index value of the guide curves derived here, the curve for operational group 12 derived by Ray *et al.* should be used to compare operational 13 group derived in the present study. Neither curve overlapped. Finally, operational group 14 for both studies was close only from ages 50 to 60.

In a recent study, Payandeh (1991) derived site index curves based on temporary sample plot data from the Northern Clay Belt (Figure 7). Operational group 11 for both studies were totally different. They only indicated the same site index value. Operational group 12 for both studies had very close values until age 60. The site index curve for operational group 14 derived in this study had the same shape as the curves derived by Payandeh (1991), but it indicated higher productivity.

Even though the curves derived in the present study were close to those derived by Ray *et al.* and Payandeh (1991) within certain age limits, substantial differences did occur, specially after age 70. The main cause of discrepancies was probably the number of trees used to estimate site productivity. In this study, the largest 100 trees/ha (40 trees/acre) were used to estimate top height, and most of the plots measured 1 acre (0.405 ha). In the study of Ray *et al.*, the number of dominant and co-dominant trees measured in each operational group varied between 2 and 33. In his study, Payandeh (1991) measured only three to five dominant and co-dominant trees for each sample plot. In the present study, a large number of trees was used to better reflect the average growing conditions of the stands. When only some trees are measured to estimate site productivity, the selection of dominant or co-dominant trees becomes more subjective, and the site index curves derived reflect the productivity of a small proportion of the stand. Also, such curves are more biased and less precise. On the other hand, the analysis of a large number of trees for site productivity determination poses a particular problem; remeasurement data from permanent sample plots are rare, and stem analysis is very expensive. Therefore, research efforts should focus on better integrating permanent sample plot data and stem analysis data by designing appropriate sampling strategies.

Conclusion

The derivation of polymorphic site index curves based on the FEC allowed the integration of basic ecological information with growth data. Because the specific ecological information provided a good explanation of the growth pattern of each operational group, better prediction of long-term height growth can be made than when anamorphic curves are used. However, future studies based on analyzing data from permanent sample plots or stem analysis should focus on filling the gaps in the data set used for this study. As the curves derived here approximated those derived by Ray *et al.* for a wide range of ages, using remeasurement data or stem analysis techniques might provide two complementary approaches.

Figure 5: Guide curves derived for each operational group overlaid on curves derived by Payandeh (1978)

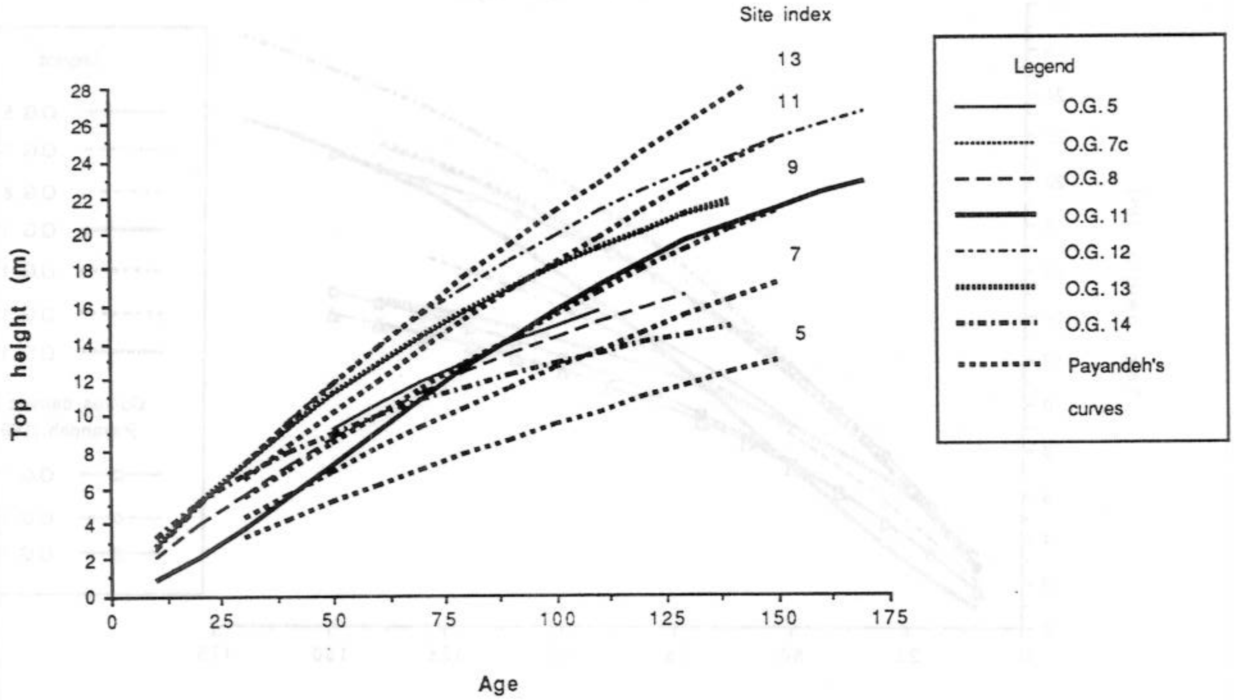


Figure 6: Guide curves derived for each operational group overlaid on curves derived by Ray et al.

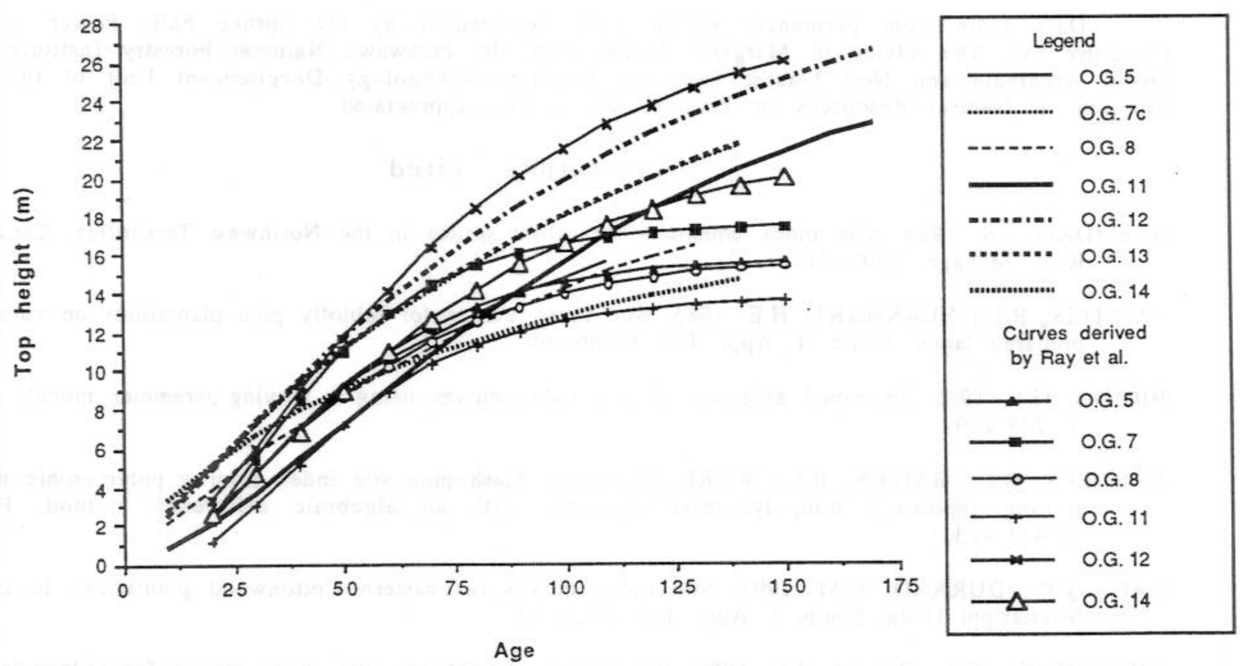
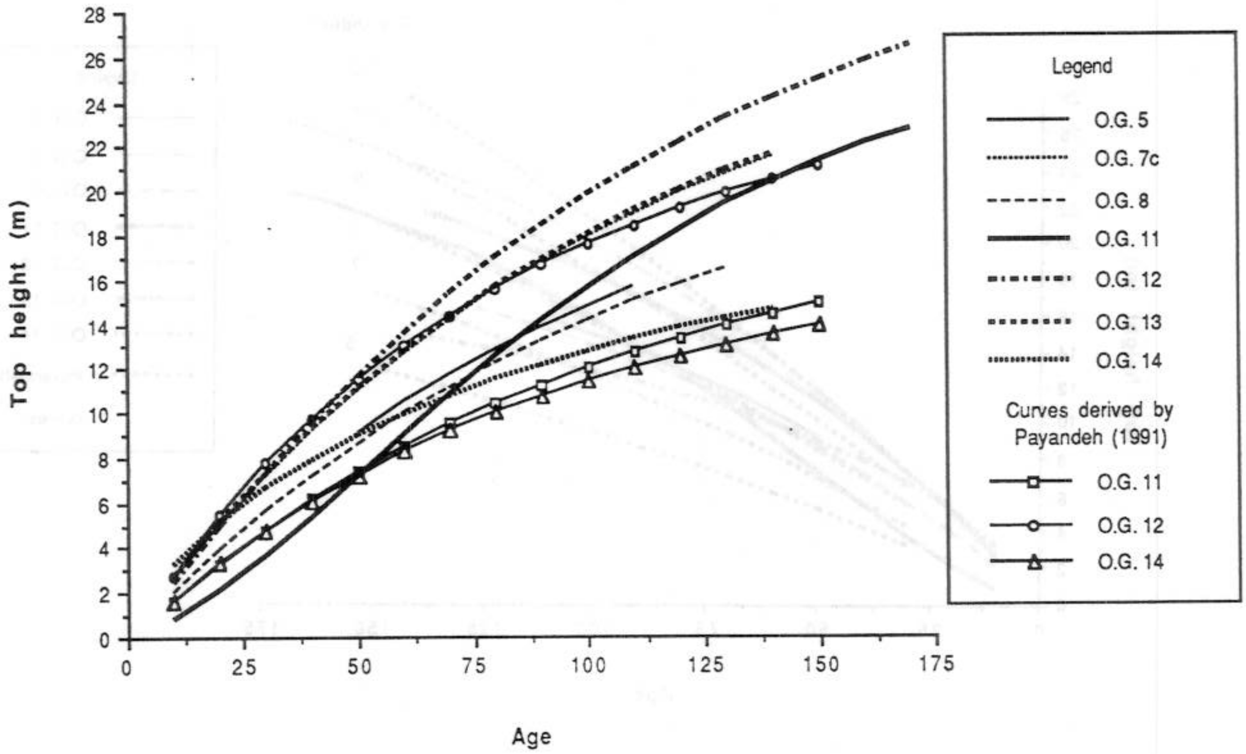


Figure 7: Guide curves derived for each operational group overlaid on curves derived by Payandeh (1991).



Acknowledgments

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MEASUREMENT ERROR ASSESSMENT FOR A NATIONAL FOREST SURVEY

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RESUME

Most statistically based national forest surveys explicitly account for sampling error but do not account for nonsampling errors due to function and measurement errors. Using approximations, an assortment of nonsampling errors was accounted for in the First Swiss National Inventory. After errors were accounted for, simple error budgets were developed. An error budget displays the effects of individual errors and groups of errors on the accuracy of estimates. It can be considered to be a catalog of the contributions of the different error sources to the overall accuracy of a survey system. Based on the error budget, it was found that in general the national survey system for Switzerland was not very sensitive to unbiased random errors but was extremely sensitive to systematic errors.

INTRODUCTION

The First Swiss National Inventory was conducted during the last decade. Currently, the Second Swiss National Survey is in the planning stage and will be implemented in the middle of this decade. There are many different objectives and goals in conducting the last and the upcoming surveys. These are due to the multitude of uses for the survey information, for example, to determine the health of the forest ecosystem, to assess forest change, and to develop an integrated computerized inventory system. Because of these many uses of the survey results, one general and very important goal of the national survey is to provide "sound" information.

In order to have "sound" information, the first survey was intensive, with resulting estimates that were very precise. As with most surveys, it was assumed for the first survey, that in the assessment of the precision of the overall survey estimates, the only explicit source of error in the national estimates was sampling error.

Prior to conducting the second national survey, a project was initiated to estimate and explicitly account for nonsampling errors that were thought to be potentially important in the first survey. As Cunia (1965) stated, sampling error is only one source of error. There are other sources of nonsampling errors that can be very important relative to sampling error. By accounting for nonsampling errors, the importance of the different sources of errors could be assessed, and resources could then be used in the second inventory to reduce or remove these important errors. It was the intent of the project to analyze and assess the survey system and models as originally used for the first national survey, not to recalibrate the models or modify the survey system. Because of this constraint, approximations were used to account for nonsampling errors due to the complexity of models and the sampling scheme used.

In this paper, some findings are presented for the current project. The first national survey provided many different kinds of estimates for a variety of species and attributes. However, due to time and space limitations, discussion is limited here to the estimation of the total bole volume of Norway spruce (*Picea abies (l.) karst.)* across Switzerland.

The methods used to generate the budgets were essentially extensions of methods presented in two papers. First, Schmid-Haas and Winzeler (1981) developed methods for approximating and evaluating the consequences of random and nonrandom errors in the independent variables of a tree volume function that is used in the estimation of average <u>tree</u> volume. Regression function error and measurement error were accounted for. Second, Gertner (1990) expanded these methods to account for sampling error, as well as regression function error and measurement error, when estimating average <u>stand</u> volume based on a simple sample of plots for a local survey. In the current paper, the methods were extended to a national survey where the functions used are more complicated and both quantitative and qualitative variables are accounted for. The details of the methodology can be found in Gertner and Köhl (1991).

GENERAL DESCRIPTION OF FIRST NATIONAL INVENTORY

Across entire Switzerland a systematic grid of plots was established. It was assumed that the estimates based on these plots were equivalent to the estimates that would be obtained if a simple random sample of plots were used.

For each plot, the development stage, stand structure, crown density, etc., were recorded. These stand variables were mainly ocular and qualitative in nature and were used primarily for classification. On each of the plots the type of tree measurements made were dependent on the relative location of the trees within the plots, as well as on the size of the trees. Zingg (1988) describes the criteria used for selecting the trees. All trees on each plot were measured in terms of DBH, species, social position, and other easy-to-measure attributes.

A subset of the trees within each plot was also measured for total height, HT, and upper stem diameter at 7 meters, D_7. The total bole volume of the trees measured for DBH, HT and D_7 were predicted using a bole volume function previously developed from an independent large scale stem analysis study that was conducted prior to the national survey (Hoffman 1984).

After the entire national survey was completed, tarif functions were developed to predict the bole volume of all trees on each of the plots. Plots with Norway spruce were separated into 19 different tarif groups based on stand classification variables: development stage, stand structure and crown density. For other species, the exposition of the plot was also used for grouping. For each tarif group, a separate tarif function was calibrated. The predicted bole volumes for the trees measured for DBH, HT and D_7 were used as the dependent variables when calibrating the tarif functions. The independent variables of the tarif functions included DBH, slope of plot, site index, tree social position, and stem fork between .5 and 9 meters in height. For each of the plots, the predicted volumes of trees based on the tarif functions were expanded to a per hectare basis, and then summed to obtain plot volume. Using plot volumes, the mean volume for Switzerland and variance of the mean were calculated using the well known simple random sampling formulas. It was implicitly assumed that the predicted volumes were the actual volumes of the trees and that all variables were measured without error.

APPROXIMATE ERROR BUDGETS

Functions for approximating the error structure were developed and different error budgets were generated. An error budget displays the effects of individual errors and groups of errors on the accuracy of overall estimates. It can be considered to be a catalog of the contributions of the different error sources to the overall accuracy of a survey system.

To develop the error budgets, measurement errors were introduced into the system in the form of a sensitivity analysis. Initially, the amount measurement error entered into the system were those that were believed to have occurred based on a control study and on the expert opinion of those who conducted the inventory. The level of error was considered to be realistic under field conditions. Next, other levels of measurement error were evaluated.

Winzeler (1989) describes how the control study was conducted and presents preliminary results. It was assumed that the control study was of high quality and was without error. For most continuous variables (e.g., DBH, HT and D_7), determination of the estimates of measurement errors was determined directly based on the control study results. For other continuous variables, for example site index, expert opinion was needed to determine the degree of measurement errors. This was because the site index of the forest was determined with a key developed by Keller (1978). The estimation of site index was based on different ecological variables that are both quantitative as well qualitative. Due to the way the key was developed, it was not possible to calculate the precision of predictions of site index.

In addition to errors in continuous variables, errors in classification variables were accounted for. Two classification errors were accounted for. First was classification errors in stand structure and another was the classification errors in the variables used to select the tarif equation used to predict tree stem volume for plot.

A total of 4709 plots were measured throughout Switzerland with Norway spruce. Only whole plots were considered here. Assuming no measurement and prediction error, the mean total stem volume was 267.35 cubic meters per hectare, the variance due to sampling error, 11.52, and the percent root mean error (PRMSE), 1.27%.

Table 1 shows the budget for the case where it was assumed that errors due to measurement error were random and unbiased. Based on the control study and expert opinion, the percent standard deviation due to measurement error relative to input variables was set at 2% for DBH, 4% for D_7, 7% for HT, 20% for site index, and 5% for slope. As can be seen from the table, sampling error is a primary source of variability, with the variability due to the tarif functions next in importance. The PRMSE is 1.28%. It is clear that random measurement and classification errors were of minor importance in the national survey.

Even if random measurement error were doubled in terms of the continuous variable, random measurement error would be of little significance. Table 2 shows the error budget for the case where percent standard deviation due to random measurement error in DBH, HT, D_7, site index and percent slope is doubled over the levels used for Table 3. This increase in random error will have only a very minor effect on the precision of the survey estimates. The PRMSE is still 1.28%.

There was no reason to believe that there were systematic measurement errors. Every precaution was taken to avoid such errors during the national survey. But to understand how sensitive the design is to systematic measurement errors, it was assumed that some of the inputs were slightly biased. Table 3 shows the error budget where random errors are defined to be the same as for Table 2, but the bias of DBH, HT, D7 and percent slope are each set to be 1%. This very slight bias causes a very significant increase in the mean square error, particularly for D_7. Due to the bias in the inputs, PRMSE increases to 3.77%. The very large sample size used for the survey is responsible. The results are similar to the findings of Gertner (1990).

Overall, it can be concluded for the First Swiss National Inventory that random measurement errors were not of major importance. However, because of the large sample size used, the survey design is extremely sensitive to systematic bias. Even a very minor systematic bias in the inputs could potentially reduce the precision of the national estimates significantly. In conducting the next national inventory, extreme caution should taken to avoid any consistent bias in measurements.

CONCLUSION

The methods used to generate the error budgets can be extended to other systems which use the national survey information as inputs. For example, the national survey information is being used to develop a geographic information system for Switzerland. Using error propagation methods, the errors from the survey can be propagated into and through the geographic information system. Error budgets can then be developed to account for the effects of individual and groups of errors on the accuracy of estimates provided by the geographic information systems. For small area estimates, which are commonly provided by the geographic information systems, the consequences of nonsampling errors can be quite different than for national estimates.

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TABLES

Table 1. Error budget using Norway spruce plots for Switzerland. The level of measurement error was based on control study and expert opinion.

	Bole Volume Variance $(m^3/h)^2$			Bole Volume Bias (m^3/h)
Sampling Error	11.5196	(98.416%)*	[11.5203]**	0.00 (0.000%)
Function Error				
Stem Analysis	.0025	(.0213%)		0.00 (0.000%)
Tarif Function	.1291	(1.1033%)	[.15280]	0.00 (0.000%)
Subtotal	.1316			0.00
Measurement Error				
DBH	.0000	(.0000%)		0.00 (0.000%)
HT	.0017	(.0145%)		0.00 (0.000%)
D_7	.0276	(.2361%)		0.00 (0.000%)
Site Index	.0003	(.0028%)		0.00 (0.000%)
Percent Slope	.0008	(.0066%)		0.00 (0.000%)
Subtotal	.0304			0.00
Classification Error				
Crown Position	.0090	(.0768%)		0.00 (0.000%)
Tarif Function	.0143	(.1225%)		0.00 (0.000%)
Subtotal	.0233			0.00
Grand Total	11.704			0.00

*Numbers in parentheses are the percent change of the mean square error due to that source.
**Numbers in square brackets are the variances not adjusted for nonsampling error.

Table 2. Error budget when the percent standard deviations due to random measurement error of chosen continuous variables are doubled over those used for Table 1.

	Bole Volume Variance $(m^3/h)^2$	Bole Volume Bias (m^3/h)
Sampling Error	11.5173 (97.662%)* [11.5203]**	0.00 (0.000%)
Function Error		
Stem Analysis	.0025 (.0211%)	0.00 (0.000%)
Tarif Function	.1282 (1.0869%) [.15280]	0.00 (0.000%)
Subtotal	.1307	0.00
Measurement Error		
DBH	.0000 (.0000%)	0.00 (0.000%)
HT	.0068 (.0576%)	0.00 (0.000%)
D_7	.1105 (.9372%)	0.00 (0.000%)
Site Index	.0013 (.0109%)	0.00 (0.000%)
Percent Slope	.0031 (.0261%)	0.00 (0.000%)
Subtotal	.1217	0.00
Classification Error		
Crown Position	.0090 (.0762%)	0.00 (0.000%)
Tarif Function	.0143 (.1215%)	0.00 (0.000%)
Subtotal	.0233	0.00
Grand Total	11.793	0.00

Table 3. Error budget when chosen continuous variables are 1% biased.

	Bole Volume Variance $(m^3/h)^2$	Bole Volume Bias (m^3/h)
Sampling Error	11.5196 (9.427%)* [11.5203]**	0.00 (0.000%)
Function Error		
Stem Analysis	.0025 (.0020%)	0.00 (0.000%)
Tarif Function	.1291 (.1057%) [.15280]	0.00 (0.000%)
Subtotal	.1316	0.00
Measurement Error		
DBH	.0000 (.0000%)	2.72 (40.796%)
HT	.0017 (.0014%)	1.75 (27.616%)
D_7	.0276 (.0223%)	5.53 (70.120%)
Site Index	.0003 (.0003%)	0.00 (.000%)
Percent Slope	.0008 (.0006%)	0.50 (8.484%)
Subtotal	.0304	10.51
Classification Error		
Crown Position	.0090 (.0074%)	0.00 (0.000%)
Tarif Function	.0143 (.0117%)	0.00 (0.000%)
Subtotal	.0233	0.00
Grand Total	11.7049	10.51

Whatever happened to concerns about significant digits?

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Abstract: Years ago, extensive numerical calculation was difficult, expensive, and slow, hence, rare. When carefully done, the results were held in high regard by decision- and policy-makers. Today, numerical calculation is easy, cheap, fast, hence commonplace, and also held in high regard. Hand calculation was a combination of rule application and human cognition — application of rules based on notions of significant digits. Microprocessor know no such rules. This is a problem forest modelers should be concerned about. A goal should be to get significant digits in measurement, and keep them during computation. Concerns for retaining significant digits should be a part of a quality assurance/quality control program.

BACKGROUND

Why be concerned about significant digits (s.d.)? Aren't s.d. like the weather? All talk and no action? Well, I've been suffering from dissonance for a couple of decades now — ever since reading that the number of digits in equation parameter estimates is proportional to the number of digits in system observations (Bellman et al. 1966). This, of course, contradicts what has become standard belief and practice in forest growth and yield modelling — lots of measurements will overcome any shortage of s.d. in individual measurements. I argued privately with biometricians about this two decades ago, and did three brief studies to try to resolve the questions[1]. I was always outnumbered in discussion and had no easy way to check the biometrical 'facts' against my intuitions.

So my reason for taking the time now to "dig deeper" is a self-serving one. I want to shake that old dissonance by shedding light on some questions. Is it true that you can overcome lack of precision in measurements by having lots of them? If so, under what conditions? Is the the Buffon needle experiment relevant to these issues? Is there now, after 20 years, technology to answer some of these questions?

Prior to my research for this paper, I felt s.d. was mostly about rules of computation. Well, s.d. <u>is</u> about computation, but first it is about measurement. For, one cannot simply look at a number and make an informed statement about how many s.d. it contains. One must "look" at four things -- object measured, measurement scale, application of scale to object, and least count. I will use a different way of referring to digits: firm ('f') and suspect ('s'), rather than significant. and nonsignificant.

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[1]"System state measurement and growth model parameter estimation" (1970); "The effect of computer word length on three computational algorithms for solving multi-point boundary value problems" (1972); "An improved computational strategy for solving nonlinear boundary value problems" (1972).

The overall goal of a scientist, as it relates to s.d., can be simply stated: **First, get'em (through measurement), then keep'em (during computation)!** My objectives in this paper are: 1) to examine how the several aspects of measurement affect s.d. in measured values, 2) to briefly compare two methods of computation on the measured values, and 3) to examine how having, or not having, s.d. in computed values can affect the results of modeling research — scientific predictions.

Books with serious discussions on measurement and s.d. are few. One with very good sections, Wilson's "An Introduction to Scientific Research", has just been taken over by an established publisher and reprinted (Wilson 1952). The Husch et al. (1972) text, "Forest Mensuration" is the only forest measurements book I could find having a section on s.d..

MEASUREMENT

Kinds of instruments.

In a chapter "The Design of Apparatus", Wilson (1952) discusses differences between direct and null measurement. Direct "usually involves a visible scale with some sort of moving indicator (or a moving scale and a fixed indicator)". Direct has the advantage of being rapid and simple. It has the disadvantage that precision is limited by the fineness of scale graduations, and therefore constant precision can not be maintained regardless of magnitude of the item being measured. Direct has the further disadvantage of often being based on mechanical springs the fundamental properties of which may "wander" with age and use. A direct measurement instrument applied to objects of different sizes may give patterns of "firm" and "suspect" digits as follows: fff.s, ff.s, f.s. Most hand-held field measuring devices used to make the basic measurements now in long term data bases have been direct measurement devices.

What Wilson calls null measurement "involves opposing the quantity being measured by a similar quantity which is adjusted in magnitude until some indicator shows that balance has been achieved. The value of the opposing quantity required is then read off the control." Null measurement has the advantage that there is, for all practical purposes, no limit to the precision with which measurement can be made. It has the disadvantage of being slow, if balance is obtained by hand. (Recall those days in chemistry lab using the old 'analytical' balance. It was enough to drive you nuts, picking up those little weights with a tweezers!) "Modern" null measuring instruments are "balanced" by advanced feedback devices, however. A null measurement instrument applied to objects of different sizes may give the more desirable pattern of firm and suspect digits: fff.s, ff.fs, f.ffs.

Application of instrument to object.

Wilson describes two different, what I call, measurement acts. Each act involves three parties: the object being measured, the scale, and the measurer who "engages" the scale and object. There are at least two ways of applying the scale to the object being measured. In act-one measurement, the object being measured has been marked in some way so that the zero point on the measuring scale can be brought into coincidence with the mark. The scale is "laid" on the object and the scale is read at the other "end" of the object (Wilson 1952, page 251). Most forest measuring instruments have been directly applied, in an act-one manner, to the objects being measured (diameter tapes, calipers, etc.) or have been used at a distance (altimeters, etc.). In act-two measurement, the object being measured has been marked, but the zero point on the scale is not placed on that mark. Rather the scale is placed more or less at random on the object, and one must read the scale at both ends, and add or subtract readings in order to get a measured value.

Measurement of tree diameter with a d-tape can be done in each of the two ways. In an act-one measurement, the tape is placed around the bole in the usual manner and the point at which the privileged mark meets the overlapping tape is noted. In an act-two measurement of tree diameter, a vertical scribe is made on the bark, long axis vertical. The tape is then applied to the bole in the usual careful manner, but the zero point on the tape is not aligned with the vertical mark. Rather the two ends of the tape are read where they cross the mark, and the diameter obtained by either subtraction or addition, depending on tape design.

According to Wilson, in act-one measurements it is typically not possible to increase accuracy of the estimate by repeating the measurement many times and averaging, especially if the least count is large. However, in the case of act-two measurement, accuracy can be increased by making many measurements and averaging, assuming the least count is sufficiently small, and only random errors are limiting the increase in precision. Wilson urges the reader to personally verify this.

Scales on the instrument, i.e., least count.

Measuring instruments are graduated using some sort of rule to space the graduations. Two characteristics of these rules are important. First, is there a zero point or privileged mark on the scale (Bunge 1967)? Second, the fineness of scale graduations. Wilson calls the smallest scale interval the least count.

Because many of the kinds of measurements we make in forest mensuration are concerned with the linear dimension (L), the scales usually have a privileged mark corresponding to a zero length. Other notable privileged marks coincide with phase transitions of objects being measured, e.g., the freezing point of water, etc..

Wilson suggests that the least count should be only 1/3 to 1/5 of the standard deviation of a set of repeated measurements gathered with a very small least count. The idea is that "... repeated measurements will be spread over perhaps 10 to 30 intervals." Assuming that only random errors are limiting[2], a smaller least count and repeated measurements can be expected to contribute only a limited amount,

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[2]Wilson offers the following classification of errors: 1) systematic, 2) personal, 3) mistakes, 4) assignable causes, and 5) random.

about an additional digit, to measurement precision. The gradations on most hand-held field measuring devises are quite coarse.

Least count, and measurement accuracy, have been questioned by the celebrated needle experiment of Buffon[3]: draw parallel lines on a paper spaced equal to the length of a needle, randomly drop the needle on the paper. If the needle crosses a parallel line, add 1 to a counter, if not, drop it again. Pi can be calculated as (2 × number of tries/number of successes). Repeat the experiment sufficient times, and you can estimate π to any number of significant digits. So goes the claim. The experiment can be simulated with a simple computer program (Beckman 1971). We 'dropped' the needle 278 million times one weekend on an MV20000 Data General, and got π correct to 4 places.

In sum, because most measurement instruments used to collect field data for forest growth and yield modeling are direct measurement devices, are applied in act-one measurements, using scales with relatively large least counts, it is generally not possible to make several measurements, average the result, and have more significant digits than in a single measurement. Repeated measurements, on a fraction of all field measurements, can be justified, however, simply as a check for quality control in the measurement process — to check for other types of error identified by Wilson. It is possible field measuring instruments based on laser technology will revolutionize field data collection. There may also be opportunities to improve measurement precision in existing instruments by simply modifying them to increase the least count as the size of the measured object decreases. For example, why aren't diameter tapes graduated to 1/100th inch for trees less than 10 inches? Of course, instrument change is not the entire answer to the s.d. problem.

COMPUTATION

Rules for determining s.d. in hand computation.

Husch et al. (1972) present rules to follow when doing hand calculations with numbers containing different numbers of s.d.. Forms of a minimum law exist : 1) "In multiplication and division, the factor with the fewest significant figures limits the number of [s.d.] in the product or quotient.", and 2) "... the number of significant digits in [a sum or difference] can never be greater than those in the largest of the numbers, but may be fewer."

Numerical analysts caution about two operations in particular: 1) subtraction of two numbers nearly the same, and 2) division using a very small divisor (compared to the dividend). The latter is, of course, equivalent to multiplication where one number is very large compared to the other. A further caution is to never difference a noisy signal. Environmental fluctuations and their affect on tree growth ensure

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[3]When first explained to me, the experiment seemed so ridiculous on the surface that I believed I had discovered the origin of the expression "buffoon" -- clown or fool. Of course, I'd missed the double oh. Turns out buffoon is derived from the Latin name of the toad family.

noisy signals, yet differences in real growth series are routinely taken.

What happened to s.d. rules when calculation became automated?

When humans were doing the work, both the rules of arithmetic and the higher cognitive rules for s.d. were applied as required by the unique circumstances of the numbers involved. When automatic computing devices took over application of the routine rules for computation, it seems rules of s.d. were set aside.

Conte (1965) discusses four approaches to the error estimation problem in automated computation: 1) comparing computations done with different word lengths (e.g., double and single precision), 2) interval arithmetic (doing arithmetic on the upper and lower bounds of numbers known with error (Moore 1966)), 3) significant digit arithmetic, and 4) a statistical approach.

The most common method today is 1) above. But for us, the method relates to roundoff error questions, not so much s.d. questions. Interval arithmetic compilers allow variables to be declared 'INTERVAL', just as INTEGER or REAL. Personal experience with interval arithmetic suggests the results represent worst case scenarios. Conte describes significant digit arithmetic research (as of 1965) as giving results that are much too conservative, and notes that experimental work showed the methods as "not too promising". The statistical approach has been widely applied to error propogation research, but to my knowledge, not to significant digits.

While in 1965 Conte judged the future of significant digit arithmetic to be "not too promising", the possibility of doing it easily and on large problems appears to have arrived with *Mathematica* [4](Wolfram 1991). *Mathematica* offers the user the option of machine or arbitrary precision arithmetic. If arbitrary precision is selected for a number, it is treated "... as representing the values of quantities where a certain number of digits are known, and the rest are unknown. ... an arbitrary-precision number x is taken to have Precision [x] digits which are known exactly, followed by an infinite number of digits which are completely unknown. ... *Mathematica* keeps track of which digits in your result could be affected by unknown digits in your input. It sets the precision of your result so that no affected digits are ever included." (Wolfram 1991). When *Mathematica*'s facility to do arbitrary-precision mathematics is combined with its facility to execute procedural language programs, there is now the possibility of testing complete data analysis systems — from initial measured data screening and summerizing through statistical and regression analysis. The goal would be to identify data analysis procedures that unnecessarily contribute to the loss of s.d. gathered in field measurements, and, of course, either avoid them or develop alternative mathematical expressions.

In sum, when micro-processors replaced hand calculation, only part of the complete human process of mathematical calculation was taken on. Certain kinds of error, e.g., roundoff, can be easily addressed by changing machine precision. Methods to

[4]*Mathematica* is a registered trademark of Wolfram Research, Inc.

analyze error due to limited precision of measurements, lack of s.d., have been much slower to develop. *Mathematica* offers a viable system for attacking this important source of error. Before extensive computational efforts are begun, tests of the algorithms should be done using arbitrary precision arithmetic. Justification can rest with quality assurance/quality control (QA/QC) programs.

APPLICATION

Demonstration of ideas to a common growth modeling problem.

Please assume the following modelling scenario. 1) The objective is to develop mathematical equations to predict periodic diameter growth of individual trees as a function of age, site, and stand density. 2) Data available for calibrating and testing the model are diameter measurements (to one firm decimal) of numbered trees on permanent growth plots repeated every five years. 3) The desired model form is a first order differential of difference equation. 4) The model will be fit using linear or nonlinear regression methods, where periodic diameter growth is the dependent variable and initial diameter, age, site index, and stand density are "independent" variables. This generic scenario is common to many modeling projects.

The scenario requires that we have repeated diameter measurements from trees on permanent growth plots, say, estimated as $(ff.fs)_1$ and $(ff.fs)_2$. We subtract them to obtain estimated diameter growth. If the remeasurement interval is, say, five years, diameter growth will likely not exceed one inch. Thus, the difference will look like: f.fs or just .fs. So, even before analysis has begun we have lost one, perhaps two, firm digits.

Eventually we conjecture some sort of mathematical model to fit to the observations and estimate a and b using:

$$\min_{a\,b} \sum_{i=1}^{n} (\hat{\Delta d} = f(d,a,b) - \Delta d)^2$$

Clearly, minimization requires taking a second difference — this time between predicted and observed diameter growth. But we lost one, perhaps two, s.d. in taking the first difference in getting the dependent variable, so there is little left in the way of s.d. in the calculated numbers. Whatever the difference is it will consist mainly of suspect digits. The upshot of double differencing when modeling diameter growth is that there may be little significance left in the sum of squared values for which you seek a minimum. Should the sum have only one s.d. coefficients a and b will have at most a single s.d.. Using arbitrary precision arithmetic in *Mathematica* we could, I believe, determine how many s.d. a and b have.

Results of having few s.d. in model coefficients and independent variables.

If we know very precisely the values of model coefficients as well as the values of model independent variables, we can legitimately claim to predict almost any value throughout a range of the independent variables (see schematic in Figure 1). However, if we use only the s.d. in model coefficients, and s.d. in the values of independent variables we can predict at only a subset of points in the prediction space (Figure 2). While observations may occur at almost any place in the prediction space, the model, properly applied, gives a grainy prediction space.

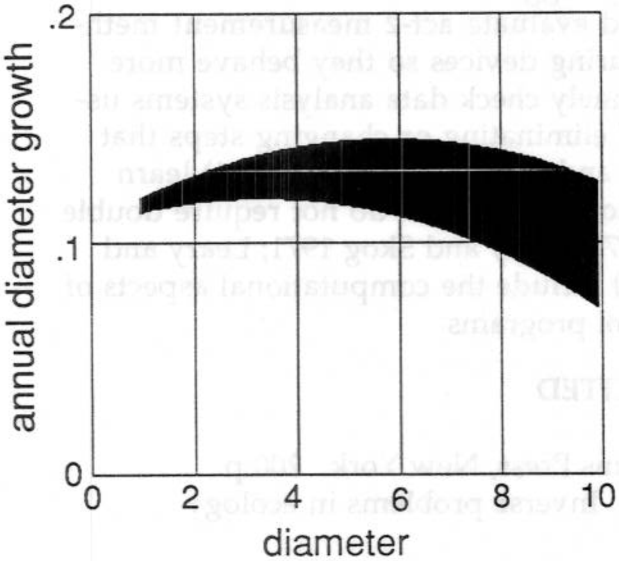

Figure 1. Illusion of complete predictability of diameter growth from initial diameter and site index.

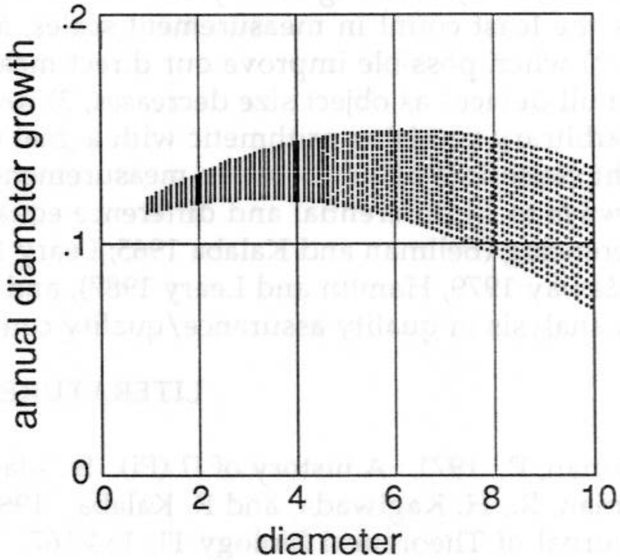

Figure 2. Graininess in predictions due to lack of significant digits in equation coefficients and independent variables.

Model evaluations should consider the graininess of prediction space. For example, if an observed value falls between two predictable values, and the model predicts one of the two neighbors, the model should be evaluated as giving a perfect prediction. It is as close as the model allows. If, however, there are predictable points between what is observed and predicted, the model could have been closer.

In sum, one result of calculating with non-significant digits is self-deception. We convince ourselves we know more than we actually do. Or what we do 'know', we think we know more precisely than we actually do. Figure 2 suggests that models based on few s. d. in observations may have a very grainy set of predictable states. System states between granules may be observable, but given the precision of our model coefficients, they may not be predictable.

DISCUSSION

I've tried to identify several reasons for the lack of s.d. in our model coefficients, and graininess in our prediction spaces. Is it that our measuring instruments don't allow us to get them in the first place? Or is it in the way we do routine calculations in data analysis? Is it the use of change (differential or difference) equations when we don't measure change directly[5], getting it instead by subtracting numbers often nearly the same? Or is it inherent in regression analyses? Or is it that trees are highly irregular objects and are difficult to measure because they grow in places where other things grow that make the measurement experience unpleasant?

Clearly, it is some of each. The graininess of the prediction space will probably not be remedied by focusing on any one "cause". My suggestions are to: 1) work to reduce the least count in measurement scales, and evaluate act-2 measurement methods, 2) when possible improve our direct measuring devices so they behave more like null devices as object size decreases, 3) routinely check data analysis systems using arbitrary precision arithmetic with a goal of eliminating or changing steps that might cause loss of s.d. between measurements and coefficient estimates, 4) learn the ways to fit differential and difference equation models that do not require double differencing (Bellman and Kalaba 1965; Leary 1970; Leary and Skog 1971; Leary and Holdaway 1979, Hamlin and Leary 1987), and 5) include the computational aspects of data analysis in quality assurance/quality control programs.

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[5]Physical scientists can observe change directly using accelerometers, and other motion sensitive measuring instruments.

Geo-Blocks - The Next Generation in GIS?

by Brad Franchi*

Abstract

The Mead Corporation, Coated Board Division Woodlands is currently Beta-Testing a new concept in Geographic Information System (GIS) named Geo-Blocks. This system is being developed by Geo-Based Systems of Raleigh, NC an EDS Company.

The unique attributes of this system begin with data storage. Traditional GIS technology is based on binary data storage, allowing for smaller file sizes and quicker redraw times. Geo-Blocks is based on SPARC technology with the platform using 16 mega- bytes of RAM and about a Gigabyte of disk storage. Performance of this system is in the 20-30 Millions Instructions per Second (MIPS) range. This type of hardware allows for map data storage in traditional database tables. No intermediate steps are required to obtain access to the GIS data. The database management system also allows for easy linking of forest inventory data, and extremely fast redraw times. Once the database is loaded, 50 mega- byte redraws in 15 seconds are not uncommon. A user defined interface, scripted in a C like language allows for automating of day to day tasks. Graphical queries of the entire 520,000 acre 400 mega- byte database is now possible, instead of relying and tabular based solution as in the past.

Introduction

Mead has been involved in GIS since 1983. As data processing has improved, we have seen our approach to data analysis change. In 1983 only limited tabular and graphic approaches were feasible. Forest inventory and map data for 435,000 acres of fee lands was available, but hardware limitations required work on about 100 acres at a time. By 1985 using the 386 based PC, query and report of all tabular data of the forest in less than 30 seconds was common place. Graphic analysis was still limited to small blocks up to about 1,000 acres.

In July of 1991, testing of Geo-Blocks, a UNIX based GIS began. The Sun SPARC machine features a 16 inch high resolution color monitor, at least 16 mega-bytes of RAM, and about a giga-byte of disk

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storage. UNIX is a multi tasking operating system, taking advantage of SUNVIEW or X Windows to provide a Graphical User Interface (GUI). Geo-Blocks is a C like interface coupled to SYBASE relational data base tables. Geo-Blocks evaluates the user request and performs the SQL calls to the data tables.

Methods

Fifty thousand acres of Mead fee lands were converted from PC format to UNIX. The DLG road data from USGS quad maps was also converted for the test area of east central Alabama. The data was loaded on the SPARC machine and tested against the 486 based PC of the main GIS system. Calculation, and drawing speed were measured as well as data conversion accuracy.

Results

The SPARC machine loads the entire data set once at the beginning of the session. This operation requires about twenty minutes as the SYBASE tables are loaded with the vector and tabular information for the test forest. After the loading is complete, the entire data set is drawn in about 20 seconds. This operation requires about 1 minute and 30 seconds on the 486 PC. After the data is loaded in Geo-Blocks and accessed, drawing speed increases dramatically. Geo-Blocks optimizes the data in memory. The test unit contains sixteen mega-bytes of ram. After a few draws, Geo-Blocks has the entire data set in RAM. Drawing and zooming times of eight seconds are consistently reproduced. The 486 based PC always requires the same drawing and zooming times of 1 minute and 30 seconds. Since Geo-Blocks is storing the entire data set in SYBASE tables, all the information is immediately available at the click of the mouse. Updates for tabular variables such as age can be accomplished using traditional SQL commands.

Conclusions

Geo-Blocks is at least four times faster than the 486 PC and after memory optimization occurs as much as twelve times faster. Geo-Blocks is allowing data analysis in ways that were infeasible on the 486 PC because of sheer speed. The SPARC machine tested is the SPARC 1 from Sun Microsystems. This machine is rated at 16 MIPS. The SPARC 2 is rated at 28 MIPS and includes 32 meba-bytes of

RAM. Hewlett Packard has similar workstations available up to 76 MIPS. This high end workstations and Geo-Blocks will allow analysis of the entire 400 mega-byte, 535,000 acre data base in a graphical fashion, instead of relying on tabular based solutions as in the past. As GIS information is added to our system such as SPOT and LANDSAT scenes, soils data, and topograhic lines, the speed and power of these workstations will provide the necessary response times for timely analysis.

STAND GROWTH: LIMIT OF DIVERSITY

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ABSTRACT

The more yield models we construct, the more obvious becomes the need for new growth information to reflect growth of various species at different locations and for specific conditions. This proliferation of growth curves poses the question: is there a limit to growth diversity? Earlier investigations showed that the diversity in growth curves reflected in existing yield tables can be reduced to a small number (15-30) of growth types. The present study demonstrates that the number of types can be further reduced to 3-5 without sacrificing accuracy of growth predictions.

INTRODUCTION

Since construction of the first yield tables about two centuries ago (Paulsen 1787 as cited in Fernow 1913), there has been an ever increasing demand for more detailed information on stand growth. It seems that the more yield models we construct, the more obvious becomes the need for new growth information to reflect growth of various species at different locations and for specific conditions. For example, Carmean et al. (1989) compiled the most comprehensive set of site index curves for the eastern United States and at the same time made it clear that many more curves are needed for adequate representation of stand growth in various situations. Environmental changes further exacerbate this demand (Kimmins 1985).

Because the number of combinations of species, locations and stand conditions, such as soil properties, climatic fluctuations, slope, exposure etc., is infinite, the approach advocated by Carmean et al. (1989) is impossible. It is also unnecessary since many of the curves they presented coincide with each other.

An opposite approach to growth modeling consists in the standardization of growth curves and construction of growth types rather than the proliferation of the curves (Zeide 1978). The objectives of the present study are to analyze existing growth types and show that their number can be further reduced without sacrificing accuracy of growth predictions.

GROWTH TYPES

Growth types are based on the assumptions that diversity of growth is limited and that there are common patterns of growth in many stands. These types do not merely reflect stand growth; rather, they present a refined picture extracted from assorted growth information. The key point in standardization of growth information was the idea that two points are sufficient to characterize any growth curve. Zeide (1967, 1968, 1978) showed that the diversity in growth curves can be reduced to a few types which accurately describe the original data. Thus, 16 curves were sufficient to express height growth of any coniferous or hardwood forest stand, 28 curves for diameter, 30 for tree number and 15 for volume. The average standard deviations of the types were 2.4, 3.2, 6.9, and 5.9 percent of the mean values for height, diameter, number of trees per unit area, and stand volume, respectively.

Two points appeared to be necessary and sufficient for representating actual growth curves. A second point is necessary because it produces a drastic increase in accuracy as compared with only one point. Two points are sufficient for growth predictions because accuracy of prediction increases very little when three, four, or more points are used.

Because they have a winning combination of low effort and relatively high accuracy, growth types became popular in the USSR, where they were first introduced (Zeide 1967, 1968), and in this country (Hoyer and Chawes 1980, Smith 1985, Hoyer and Swanzy 1986, Milner 1988, Bunce and Bonnor 1989). Under leadership of Dr. Vasily Zagreev the construction and application of growth types has grown into a minor industry of Soviet forest research. A framework of these activities is outlined in Zagreev (1978). Although growth types were mostly compiled from European yield tables (Zeide 1978), they work well in the Pacific Northwest for such species as Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Thus, Hoyer and Chawes (1980) found that the difference between height types and the local curves was within 1 or 2 percent.

Growth types were derived from yield tables that were constructed prior to the widespread application of growth formulas such as the Chapman-Richards or Weibull equations. This provides some assurance that the types reflect stand growth rather than the form of a particular equation. We still do not know which is the best growth equation or whether the best exists at all. We do know that any existing equation distorts actual growth to some degree. Although it is tempting to present the two-point concept in an equation form, table form is more accurate. In this form the types can serve as a touchstone for testing equations, as was done by Kiviste (1988).

METHODS AND RESULTS

Looking at 16 height growth types published in Zeide (1978), a question arises: is it possible to reconstruct an intermediate type from the neighboring ones? Because growth types are polymorphic, they are not proportional and the rotation of one curve about its point of intersection with another will not combine the curves. Therefore, it is impossible to condense all curves into one curve.

At the same, time it is possible to reconstruct intermediate curves through interpolation of neighboring types. For example, if we know the value of height growth for type 12 only at one age, say, 100 years, we can find values for that type at any age through interpolation of neighboring types. When we interpolate type 12 using types 10 and 14, the discrepancy between interpolated type 12 (Table 1, Column 5) and actual type 12 (Column 3) is negligible. However, if we use more remote types, for instance, 6 and 18, to interpolate the same type 12 (Column 6) the results are less accurate.

Table 1. Interpolation of growth types.

Age	Height types			Interpolated type 12 from types	
	10	12	14	10 and 14	6 and 18
30	55	49	43	49	54
40	78	74	70	74	77
50	100	100	100	100	100
60	120	124	130	125	124
70	137	146	158	147	147
80	151	165	182	166	167
90	163	182	203	182	182
100	174	196	221	196	196
110	183	208	236	208	207
120	190	218	249	218	216
130	196	227	261	226	224
140	202	235	271	234	231
150	207	242	279	241	237
160	212	248	287	247	243

This example indicates that while the two extreme types (6 and 18) cannot be relied on for the accurate reconstruction of intermediates, more closely located types (10 and 14) are sufficient for this purpose. By trial and error it was found that three types are sufficient to interpolate the other height growth types with virtually no loss in accuracy. Similarly, four types were required to interpolate the original growth types for diameter and volume. Five types were needed for number of trees (Table 2).

The difference between actual growth types and interpolated ones is much smaller than the accuracy of the types and, therefore, can be neglected. For example, the standard deviation of type 12, interpolated using HT 1.25 and HT 2.00, from the actual values of the same type was 0.23%. This is ten times less than the average discrepancy between the types and the height growth curves from yield tables which were used as original material.

Table 2. Growth types

Age	Height types			Diameter types			
	HT 1.25	HT 2.00	HT 2.75	DT 1.25	DT 1.75	DT 2.50	DT 3.25
30	0.72	0.48	0.33	0.72	0.60	0.46	0.34
40	0.88	0.73	0.63	0.88	0.80	0.71	0.63
50	1.00	1.00	1.00	1.00	1.00	1.00	1.00
60	1.09	1.25	1.43	1.09	1.18	1.31	1.45
70	1.15	1.48	1.84	1.14	1.34	1.63	1.93
80	1.19	1.68	2.20	1.18	1.49	1.94	2.39
90	1.22	1.85	2.50	1.22	1.63	2.23	2.83
100	1.25	2.00	2.75	1.25	1.75	2.50	3.25
110	1.27	2.13	2.96	1.28	1.86	2.75	3.63
120	1.29	2.24	3.14	1.30	1.96	2.98	3.98
130	1.31	2.33	3.30	1.32	2.04	3.18	4.29
140	1.32	2.41	3.43	1.34	2.12	3.36	4.57
150	1.33	2.48	3.55	1.35	2.19	3.53	4.83
160	1.34	2.54	3.66	1.36	2.25	3.68	5.06

Age	Tree number types					Volume types			
	NT 2.5	NT 4	NT 7	NT 12	NT 20	VT 1.25	VT 2	VT 3	VT 5
30	3.05	5.87	13.58	30.39	63.92	0.66	0.47	0.35	0.24
40	2.50	4.00	7.00	12.00	20.00	0.87	0.73	0.62	0.48
50	2.10	2.92	4.37	6.26	9.08	1.00	1.00	1.00	1.00
60	1.78	2.24	2.95	3.80	4.83	1.09	1.25	1.45	1.76
70	1.52	1.79	2.12	2.50	2.96	1.15	1.49	1.89	2.62
80	1.31	1.45	1.61	1.77	1.96	1.19	1.69	2.30	3.49
90	1.14	1.19	1.25	1.30	1.35	1.22	1.86	2.67	4.30
100	1.00	1.00	1.00	1.00	1.00	1.25	2.00	3.00	5.00
110	0.89	0.86	0.83	0.80	0.76	1.27	2.12	3.27	5.60
120	0.80	0.75	0.70	0.65	0.60	1.28	2.21	3.49	6.12
130	0.72	0.66	0.60	0.54	0.49	1.29	2.28	3.67	6.57
140	0.64	0.58	0.52	0.46	0.40	1.30	2.34	3.83	6.96
150	0.57	0.51	0.45	0.39	0.33	1.31	2.39	3.97	7.30
160	0.50	0.45	0.39	0.33	0.27	1.32	2.43	4.09	7.60

Values of these second generation growth types at 50 years were set at 1.00 for variables increasing in the course of time (height, diameter, and volume). For the decreasing variable, tree number, values at 100 years were set at 1.00. The ratio between values at 100 and 50 years was used to identify the types of increasing variables. For example, HT 2.00 signifies that the height at the age of 100 years is twice as much as the height of 50-year old stand. For decreasing variables the ratio between values at 40 and 100 years was used for type identification.

APPLICATION

The fact that values at 100 and 50 years were used to label the types does not mean that one has to measure forest stands only at these ages to apply the types. Measurements at any two ages that differ by 30 years or more can be used to reconstruct the entire growth series. Yield tables constructed by Marty (1965) for white pine (*Pinus strobus* L.) stands in Wisconsin will help us demonstrate the application of growth types.

Using volumes at 90 years (10400 cu. ft.) and at 40 years (4200 cu. ft.) from the table for stands of site index 60, we can determine that the ratio between these volumes is 10400/4200 = 2.476. The corresponding ratios for VT 2 and VT 1.25 from Table 2 are 2.548 (= 1.86/0.73) and 1.402 (= 1.22/0.87), respectively. By interpolating these ratios, one can find that the value of 2.476 corresponds to volume type VT 1.95. Values of this type at ages other than 90 and 40 years can be calculated by interpolating neighboring types VT 1.25 and VT 2.00. The results of interpolation are given in Table 3, Column 2.

Table 3. Application of growth types.

Age	VT 1.95	White pine volume, cu. ft.		
		calculated	yield table	difference
30	0.48	2740	2250	490
40	0.74	4200	4200	0
50	1.00	5680	5800	-120
60	1.24	7050	7200	-150
70	1.47	8350	8470	-120
80	1.66	9430	9500	-70
90	1.82	10340	10400	-60
100	1.95	11100	11100	0
110	2.07	11750	11700	50
120	2.15	12230	12200	30

We convert the type values to volume values by multiplying VT 1.95 by 4200/0.74 (where 4200 is stand volume and 0.74 type volume at the same age of 40 years). The difference (column 5) (the average standard deviation) between the actual and calculated values amounted to 2.2 percent.

This example shows that it is indeed possible to further reduce the number of growth types without losing much accuracy of growth predictions.

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Estimating Log Volume Using the Centroid Position

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ABSTRACT

In 8 of 15 comparisons by tree species (6 Australian and 9 American), log volumes were estimated with more precision when the inter-log position for measuring cross-sectional area was located at the mid-volume (centroid) position rather than the mid-length (Newton) position. It is concluded that the centroid of a tree or log defines a position of special significance for estimating volume. A formula is developed for estimating log volume based on measurements of log length and diameter at both ends of the log and at any intermediate position.

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INTRODUCTION

A number of mensurationists have reported that the optimum height on a tree bole to take a single measurement of diameter for estimating the volume of the bole is at 0.3 of total height (Ueno 1978, Forslund 1982, Wood _et al_. 1990). Wood _et al_. (1990) established that this position occurs at the centroid (the center of volume of the bole) of second degree paraboloids. The major portion of most tree boles approximates this shape (Gray 1956). Reliable estimates of bole volume based on a diameter measurement at the centroid have been obtained with radiata pine (_Pinus radiata_ D. Don) (Wood _et al_. 1990) and a number of Australian and American hardwoods (Wiant _et al_. 1991).

Newton's formula has long been considered the most accurate of the formulae commonly used for estimating the volume of logs (Wenger 1984, p. 261-262), viz.:

$$V_{*} = ((B+4M+S)/6)L \qquad (1)$$

where V = cubic volume (m^3 or ft^3),

B = cross-sectional area at large end of log (m^2 or ft^2),

M = cross-sectional area at mid-length of log (m^2 or ft^2),

S = cross-sectional area at small end of log (m^2 or ft^2), and

L = log length (m or ft).

Newton's formula is exact for all simple solid bodies, e.g. cylinder, paraboloid, conoid and neiloid. Eq. 1 can be derived by fitting a second-degree curve to the small-end area (S), mid-length area (M), and large-end area (B) for a given length (L) of a solid body as (Fig. 1):

$$S = b_0 + b_1(0) + b_2(0)^2 \qquad (2)$$

$$M = b_0 + b_1(L/2) + b_2(L/2)^2 \qquad (3)$$

$$B = b_0 + b_1(L) + b_2(L)^2 \qquad (4)$$

As $b_0 = S$ (Eq. 2), these relations can be solved using simultaneous equations. We followed this procedure letting C be the cross-sectional area at any distance ℓ from the small end of a log, giving (refer to Appendix 1 for the derivation):

$$b_1 = (B - S - b_2L^2)/L \qquad (5)$$

$$b_2 = (B - C(L/\ell) - S(1-L/\ell))/(L^2 - L\ell) \qquad (6)$$

$$V = SL + 1/2b_1L^2 + 1/3b_2L^3 \qquad (7)$$

This permits the volume of a log to be estimated given a cross-sectional area at any distance from the small end. Assuming we require the distance (ℓ_c) to the centroid, it can be calculated from the formula given by Wood et al. (1990), viz.:

$$\ell_c = (((D/d)^4+1)^{0.5}-2^{0.5})/(2^{0.5}((D/d)^2-1))\ L \qquad (8)$$

where D and d are the diameters at the large and small ends of the log respectively.

The study reported here was conducted in an attempt to establish that log volume derived using the cross sectional areas at both ends of the log and an intermediate position is as reliable when the latter position corresponds with the centroid as when Newton's mid-length position is used.

METHODS

The Newton and centroid methods of deriving bole volume were simulated using felled sample tree data for radiata pine, five Australian hardwoods, and nine Appalachian hardwoods (Table 1). The average interval between measurement points along the tree boles was about 1 m for radiata pine, 2.3 m for the Australian hardwoods, and 1.2 m for the American hardwoods. To avoid the points of inflection on the bole which occur at the butt end (change in solid shape from neiloid to paraboloid) and in the crown (change in solid shape from paraboloid to conoid), we confined the study to the section of the bole between 2 m above ground and an outside-bark top diameter of not less than 15 cm for radiata pine and the American hardwoods and 30 cm for the Australian hardwoods. The bole volumes were calculated using the mid-length and mid-volume cross-sectional areas, linearly interpolated between the nearest two measured diameters on the bole, and formulae (1) and (7) respectively. The "true" volume (V_t) of each bole was determined by aggregating the volumes of measured short sections using Smalian's formula. Data were analyzed using the methods recommended by Reynolds (1984) and the related ATEST program developed by Rauscher (1986).

RESULTS

Estimates of mean volume derived using Newton's formula more closely approximated true volume for 9 of the 15 tree species investigated. However, the estimates derived using the centroid position were more precise (narrower tolerance interval) for radiata pine and for half of the hardwood species investigated (Table 1). The tolerance interval indicates the 95 percent confident that at least 95 % of the population of percentage errors will fall in this interval (error % = 100 $(V_t-V_p)/V_t$ where V_p is the predicted volume).

DISCUSSION

The results indicate that we can expect the volume of a log derived using diameter measurements at its centroid and both ends to be as reliable as that derived using Newton's formula. As the length of logs decrease, the centroid and mid-length positions will tend to approach each other and eventually will reach a point where the derived volumes are identical. The time required to apply each method is identical but determining the centroid position on a log requires a pocket sized calculator to compute Equation 8.

Wood and Wiant (1991) demonstrated that the centroid method is superior to Huber's formula for deriving log volume based on a single measurement of diameter, and here we present evidence that volumes of logs derived using diameter measurements at both ends and at the centroid are as reliable as those derived using Newton's formula. Thus, this study reinforces the notion that the centroid of a tree or log defines a position of special significance for estimating its volume.

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Appendix 1.

Deriving the volume of a log given its length, diameter at both ends, and an additional diameter any any distance from the small end:

Referring to Fig. 1, let SB define a curve of the second degree relating sectional area to length and let ℓ be any distance between 0 and L. Then:

$$S = b_0 + b_1(0) + b_2(0)^2$$

$$= b_0 \qquad (1)$$

and as $b_0 = S$

$$C = S + b_1(\ell) + b_2(\ell)^2 \qquad (2)$$

$$B = S + b_1(L) + b_2(L)^2 \qquad (3)$$

Multiplying (2) by L/ℓ, substracting the product from (3) and simplifying the result, we have:

$$b_2 = (B - C(L/\ell) - S(1 - L/\ell))/(L^2 - L\ell) \qquad (4)$$

Substituting (4) into (3) and solving for b_1 gives:

$$b_1 = (B - S - b_2L^2)/L \qquad (5)$$

Then,

$$V = \int_0^L (b_0 - b_1\ell + b_2\ell^2)\,d\ell$$

$$= SL + 1/2\ b_1L^2 + 1/3\ b_2\ L^3 \qquad (6)$$

TABLE 1. Descriptive statistics and tolerance intervals for volumes derived using the centroid and Newton methods on radiata pine and some Australian and American hardwoods

Species	No. trees	Mean values[a]			Mean volume(m^3)			Tolerance interval(%)[b]	
		D	d	L	True	Cent.	Newton	Cent.	Newton
Pinus radiata	110	25.2	15.6	8.8	0.348	0.347	0.353	4.6	5.1
Australian hardwoods									
Euc. pilularis	15	69.0	48.3	15.9	4.393	4.372	4.410	12.3	6.7
Euc. maculata	12	62.5	47.0	14.6	3.404	3.411	3.424	4.1	4.4
Euc. sieberi	34	58.0	31.1	19.0	3.222	3.217	3.257	18.3	14.0
Euc. diversicolor	17	72.5	31.7	28.9	9.876	9.255	10.104	12.0	7.4
Findersia brayleyana	9	73.4	54.0	14.9	4.794	4.785	4.792	1.6	3.4
American hardwoods									
Quercus rubra	10	26.6	17.1	9.5	0.419	0.430	0.436	22.8	24.8
Q. coccinca	12	26.5	16.6	8.2	0.356	0.346	0.354	15.4	11.1
Q. velutina	12	25.7	17.0	7.9	0.324	0.330	0.325	10.8	16.3
Q. alba	11	26.3	16.6	8.6	0.363	0.354	0.371	9.7	7.9
Q. prinus	12	25.8	16.9	7.7	0.314	0.333	0.306	34.5	28.9
Carya sp.	9	26.5	16.7	9.3	0.409	0.387	0.390	14.2	23.6
Liriodendron tulipifera	12	27.2	16.1	11.5	0.505	0.500	0.513	9.6	7.0
Prunus serotina	11	26.1	17.8	9.1	0.399	0.399	0.395	12.7	15.0
Acer rubrum	10	25.1	18.7	7.8	0.321	0.325	0.320	13.3	14.1

[a]D = diameter (cm) at large end of log.

d = diameter (cm) at small end of log.

L = length of log (m).

[b]95% confidence that 95% of the population of percentage errors will fall in this interval.

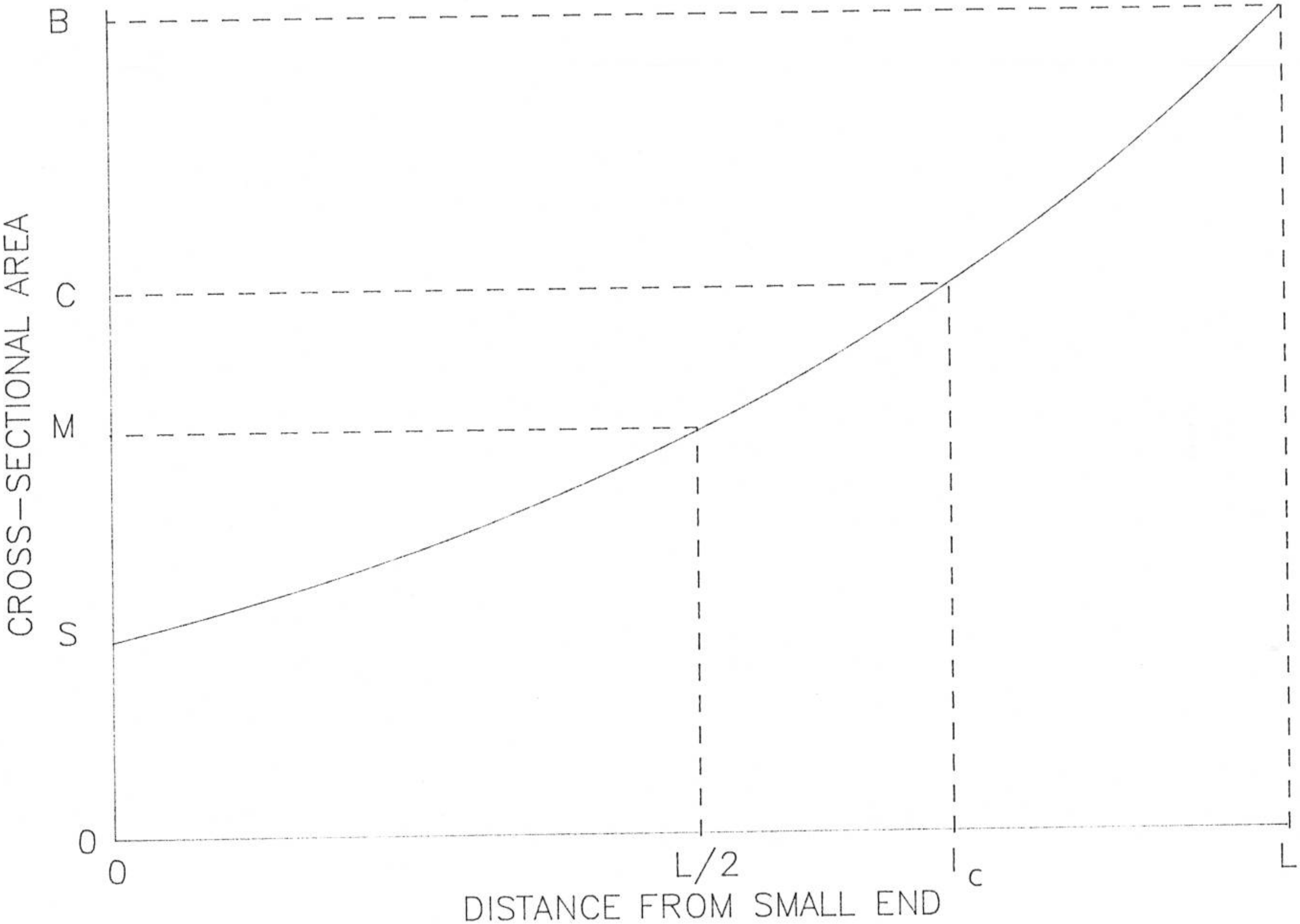

Figure 1. An idealized plot of the cross-sectional area of a log of length L over distance from the small end. B is area at the butt end, C is area at the centroid, M is area at mid-length, and S is area at the small end.

II

ABSTRACT OF POSTERS

NEEDS FOR R & D IN GROWTH AND YIELD IN QUEBEC

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ABSTRACT

One of the main problems in growth and yield information in Quebec is that existing growth and yield models are not management oriented. The second major prblem is that Quebec forest inventory is at the Provincial level while the informationis required at the regional level. The needs include inventory, yield estimates, ecological information, information on disturbance and many other areas. This paper describes recommended methods to fulfill some of the above needs and information which includes the use of both permanent and temporary sample plots.

1. Present problems

The needs for growth and yield modelling has increased in Quebec since the application of the new forest policies. Contrary to managers' hopes, the growth models presently available cannot serve as a guide to managing forests for two reasons.

First, most of the yield studies concern natural unmanaged stands. The resulting growth models are not adapted to the treatment of managed stands because construction rules vary depending on whether only one silviculture or several are considered. Basic data presently available are generally anamorphic (in opposition to the polymorphism revealed by stem analysis or observations of permanent sample plots over long periods). Reliable data are seriously lacking for silvicultural needs. Secondly, it must be noted that the provincial inventory has been conceived to serve as a base for the provincial management while the present needs of the stakeholders necessitate a regional knowledge of the wood yield. This change forces Quebec's managers to ask serious questions about the data validity, and the methods used by the Ministry of forests to estimate Quebec's forest growth.

2. Identified needs

Based on the principles of forest management, five groups of needs have been identified: (1) forest inventory, (2) estimating and predicting yield, (3) ecological framework, (4) disturbances, (5) education of qualified personnel about growth and yield, site-production relation, and biometrics, and (6) consolidation of strong links between growth and yield and management.

3. Recommended methods of meeting identified needs

3.1 Forest inventory

The intensive handling of the available data from permanent plots is essential to make sound decisions is important to improve their representativeness at the regional level. Only silvicultural experiments carried out on permanent plots with well-followed thinning schedules will allow the construction over the medium term of variable-silviculture yield tables. Coordination and regionalization of efforts and standardization data collection are recommended. Their conception and implementation procedures must be communicated to all forest participants and uniformly followed in order to permit a certain homogeneity. This is essential in obtaining compatible data.

As for temporary plots, intensive analysis of their data is essential before deciding to increase their number per strata. It is not suggested to use the data available in these plots to construct growth models at the regional level particularly for hardwood forests.

The quality of the environment of the database system should be improved by simple interactive requests and conversational software.

Research on volume tables has produced essential results and the application phase of these results by the users is underway. The present research is focused on the methodology for calculating errors in data inventory (budget errors):

* errors in the measure of tree characteristics (the impact of these errors is as high as the model for volume estimation is accurate);
* errors in the tree volume estimation;
* errors for sampling plots and trees;
* notion of cost that is linked to the error for measuring the tree characteristics and the sampling error.

Traditionally, forest samplings are analyzed by applying the classical sampling theory. This theory has two drawbacks: (1) an accurate estimation of the variance of the estimated quantities is impossible in the case of systematic sampling plans, and (2) results and their interpretation are not independent from the plot area.

By considering the geographic position of the plots, the geostatistics allows a rigorous and accurate estimation of the studied quantity from a systematic sampling by knowing a experimental function: the variogram. Moreover the geostatistics is not based on restrictive hypotheses as stationarity and isotropy which are heavy and rarely realized in forest.

Therefore, in the studied forests, geostatistics is used to detect the eventual superposition of structures of different scales allowing one to establish both the optimal sampling rate and the sampling plan.The spatial tendency of the productivity in a forest can be underlined by geostatistics with the kriging method. This possibility represents the most interesting point: the manager has a tool allowing a fiable macro- mapping of the forest with a reduced cost because only a small part of the forest is inventoried.

3.2 Growth and yield modelling

The pragmatic route which should be adopted for estimating and predicting yield of Quebec forests, should be to separate clearly the work to be done in the juvenile phase from those to be done in the adult phase.

For the juvenile phase, a short range of treatments has been tested. More practical experiments on juvenile treatments are necessary to establish reference tables of cleaning and first thinning. Concerning the adult phase, two approaches for growth determining have to be used jointly: (1) yield tables for long term planning, and (2) increment borings and comparison of inventories for medium term planning and for control of long term planning.

The route which should be followed for progressive improvement in growth modeling consists of:

- short-term development of tree models and of provisional normal yield tables at the regional scale with stem analysis, and using these tables, development of simulation models to help frame the most original tending rules for typical, well-known stands. These tables will also enable the yield prediction with better precision than tables at the provincial scale, until better information is available;

- medium-term development of yield tables for variable-silviculture as a function of accepted silvicultural prescriptions (time, intensity, nature of intervention). To reach this target, experimental silvicultural plots would be installed as close as possible to existing Quebec forest inventory plots and in high yield potential forest to complete those already established. These plots should be treated and followed by an R & D consortium.

There are two important premises for our growth modelling activities:

- The selection forest system, in spite of its relative difficulty of application, must be considered because of its greater adaptation than the regular forest system to the aesthetic and environmental constraints;

- Yield tables cannot be considered as the first and principal objective of the growth modelling research. Indeed, their errors prediction are considerable in spite of the high control of ecological conditions because of the climatic change. They are also difficult to improve by adding information on stem distribution by size classes or knowledge on wood quality. Yield tables must to be considered as an issue rather than a starting point.

Following this, three strategies of growth modelling research must be considered:

* Strategy 1: Distance independent tree model

The three constraints for this strategy are:

- The model has to be developed quickly in order to answer to the urgent needs of forest managers and industry;
- It must describe the growth of various more or less mixed and/or unevenaged stands;

● It has to be useable from classical inventory data.

This model is directly used for operational needs (inventory projection, simulation of stand management). It also serves as a base for development on the link between growth and wood quality.

* Strategy 2: Stand model (yield table)

The two constraints are:

● The model must be simple and have a well-known mathematical behavior;

● It must be able to be used in different ways by forest companies for the stand level management, for the local medium term planning and for the regional long term planning. This model is the final issue and will not the subject of future development.

* Strategy 3: Distance dependent tree model 11

This model is not intended to be directly used by managers. It serves:

● To study questions on the effect of plantation density, of the thinning and pruning on the total production, on the quality and value of wood products;

● To give a scientific framework for analyzing the interactions between the wood production, the silviculture and for example, an insect outbreak;

● To construct variable-silviculture yield tables for the use of managers.

3.3 Site catalog

It is convenient to establish for each ecological region a catalog of forest sites to serve as a framework for silvicultural planning. It is important to make sure that these catalogues have received the consensus of both ecologists and practicians. User guides are essential. For the problem of site-yield relation, it is recommended to determine the variables and the ecological processes influencing species growth by starting with high-yield forests.

3.4 Insect outbreaks and old stands decline

Combination of the forest inventory with entomological and pathological inventories has to be undertaken when the growth estimation is done. Il is recommended to evaluate the spruce budworm's impact on the yield with existing data. Collaboration with other provinces in the research is necessary. During the identification of entomological and pathological problems in a given region, the annual observation of damage in permanent plots should be realized. Silvicultural experiments should also be undertaken to reduce the spruce budworm's impact. Studies in mature stands should be undertaken to determine the onset and the speed of their decline.

3.5 Qualified staff training in growth and yield, in site-yield relation and in biometrics

To permit the application of knowledge and methods relative to the four precedent axes, it is recommended to form in the short term the expertise at the graduated studied in growth and yield, in site-yield relation and in biometrics. This expertise training will be achieved through the hiring of competent research professionals and the granting of fellowships to graduate students.

3.6 Consolidation of strong links between growth and yield and forest management

An expertise in growth and yield research exists in universities, governments and industry. Nevertheless this expertise has not been fully used for the management of the Quebec forests. Users should have advantage to develop strong links with researchers in growth and yield and these researchers should orient their works in function of the needs clearly identified by forest managers.

4. Priorities in R & D

By chronological order, the priorities in R & D are the following:

- Development of a forest database system with contents and periodical update based on consensus.
- Development of efficient sampling methods at the regional level by integrating basic ecological data.
- Improvement of accessibility to the database by standardizing its contents through a user consensus and the establishment of necessary tools allowing for easier use.
- Construction of tree and stand models at the regional scale, and development of simulation models for the forest yield in order to facilitate decisions on the most adequate management strategies according to the characteristics and the socio-economical management constraints.

5. R & D consortium in growth and yield

In order to meet several identified needs in R & D, it is recommended to form an R & D consortium in growth and yield. In order that this consortium obtains a credibility at the provincial and national scale, it is crucial to concentrate principal activities relative to the forest management. The works of the consortium should be realized in the three vast forest areas (boreal, mixed and meridional forests).

To realize these works, it is necessary that the consortium can imply forest participants working in regions (universities, forest industry, regional governmental offices or consultants) in order to profit from the current works in different regions of Quebec. Moreover, the sharing of information is essential and will allow members to take advantage of combined abilities.

6. Conclusion

The most important effort should relate to obtaining data. Work on growth modelling and improving the user-friendly database system is important; but it represents only a minimal part of this immense project of progressive improvement of the quality of yield estimation of Quebec forests. Indeed, an in-depth and thorough analysis of sampling methods to optimize the estimation of standing stock and to establish the typing and the structure of stands, deserves particular attention in the next few years. Moreover, a thorough analysis of the design of permanent plots, tied in to analyses of presently available data, should be undertaken before adding others to the present network.

Independent of the network of Quebec forest inventory plots, experimental silvicultural plots (indispensable for the construction of variable-silviculture yield tables) should be designed and established without delay to complete the older ones in forests with high yield potential. These plots should be designed and established by an R & D consortium. Methods for their design, procedures for their installation, and measurement guidelines should be distributed to all forest agencies and uniformly monitored to permit some degree of uniformity, an essential condition for obtaining compatible data. Passing from the provincial scene to the regional, the management of Quebec forests is at an historic turning-point. Although it is indispensable, regionalization should nevertheless be based on a strong, structured central organization in order to maintain the long term data collection procedure.

ON ESTIMATING THE NUMBER OF SEED CONES IN JACK PINE SEED ORCHARDS IN ONTARIO

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ABSTRACT

Methods appropriate to Ontario conditions for constructing a sampling plan to estimate the number of seed cones in jack pine (*Pinus banksiana* Lamb.) seed orchards are described. Stratified random sampling with strata equally wide with respect to relative crown height proved to be cost-effective and should be easy to implement operationally. The optimum number of strata in this scheme, however, depends on the costs of moving the equipment used for sampling from place to place in the orchard, with the number of strata being inversely proportional to the moving costs. The potential influence of variations in the type of equipment used and the costs incurred in conducting the sampling are illustrated.

INTRODUCTION

Many seed orchards have been established in Ontario to produce genetically improved seed for reforestation. These orchards constitute a substantial economic commitment and hold the promise of important genetic gains. In most of these orchards, cone yields are evaluated at harvest. (Since seeds are held within cones, it's simpler to count cones as an indicator of the size of seed crops). Because proper decisions in seed orchard management often depend on the predicted value and size of future crops and the expected losses incurred during cone development (Bramlett 1987), estimates of the size of the crop of seed cones initiated each year are also useful.

To make these estimates, sampling methods that can take advantage of the non-random distribution of cones in the crown and that are simple enough to employ operationally are preferred. Most seed cones in jack pine (*Pinus banksiana* Lamb.) occur in the upper half of the crown depending on the size, spacing, and age of the trees (Rauf and Benjamin 1983, Rudolph and Yeatman 1982). Although cone production in conifers can also change with crown size (Thorbjornsen 1960), aspect (e.g. Owens and Blake 1985), and branch length (Mattson 1979), we do not pursue these factors here. In this paper, we extend earlier work (Fleming *et al.* 1990, Fleming and de Groot 1992) in designing general sampling methods for young jack pine and in comparing some specific sampling plans for crop size estimation.

METHODS

Sampling plans generally have two basic operational characteristics: the cost of collecting the samples needed to attain a required precision, and the precision achievable when the resources available are limited. These characteristics are estimated from small preliminary samples.

For simple random sampling, the preliminary sample requires counting the number of seed cones on n randomly selected orchard trees. Sampling methods that exploit the spatial pattern of cones in the crown, however, require preliminary samples of cone location. In trees with a well-defined whorl structure, branch location is a convenient reference and multistage variable probability sampling is recommended (Bartram and Miller 1988). Jack pine's variable branch architecture and multinodal form, however, preclude using branch location as a reference, and instead require that the heights of seed cones be measured directly.

We conducted the preliminary sampling over two years on open grown jack pine aged 9-20 years and randomly selected from three plantations near Espanola and Thessalon, Ontario. As part of this sampling, the live crown length was measured as the height of the tree minus the height above ground of the lowest point on the bottom branch. The relative crown height, H, was then defined as the distance up the crown from the bottom (H = 0) as a fraction of the live crown length. Therefore H = 1 at the top of the tree. Fleming *et al.* (1990) describe other aspects of the cone counting methods.

RESULTS

Seed cone numbers varied considerably with height in the crown (Table 1). An average of 311 seed cones per tree was counted among the 35 jack pines sampled and the variance in the counts was 46,174. The within crown distribution of seed cones for each year of sampling in each plantation is detailed in Fleming and de Groot (1992, Fig. 1). Variations in the average number of seed cones per tree among plantations and year of sampling showed no clear dependence on live crown length (Fig. 1).

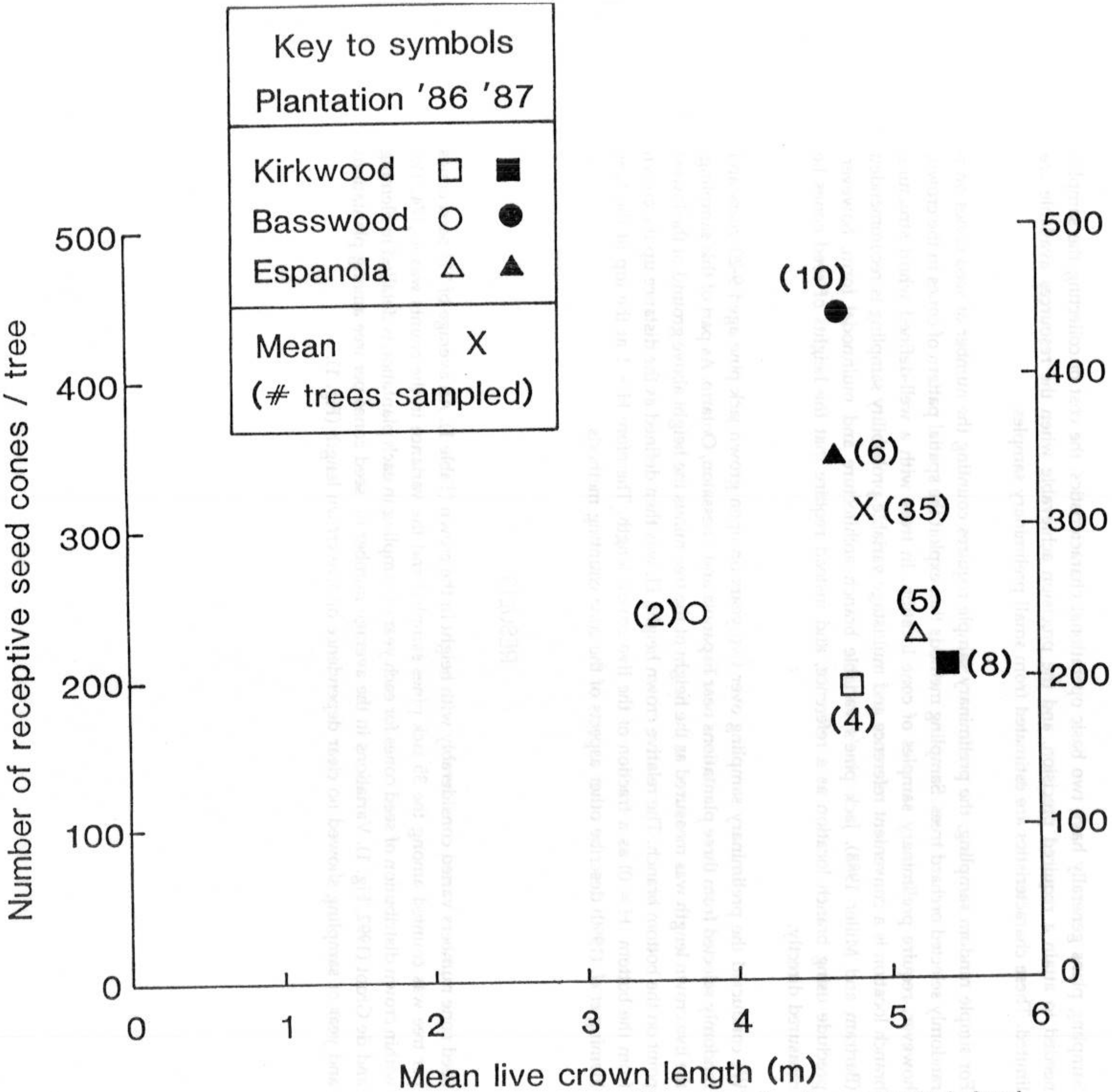


Fig. 1. The numbers of receptive seed cones per tree in different plantations by year (see key) plotted against the corresponding mean live crown length.

Stratified random sampling was identified as a methodology capable of exploiting the height dependent distribution of seed cones in the crown. In this approach, the population is segregated into nonoverlapping parts, or strata, and an independent simple random sample is collected in each stratum. Stratified random sampling will usually produce a lower variance for the estimated mean than simple random sampling if strata are selected so that the variance among observations within each stratum is substantially less than the population variance.

The substantial variability among cone counts in the preliminary sample at different heights in the crown (Table 1) suggests using relative crown height, H, as a basis for determining strata. To find strata that minimize the variance of the estimated mean for a given sample size, we followed Cochran's (1977) prescription. First the square root of the seed cone count in each interval of relative height in the preliminary sample was calculated. This process is demonstrated in Table 1 for intervals 0.1 wide. To estimate the ideal stratum width, the sum of the square roots of the counts (SSRC) accumulated over all intervals (310.37 in Table 1) is divided by the number of strata, L. Thus, in Table 1, 62.07 is the ideal width for L = 5 strata, and the integral multiples of 62.07 listed in the right-hand column are the ideal stratum boundaries. The operational choices for stratum boundaries are the relative heights (0.3, 0.5, 0.7 and 0.8) corresponding to the nearest square root sums in Table 1's fourth column.

Table 1. Results of applying the sum of the square roots of the counts, SSRC, procedure to the preliminary sample data (after Fleming and de Groot 1992)

relative crown ht. (H)	number of seed cones counted	square root of the count	SSRC (sum of the square roots)	divisions for 5 strata
0.0-0.1	226	15.03	15.03	
0.1-0.2	211	14.53	29.56	
0.2-0.3	438	20.93	50.49	62.07
0.3-0.4	789	28.09	78.58	
0.4-0.5	1083	32.91	111.49	124.14
0.5-0.6	1551	39.38	150.87	
0.6-0.7	2052	45.30	196.17	186.21
0.7-0.8	2141	46.27	242.44	248.28
0.8-0.9	1605	40.06	282.50	
0.9-1.0	777	27.87	310.37	310.35

Determination of the proportion, q_j, of the sampling to be conducted in each stratum, j, occurs after the number of strata and their boundaries have been at least tentatively set. This requires estimates of the costs of obtaining a count per tree, c_j, and estimates of the variance, s_j^2, of the counts among trees in each stratum, j. These costs account for the time spent counting, setting up equipment, and marking stratum boundaries. For instance, the costs listed in Table 2 follow (Fleming *et al.* 1990) from the fact that it took about 0.125 man-hr to delineate a stratum boundary and 1 man-hr to count the cones on an average jack pine. Substituting these costs into a simplification of Cochran's (1977) general formula gives the sampling proportions,

$$q_j = s_j(c_j)^{-0.5} \,/\, \{ \sum_{i=1}^{L} s_i(c_i)^{-0.5} \}, \qquad (1)$$

which minimize both the expense of attaining a desired error bound and the error bound attainable with limited resources.

Table 2 lists the results for five strata based on data from the preliminary sample. As expected, the SSRC procedure which produces unequal stratum widths (Table 1) results in a smaller range and sum f stratum variances than the arbitrary adoption of strata equal in width.

Table 2. Stratified random sampling with five strata equal and unequal in width with respect to relative crown height, H. Variances and costs (in man-hr) were derived from preliminary sample results. Proportions were calculated using equation (1). (After Fleming et al. 1990)

Stratum (j)	Width (H)	Variance (s_j^2)	Costs (c_j)	Proportion (q_i)
Equal stratum widths				
1	0.0 - 0.2	189	0.16	0.090
2	0.2 - 0.4	1095	0.35	0.146
3	0.4 - 0.6	3145	0.46	0.216
4	0.6 - 0.8	6074	0.59	0.265
5	0.8 - 1.0	3714	0.32	0.282
Unequal stratum widths				
1	0.0 - 0.3	680	0.20	0.146
2	0.3 - 0.5	1673	0.40	0.162
3	0.5 - 0.7	6109	0.54	0.267
4	0.7 - 0.8	1608	0.42	0.155
5	0.8 - 1.0	3714	0.32	0.270

Figure 2 illustrates how equation (1) implicitly calls for intensified sampling in strata where the costs of gaining information (i.e. counting) are small and where the information to be learned, which is proportional to the variance, is large. The slopes of the lines are equivalent to the denominators in equation (1) corresponding to equal and unequal stratum widths as suggested by the key.

Each stratum in the plans outlined in Table 2 involves an interval of relative height in every tree in the orchard. Accordingly, the general formula (e.g. Scheaffer *et al.* 1979) approximating the required sample size for estimating $\bar{x}_L$, the mean seed cone number per stratum per tree can be simplified. The sample size (in parts of tree crowns) needed to estimate the mean count per tree, $\bar{x} = L\bar{x}_L$, with a bound $B = b\bar{x}$ on the error is then approximately

$$n = 4N \sum_{j=1}^{L} (s_j^2/q_j) \; / \; (4 \sum_{j=1}^{L} s_j^2 + B^2 N) \; . \tag{2}$$

In this expression B represents two standard errors and is a bound on the estimation error that ensures with at least 75% confidence (Hogg and Craig, 1970) that $\bar{x} \pm B$ includes the true population average. (For most distributions confidence increases to 80-90%; for normal distributions to over 95%). To increase precision when expecting small crops, B can be measured as a proportion of the sample mean, i.e. $B = b\bar{x}$, where $0 < b < 1$ is the relative error. Therefore, in an orchard of $N = 10{,}000$ jack pines, a plan involving five strata of uniform width needs counts in $n = 62$ (61.8 rounded upwards) sampling units to estimate the tree mean with 20% precision with at least 75% confidence.

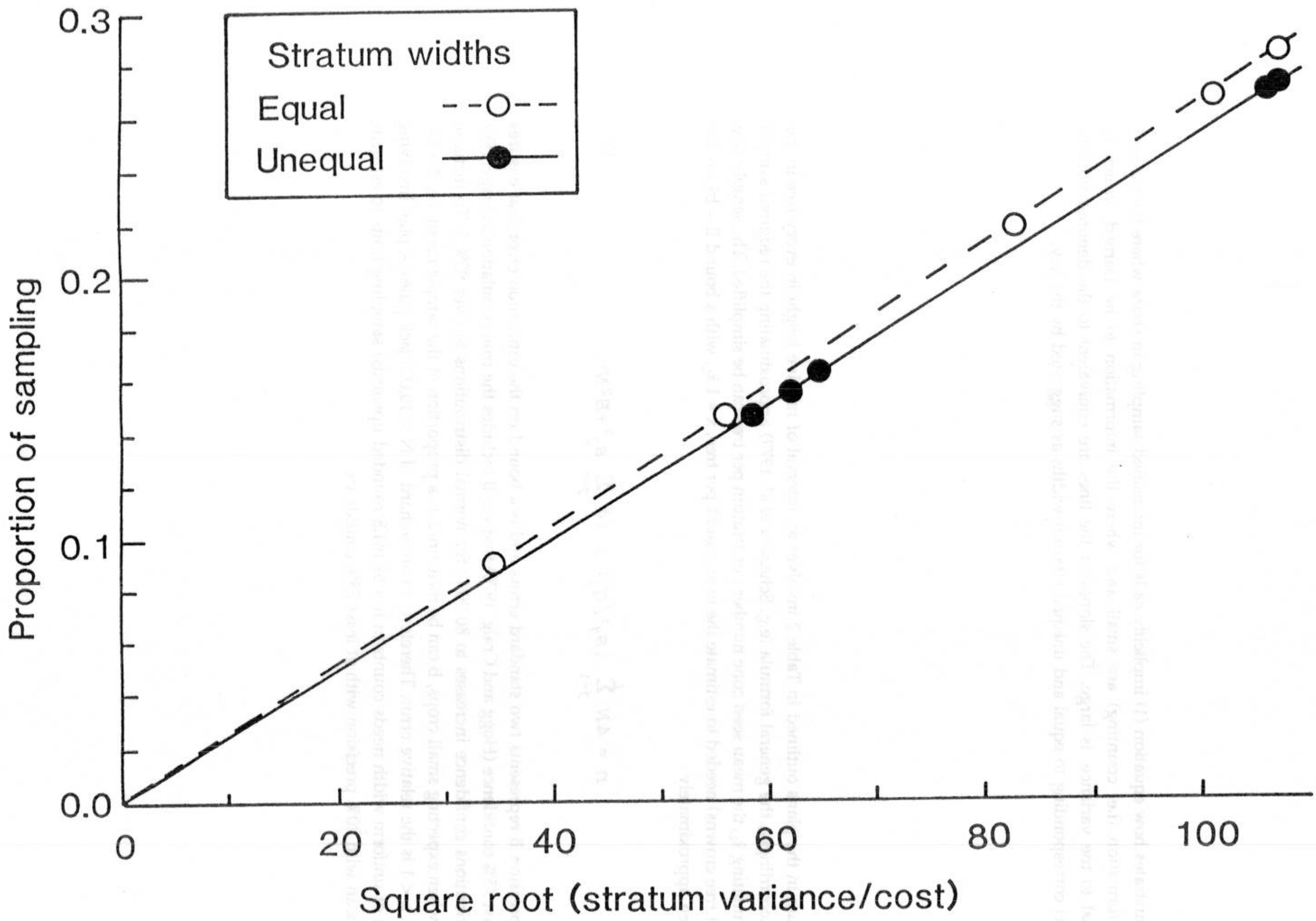


Fig. 2 Illustration of equation (1) showing, for each stratum, the proportion of the sampling units selected plotted against the square root of the seed cone variance divided by the per unit sampling cost. Stratified random sampling plans with 5 strata of equal and unequal widths are distinguished (see key).

In stratified random sampling, stratum j is allocated a sample of size $q_j n$ rounded to the closest integer, so the resources needed to conduct the plan are

$$R = n \sum_{j=1}^{L} q_j c_j . \tag{3}$$

Solving this equation for n gives the size of the sample possible with R man-hr available to carry out the sampling plan. For instance, the results in Table 2 suggest that n = 100/0.412 = 242 (rounded downwards) complete sampling units can be handled given R = 100 man-hr to conduct a sample using five strata of uniform width.

Algebraically manipulating equation (2) produces an expression for the error bound achievable in estimating the mean,

$$B = 2 \{(1/n) \sum_{j=1}^{L} (s_j q_j^{-0.5}) \sum_{j=1}^{L} (s_j q_j^{0.5}) - (1/N) \sum_{j=1}^{L} s_j^2\}^{0.5} . \tag{4}$$

Setting n = 242 and using Table 2 to substitute for s_j and q_j results in B = 31.4 seed cones per tree in an orchard of N = 10,000 jack pines.

The different sampling plans can be conveniently compared in terms of the costs of attaining a specified precision. For instance, the stratified random sampling plans with equal and unequal stratum widths in Table 2 require 99.0 and 101.8 man-hr of sampling, respectively, to get a 10% error bound in a large (N = 10,000) orchard. It takes 188.0 man-hr to do the same job using simple random sampling. For each sampling plan, costs were only slightly less in large orchards, but doubling the acceptable error cut costs by almost 75% (Fleming *et al.* 1990). Thus, simple random sampling is almost twice as costly as either stratified plan for a given precision regardless of orchard size. More importantly, there's little reason to use the potentially confusing stratification with unequal widths when the simpler alternative with equal widths can do the job at almost the same cost.

Changes in the number of strata affect the total sampling costs and the precision attainable. For instance, according to the preliminary sample, 20% precision in a 10,000 tree orchard requires approximately 48.0, 34.3, 28.7, 26.9 and 25.5 man-hr as the number of equally wide strata increases from 1 to 5, respectively. Similarly, given 100 man-hr in the same situation, one can obtain 13.7%, 11.6%, 10.7%, 10.4%, and 10.1% precision, respectively, as L increases from 1 to 5. (L = 1 strata represents simple random sampling). Thus the stratified plans generally become more cost effective as the number of strata increases. These increases typically produced narrower strata and allowed more crowns to be visited per man-hr. Neither orchard size nor the method of stratification (i.e. equal or unequal widths) had much influence (Fleming *et al.*

1990). Using over five strata proved to be operationally impractical. Because the strata were so narrow, many cones occurred near a stratum boundary where misidentification of a cone's stratum potentially limited the reliability of the cone counts.

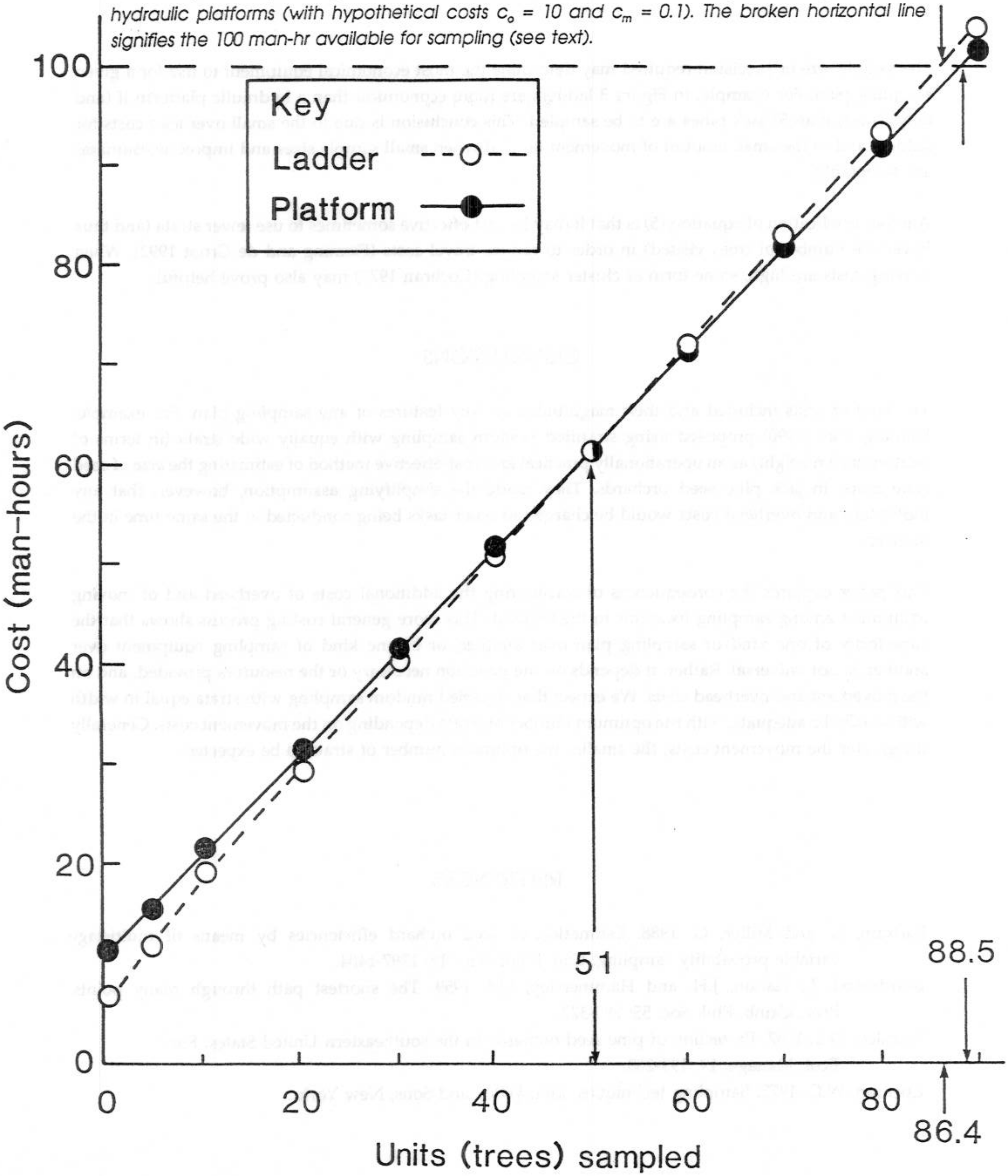
So far we have implicitly assumed that crop size estimation is combined with other tasks (e.g. monitoring) requiring travel with the same equipment through the orchard. In this case, the time spent moving between trees and the overhead costs of acquiring and maintaining equipment can be considered negligible for crop size estimation. This is not usually the case, however, and overhead costs, c_o, and moving costs, $c_m n^{0.5}$, should be considered in the costs:

$$R = c_o + c_m n^{0.5} + n \sum_{j=1}^{L} q_j c_j . \tag{5}$$

Following Beardwood *et al.* (1959), the moving costs increase roughly in proportion to the square root of the sample size, $n^{0.5}$. The constant of proportionality, c_m, is the per unit travel cost. It is determined by orchard conditions (e.g., terrain, spacing, number of trees) and the kind of equipment used.

Next, to find the sample size possible with limited resources, equation (5) can be solved for n, but this produces a very complicated expression (Fleming and de Groot 1992). A more intuitively appealing approach is to plot the cost, R, from expression (5) against n to find the value of n at which this curve crosses the horizontal line denoting the resources available. Figure 3 shows such a plot for simple random sampling using orchard ladders (with hypothetical costs $c_o = 5$ and $c_m = 0.8$) and a hydraulic platform or cherry picker (with hypothetical costs $c_o = 10$ and $c_m = 0.1$). The overhead costs would be higher if the equipment were not used for many other tasks (which therefore share the overhead). The intersections with the horizontal line at R = 100 man-hr show that 86 and 88 trees, respectively, could be completely sampled by ladder and platform in 100 man-hr.

Fig. 3. Illustration of equation (5) showing the cost of simple random sampling ($L=1$, $q_{1=1}$, $c_{1=1}$ man-hr) plotted against sample size. According to the key, the diagonal lines distinguish relationships corresponding to orchard ladders (with hypothetical costs $c_o = 5$ and $c_m = 0.8$) and hydraulic platforms (with hypothetical costs $c_o = 10$ and $c_m = 0.1$). The broken horizontal line signifies the 100 man-hr available for sampling (see text).



The sample size or precision required may determine the most economical equipment to use for a given sampling plan. For example, in Figure 3 ladders are more economical than a hydraulic platform if (and only if) less than 51 jack pines are to be sampled. This conclusion is due to the small overhead costs for ladders and to the small amount of movement needed when small sample sizes and imprecise estimates are acceptable.

Another implication of equation (5) is that it may be cost-effective sometimes to use fewer strata (and thus lower the number of trees visited) in order to reduce travel costs (Fleming and de Groot 1992). When moving costs are high, some form of cluster sampling (Cochran 1977) may also prove helpful.

CONCLUSIONS

The kind of costs included and their magnitudes are key features of any sampling plan. For example, Fleming *et al.* (1990) proposed using stratified random sampling with equally wide strata (in terms of relative crown height) as an operationally practical and cost-effective method of estimating the size of seed cone crops in jack pine seed orchards. They made the simplifying assumption, however, that any movement and overhead costs would be charged to other tasks being conducted at the same time in the orchard.

This paper explores the consequences of considering the additional costs of overhead and of moving equipment among sampling locations in the orchard. This more general costing process shows that the superiority of one kind of sampling plan over another, or of one kind of sampling equipment over another, is not universal. Rather, it depends on the precision necessary or the resources provided, and on the movement and overhead costs. We expect that stratified random sampling with strata equal in width will usually be adequate, with the optimum number of strata depending on the movement costs. Generally the greater the movement costs, the smaller the optimum number of strata to be expected.

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RECENT PROGRESS OF THE GREAT LAKES FOREST GROWTH AND YIELD COOPERATIVE

D.K. Walters and A.R. Ek[1]

ABSTRACT

Through cooperation among researchers, land managers, and wood procurement professionals, the GLFGYC is fostering the collection, pooling, and synthesis of forest growth and yield prediction information in the Great Lakes region of Canada and the United States. The cooperative also aims to identify priorities, provide direction, and encourage the development of new growth and yield models and the improvement of existing models. These objectives are pursued from funds developed within and external to the cooperative. Some of the projects currently under way are:

1. the development of empirical yield equations for localized areas.
2. the development of stand level growth and mortality equations for the state of Minnesota.
3. the development of models of aspen decay as it relates to stand level attributes.
4. compilation of a catalogue containing information on the data currently held by members.

The GLFGYC is a cooperative organization composed of 28 private and public organizations throughout the Great Lakes region.

INTRODUCTION

The Great Lakes Forest Growth and Yield Cooperative arose from the need for accurate, localized and broadly useful forest growth and yield. Similar cooperatives have already been developed in other areas of the U.S. and Canada. The cooperative's establishment was made possible with a grant from the Legislative Commission on Minnesota Resources and support from existing projects of the University of Minnesota Agricultural Experiment Station, the Minnesota Department of Natural Resources, and the USDA Forest Service North Central Forest Experiment Station. The cooperative has attracted membership from six states and the Canadian province of Ontario in the Great Lakes Region.

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JUSTIFICATION AND OBJECTIVES

The availability of long-term remeasured plot data describing forest growth and yield is fundamental to forest growth and yield prediction. Much data is already collected by a variety of organizations. The primary objective of the cooperative is to foster the collection, pooling, and synthesis of such data within the region to provide a strong data base for developing and refining forest growth and yield prediction methods. The cooperative also aims to identify priorities (see Table 1), provide direction, and encourage the development of new growth and yield models and the improvement of existing models. These objectives will be pursued from funds developed within and external to the cooperative. The cooperative's specific objectives are thus:

1. Provide guidelines, recommendations, and limited technical assistance for data collection, especially for compatible procedure and quality control, to ensure the collection of broadly useful data.
2. Identify areas where data collection is needed and design and, where possible, install the necessary study plots or record keeping procedures (in the case of existing installations).
3. Encourage and coordinate growth and yield data collection including the establishment of priorities for research and data storage, retrieval, and access.
4. Encourage the pooling of growth and yield data, specifically by accepting such data from cooperators and cooperative members and pooling that data to make it available to cooperative members and researchers working with the cooperative.
5. Stimulate the development and localization of growth and yield prediction models to be made available to participants and cooperating organizations within the region.

Table 1. Important issues in forest growth and yield in the Great Lakes region as identified by the members of the GLFGYC in July, 1988.

Ranking of Importance	Issue/Concern
1	The development of procedures and guidelines for the installation of permanent plots.
2	The development of localized, empirical yield tables in the Great Lakes Region, especially for young stands.
3	A vehicle for communicating information about growth and yield research and to enhance the availability of data for various studies.
4	Development of a system for cataloging, storing, an dretrieving data sets available for growth and yield research projects.
5	Development/refinement of young stand growth and yield information and models.
6	Collection, screening, and cleaning of growth and yield data.
7	Refinement and improvement of site index/quality classification and prediction.
8	Development of Linkages between growth and yield information and allowable cut programs.
9	Development of implementation software for using growth and yield research.
10	Uneven-aged management research in the Great Lakes Region.

ORGANIZATION

The Advisory Committee consists of representatives from each of the following groups: universities; federal forestry research organizations; local, county, state, provincial, and federal forest management agencies; industry; and other full members (as defined below). The universities and research organization roles are primarily that of research. The management agency role is to represent forest land management interests of the various landowners. In order to recognize the bilateral nature of the members, the advisory committee has two Co-chairs, each representing one of these groups. The Advisory Committee will meet at least once per year to discuss and set research priorities, review progress and approve research projects. The development of operational bylaws was an early agenda item. The bylaws were approved at the January, 1989 meeting of the cooperative. The cooperative also has at its disposal various administrative personnel to handle budgetary and accounting aspects of income, grants, and expenditures and insure that the cooperative follows established rules and procedure regarding funding and staffing. In addition to the advisory committee and its chairs, the cooperative is guided by the direction of an Administrator, whose responsibilities include overseeing the membership meetings, locating possible funding sources, and directing the work of a research specialist. This forest growth and yield research specialist will help accomplish the various objectives of the cooperative by soliciting data and cooperation, assisting in research plot establishment, collecting and pooling data and information, developing and maintaining this data base management system, and in growth model development. These developments are expected to have application across the Great Lakes region as the cooperative progresses.

FUNDING

Initiation of the cooperative is facilitated with a portion of a grant from the Legislative Commission on Minnesota's Resources. The grant was for a project entitled "Future Timber Supply Scheduling Techniques." The cooperative also receives nominal support from members to facilitate its meeting, information, and communication efforts. The cooperative will also, itself and through encouragement of participating scientists, seek grants for specific projects that further the cooperative's objectives. The cooperative will continue with staff and/or financial support from the lead organizations as it develops.

The fee schedule for participation in the cooperative is as follows:

1. Full Membership entitles members to voting rights in the cooperative and, therefore, gives the opportunity to set priorities for research projects and other cooperative activities. Full members will automatically have representation on the Advisory Committee. Full members are also entitled to participate in the annual review of cooperative activities and receive all correspondence, study plans, and research results. Annual fee: public agencies, industry, and individuals - $250.

2. Contributing Membership entitles contributors to technical correspondence and research results. Contributors do not have voting rights concerning the activities of the cooperative. This membership is available to donors of field plot data records and sponsors of general or specific projects that are prohibited from paying dues by internal regulations.

The cooperative recognizes that its success will lie primarily with nonmonetary assistance from members and other cooperators, especially through their investments in field plot data collection, and the pooling of that information. Consequently, the funding support requested from members is nominal, sufficient only to cover administration and communication costs. In Minnesota, the LCMR support will furnish the first two years of project funding to cover the salary of a research specialist, travel, and data synthesis support. Beyond that the lead organizations are expected to continue to provide scientists and support staff in this general area to facilitate cooperative objectives. Staffing beyond the first two years of the cooperatives' initiation will be contingent upon scientific and technical support from member organizations and grants for specific projects obtained by the cooperative itself or cooperating scientists. The cooperative is intended to be self supporting, at least at a minimal level, due to continued interest in the subject matter.

DATA POOLING/SHARING RESPONSIBILITIES

Forest growth and yield plot data contributed to the cooperative will be maintained in confidence in computer-based storage. Upon request, members who contribute data may limit access to ownership and location information so as to maintain confidentiality of the source except for the forest type, site quality, and related stand and tree information. Contributors may also ask that their permission be obtained before data is released for specific projects. Data will be made available for studies approved by the advisory committee. The data will be maintained by the cooperative, though not necessarily at one location.

REPORTING

A primary benefit of cooperative membership will be access to the latest and best available information and models for growth and yield prediction. Cooperating scientists and their employing organizations will determine final publishing outlets. However, dues paying cooperators will be provided results in preprint format whenever possible.

PROJECTS

Specific projects currently underway or completed are:

1. Develop guidelines for the installation, maintenance, measurement and reporting of permanent plot records. A document, has already been written and distributed to the cooperative's members for their review (Walters and Ek, 1988). This document and refinements will serve as a basis to guide the data collection efforts of the members.
2. Identify gaps in existing permanent plot data and seek the establishment of plots to fill those gaps. During the 1988 field season, GLFGYC employees established 50 permanent growth plots at two locations in Minnesota. Both locations, the North Central Experiment Station in Grand Rapids, Minnesota, and the Cedar Creek Natural History Area near St. Paul, Minnesota, were selected because of their close proximity to weather stations. These plots should help researchers better

explore the relationship between forest growth and climatic changes.

3. Develop a research oriented data storage and retrieval system for forest growth and yield plot data. The membership has already been asked to respond to a questionnaire aimed at assessing the availability of member data sets. The results of this questionnaire have been placed into a computerized catalogue system for member use. This will be updated periodically.
4. Develop simple empirical yield models for major forest types of the region with emphasis on young stands and regeneration. A case study of this problem has been completed using forest industry inventory data from Wisconsin. The results are being expanded using the U.S.F.S. Forest Survey data in Minnesota in 1989 and a project has been proposed to do the same with the Wisconsin Forest Survey data.
5. Develop refinements to the STEMS and TWIGS forest growth modelling systems to a) make them more accurate locally (e.g., develop site-specific adjustments to the simulation models) and b) facilitate their use for a wide range of user data types.
6. Develop software to facilitate the linking of these growth and yield models to forest planning systems. The GLFGYC is involved in the development of a planning system to be used by state and county land management agencies in Minnesota. This project is scheduled for completion in mid-1989.
7. Develop models predicting aspen decay as a function of stand level attributes. Data collection for this project is currently underway and modelling will begin in late 1991.
8. Incorporation of simple yield/growth models into a G.I.S. This work is underway and should be complete in late 1991.

As these projects are completed, the cooperative will shift to other work as directed by the membership. New projects are encouraged, provided they fall within the context of the GLFGYC, and are approved by the membership. Questions concerning cooperative projects should be directed to: Administrator, Great Lakes Forest Growth and Yield Cooperative, Department of Forest Resources, College of Forestry, University of Minnesota, 110 Green Hall, 1530 N. Cleveland Avenue, St. Paul, MN 55108. Phone: 612/624-3400.

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THE EFFECT OF STAND DENSITY ON BLACK SPRUCE VOLUME

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ABSTRACT

Black spruce (*Picea mariana* [Mill.] B.S.P.)-dominated stands cover 84% (42,000 square kilometres) of the productive forest land in the Clay Belt region of northern Ontario. The aim of this study is to quantify the relationship between mean tree volume and stand density. It is part of an ongoing project to produce a growth model for black spruce on the Clay Belt.

The database was provided by the Spruce Falls Power and Paper Company Limited. To date 165 permanent sample plots have been classified into Operational Groups, using the Forest Ecosystem Classification developed by the Ontario Ministry of Natural Resources for the Clay Belt region.

Results from three Operational Groups (OG) are presented and represent a range of sites: OG 7, a mixedwood-herb rich site on fresh, fine loam-clay soil; OG 11, a ledum-dominated site on wet moderately decomposed organic soils; and OG 13, an alder-herb rich site on well-decomposed, wet, organic soils. The OG's differ also in terms of stand composition with mixed stands being the most common on OG 7, and spruce stands being most common on OG 11.

Height-dbh curves for black spruce were estimated by Operational Group, mode of origin, and treatment. The data for the other were limited and were combined across the Operational Groups. The Chapman-Richards function was used to estimate height.

Site-index curves were fitted to top height (average height of the 100 trees with the largest dbh per hectare) using the Weibull function.

Local volume tables were constructed by Operational Group, age, and dbh, using predicted heights and Honer's standard volume tables. Merchantability limits were set at 30 cm stump height and 8 cm top diameter, and only the trees greater than 2 cm dbh were considered. The plots were classified by spruce content, i.e. plots with more than 75% of the basal area composed of spruce stems were classified as 'spruce' plots, and the remainder classified as 'mixed' plots. Size-density relationships were plotted and a maximum size-density line estimated as well as quadratic mean dbh isolines.

The similarity in slope of the maximum size-density lines suggests that, although mechanisms limiting

black spruce growth may vary with Operational Group, the end result is similar across all Operational Groups. This implies that competition between trees for resources limits individual tree growth. The competitive effects of mixed stands in black spruce growth are less than that of pure spruce.

The flatness of the dbh isolines suggests that the effects of the density on volume may be summarized by the effect of density on dbh. However, the relationship between quadratic mean dbh and mean tree volume, although similar across the Operational Groups examined, changes significantly with the spruce content of the stands.

SEQUENTIAL SAMPLING FOR POINT-DENSITY ESTIMATION WITHIN SEEDLING POPULATIONS. II. EVALUATION.

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A sequential counting plan for estimating point-densities within mixed black spruce/balsam fir seedling populations was developed (Newton, P.F. 1989. Forest Ecology and Management 27: 295-308). The plan is based on the assumption that the estimated mean-variance relationship used to calibrate the sampling rule is equal to that observed within the populations to be sampled. Consequently, the stated precision levels specified in the plan will only be achieved when the variance-mean relationships are equivalent. However, due to the spatial pattern heterogeneity commonly observed within naturally regenerating seedling populations, the actual precision levels attained during sampling and those specified by the plan will differ. Hence, determining the degree of variability in the stated precision levels is an essential prerequisite to the operational implementation of the plan.

Therefore the objective of this study was to evaluate the performance of the plan when applied to actual seedling populations using computer-based sampling simulations. The data base consisted of count frequency data derived from 43 seedling populations situated on recently disturbed sites within central insular Newfoundland. The criteria used to evaluate the plan included sample size requirements and bias in sample estimates and precision levels. The method consisted of splitting the data into estimation and prediction data sets, calibrating the plan at each precision level (standard error of the mean/mean ratios of 0.175, 0.250 and 0.325) by quadrat size (4.0 m^2, 8.1 m^2, 10.1 m^2 and 12.1 m^2) using the estimation data set, and simulating the calibrated plan 100 times on each seedling population within the prediction data set. This procedure was repeated ten times yielding a total of 11000 simulations for each precision level-quadrat size combination. Results indicated that the number of samples required to reach a terminating decision exceeded 100 for (a) quadrat sizes 4.0 m^2, 8.1 m^2, 10.1 m^2 and 12.1 m^2 at a precision level of 0.175, (b) quadrat sizes 4.0 m^2 and 8.1 m^2 at a precision level of 0.250, and (c) quadrat size 4.0 m^2 at a precision level 0.325. Mean density estimates were over-estimated for all precision level-quadrat size combinations evaluated. However, the degree of over-estimation is within tolerable limits for most operational and research applications (e.g., less than -0.23 seedlings/quadrat). Similarly, actual precision levels attained during sampling were less precise than those specified in the plan. Consequently, stated precision levels should be increased when interpreting sample statistics. Furthermore, precision level bias increased with decreasing stocking and increasing spatial pattern heterogeneity, indicating that the plan should be used with caution when assessing seedling populations characterized by very low stocking or highly aggregated spatial patterns.

BLACK SPRUCE STAND DENSITY MANAGEMENT DIAGRAM

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ABSTRACT

Stand density management diagrams (SDMD's) are average stand-level models which graphically illustrate the relationship between yield, density and mortality at various stages of stand development. These diagrams are used in crop planning (e.g., deriving density control regimes for specific management objectives). A SDMD for black spruce was developed using data derived from 49 0.081-ha semi-permanent sample plots and 257 open-grown sample trees, located within natural stands, throughout central insular Newfoundland. The approach employed consisted of the following procedures: (i) determining the mean volume-density relationship and relative density index (ratio of the observed stand density to the maximum stand density attainable in a stand with the same mean volume) corresponding to (a) the asymptotic volume-density condition (-3/2 power law for self-thinning), (b) the lower limit of the zone of imminent competition-mortality (ZICM is the stage of stand development in which density-dependent mortality is likely to occur), and (c) approximate crown closure; (ii) calibrating the reciprocal equation of the competition-density (C-D) effect at specific stages of stand development using a two-stage regression modeling procedure; (iii) deriving quadratic mean diameter and merchantable volume/total volume ratio isolines empirically. Superimposing the reciprocal equation of the C-D effect, self-thinning rule, lower limit of the ZICM, approximate crown closure line, and isolines for relative density index, merchantable volume/total volume ratio and quadratic mean diameter, on a bivariate graph with mean volume on the ordinate axis and stand density on the abscissa, a SDMD was developed. The potential utility of the diagram in crop planning applications was demonstrated by evaluating commercial thinning alternatives within density-stressed stands. Limitations and further research directions were also identified.

"ONTWIGS" CALIBRATION

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ABSTRACT

"ONTWIGS" is an adaptation of the "LSTWIGS" growth and yield projection system developed for the Lake States. Because of similarities of growth conditions in the Lake States and Ontario, the "LSTWIGS" was modified for Ontario. This involved INPUT/OUTPUT metrification species codes and model coefficient substitution, where necessary.

Preliminary validation results with SPRUCE-FIR stands from Northern Ontario and RED PINE plantations from Ottawa Valley, indicate that, "ONTWIGS" model may be used as an adequate Growth and Yield Projection System for short to medium projection periods.

The data used to validate "ONTWIGS" so far consist of: 2 to 77 permanent sample plots(points)/species from Northern Ontario, and 2 red pine plots 0.2(ha(1/2 acre) plantation from Rockland, Ontario.

The SPRUCE-FIR plots were remeasured ONCE in five years; RED PINE plots were remeasured TEN TIMES during a 48-year period. One RED PINE plot was thinned in 1963, 1951 and 1956. Individual tree data were expanded to a per hectare basis as required by "ONTWIGS". Data from each plot were considered as a tree list. Ingrowth trees were added and thinned trees were removed from the tree list as indicated by remeasurement data.

The Stand Characteristics used for validation were:
Quadratic Mean Diameter - QDBH, as a tree growth estimator.
Number of Trees per Ha - TPH, as a measure of tree survival.
Basal Area per Ha - BAH, as a measure of overall system performance.

"ONTWIGS" overpredicted tree survival, QDBH, and BAH for the species examined ranging from 7.2% to 28.7%, 0.9% to 6.9% and 4.6% to 31.4%, respectively, over a five year projection period.
For the UNTHINNED Red Pine plantation "ONTWIGS", on average, overpredicted survival, QDBH, and BHA by 14.5%, 3.8%, and 20.3% for a five year projection period. However, for the entire 48 - year period, the model overpredicted survival by 18.9% and basal area by 13.2% but underpredicted QDBH by only 2.4%. Results for the thinned plantation were surprisingly accurate, where the model overpredicted

survival, QDBH and BAH by 0.7%, 2.5%, and 5.8% for a five year period. For the entire projection period the model performed extremely well for the thinned plantation by overpredicting survival and BAH by 3.1% and 1.5% respectively, and underpredicting QDBH by only 0.8%.

IT MAY BE CONCLUDED THAT, "ONTWIGS" CAN BE USED AS AN ADEQUATE SYSTEM FOR THE ONTARIO MIXEDWOOD TYPES FOR SHORT PROJECTION PERIODS AND FOR RED PINE PLANTATIONS AS LONG AS 30 TO 50 YEARS.

PLANT PC: SIMULATION OF ARTIFICIAL FOREST REGENERATION IN ONTARIO ON PERSONAL COMPUTERS

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Mike M. Punch
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ABSTRACT

The simulation model "PLANT PC" has been developed to aid forest managers in Ontario with their forest renewal problems.

The model treats the regeneration process as three separate, but interdependent phases of: 1) stock production, 2) storage, and 3) plant management. During each phase, growth and survival of seedlings are simulated according to empirical submodels reflecting the effects of various biological factors as well as management options.

Large data sets from several greenhouse/nursery operations and plantations established in northern Ontario were used to construct predictive models. Such regression models were derived by first identifying factors affecting stock production and plantation performance via stepwise regression procedures, and then developing nonlinear models expressing tree growth and survival as functions of time, management options, and silvicultural practices.

The model simulates various regeneration options according to the users choice. It compares and optimizes the results based on Regeneration Cost Effectiveness Index. RCEI in effect combines the cost of production with growth, survival, and the quality of the resulting "free-to-grow" stand.

The model has been calibrated for black spruce, white spruce, and jack pine plantations from northern Ontario.

The program is written in Turbo Pascal, and runs on IBM PC compatible computers.

FIDME-PC: FORESTRY INVESTMENT DECISIONS MADE EASY ON PERSONAL COMPUTERS

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ABSTRACT

Most forestry investments are long-term by nature and therefore subject to much risk and uncertainty. In the case of forest renewal investments in particular, it is essential that they be chosen from among the most promising alternatives possible. To evaluate and screen out investment alternatives with relative ease and greater precision, forest managers need a technique that not only enables them to predict the costs of production and rates of return but also indicates the likelihood of their being achieved.

FIDME-PC was developed to serve the above need. Up to four investment alternatives may be compared by using any one of the following four economic criteria: 1) cost effectiveness, 2) benefit:cost ratio, 3) present net worth, and 4) internal rate of return. The input estimates for the model may be expressed in the form of either point or subjective probability estimates. Simulated results indicate the probability that one investment might differ from others. In this way, the forest manager can choose, with a known degree of confidence, between investment alternatives.

FIDME-PC is written in Turbo PASCAL language, which may run on an IBM PC-compatible system. A diskette copy of the program listing input examples and an installation guide may be obtained from the authors.

A NEW POLYMORPHIC HEIGHT GROWTH MODEL FOR INVESTIGATING STRESS FACTORS

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ABSTRACT

A method for obtaining a biologically sound nonlinear, asymptotic, base-age, invariant, polymorphic height growth model was derived. The method regards that a tree follows a predetermined pattern of growth coded in the genes (genetic potential) and at the same time reacts to specific growth conditions. To approach the practically undefinable genetic potential the method based on modifying a generic growth pattern (assumed to be a monotonically increasing convex asymptotic function, called BASIC) was accepted. The asymptote (ASYM) in the model expresses in a complex way the influence of stress factors acting relatively consistently over a tree's lifespan (abiotic site quality). A modifying asymptote-dependent multiplier (HMF) of the generic pattern asymptotically approaches one when time $\rightarrow \infty$ ($0 < HMF \leq 1$).

The general form of the model is:

$$[1 + \tau * \ln(ASYM)]$$
$$REAL=BASIC*HMF$$

where REAL is the observed (measured) height. To predict future or past height (REAL2) at the desired AGE2 with help of the model, one has to know the height of the tree at a particular age.

The above approach provides a tool to obtain a highly flexible model of polymorphism controlled either by HMF, or ASYM, or both (in fact, both BASIC pattern as well as HMF is a user choice). A traditional site index can be obtained analytically from the above model, however it has the potential of describing two curves of different size indices but of the same asymptote (e.g., situation where we observe the same site quality but different history of other than site stress factors).

The approach was preliminarily tested with stem analysis data of jack pine (*Pinus banksiana* L.) in central Ontario, lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) in Alberta, and Norway spruce (*Picea abies* (L.) Karst.) in Germany. Algebraic ratio formulae were fit using nonlinear regression technique. In case of jack pine and lodgepole pone the above formula was fitted. In case of Norway spruce HMF was modified to describe height growth of trees of different biosocial status across the range of site quality.

MAPLE1: SUGAR MAPLE GROWTH MODEL

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ABSTRACT

MAPLE1 is a diameter distribution growth model designed for sugar maple (*Acer saccharum* Marsh.) stands. It presents results in imperial measure since hardwood lumber are still commonly measured and sold in inches and board feet.

From 1967 to 1978, 258 hardwood permanent growth sample plots (PSP's) were established in southern, central and eastern Ontario. They have been remeasured on an approximate 5 year cycle since establishment. In 1988, the Mensuration Unit of the Ontario Ministry of Natural Resources undertook an evaluation of these plots by compiling the plot data for construction of a growth model.

Forty-six plots yielding 159 measurements were selected and used in the construction of the model (OMNR, 1989). These 46 plots limit the scope of possible model conclusions by their location, ranges of age, density, quadratic mean diameter and dominant height. Table 1 lists the minimum and maximums of the data.

The Ontario Ministry of Natural Resources does not warrant this program's completeness, reliability, or suitability for any situations beyond the limits of the data set used in its' construction. Projections with MAPLE1 should not exceed 20 years into the future as anything greater than that is beyond the range of the data. Sample size for stands being projected with MAPLE1 should not be less than 1/10 acre in size.

GROWTH AND YIELD/STAND DYNAMICS IN THE NORTHEAST REGION

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Timmins District

ABSTRACT

The Northern Forest Development Group has initiated a Growth and Yield program for the Northeast Region of the Ontario Ministry of Natural Resources. The program is intended to address immediate client needs by providing information and tools on forest growth, yield and stand development. This information is the key to reducing uncertainty for wood supply, habitat supply, and silviculture investment decision making functions.

Our clients have identified these areas as requiring immediate attention:

- Modelling -Yield Curves
  -Growth Models
  -Wood Supply
- Inventory -Large Scale Photography
  -Ground Sampling
- Habitat -Stand Structure
  -Snags
  -Browse

Our program uses strategies identified in the Provincial Growth and Yield Program of temporary sample plots, chronosequencing, and exploitation of existing data sets to generate interim information while a permanent sample plot network is being established. This information includes volume equations, inventory, yield curves and habitat descriptions. The structure of the program and the products delivered to date are presented.

A VARIABLE-FORM TAPER FUNCTION

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ABSTRACT

The topic of stem form and taper has been studied for over a century and is still of high priority in forest research for perhaps two reasons. First, no single theory has been developed that can explain how stems may vary in form, both within and among trees. Thus it has not been possible to construct a satisfactory taper function that would be uniformly acceptable over a wide range of conditions. Second, and more important from a practical point of view, a taper function that can accurately predict the diameter at any point on the stem from one or two readily measured variables, is essential for estimating the volume of standing trees and for constructing volume tables to different merchantable limits.

The taper function described here is relatively simple. The stem is considered to be a solid with a form that varies continuously from the stump to the tip. An allowance is also made for the effect on form of live crown ratio. The model has been tested on data from a red pine spacing experiment at the Petawawa National Forestry Institute and found to give accurate and unbiased estimates of stem diameter and volume.

AUXASIA

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ABSTRACT

Growth models in general are under-utilized in forestry practice due, partially, to limited comprehension of their operation with a corresponding lack of confidence in their performance. Software has been developed that enables presentation of a tree growth model in such a manner that an understanding of the model's usage and workings are within reach of other than solely forestry biometricians. The standard interface is a pair of two- or three-dimensional views depicting the state of a forest stand at any given point in time. Users can dynamically manipulate the vantage point of a view thereby establishing a "walk through the stand." Multiple growth simulation runs for an individual stand or an individual run for multiple stands can be easily compared using growth animation or more standard mensurational displays. Options can be selected for interpreting why growth is projected as it is; for example, overlap of trees' zones of influence can be depicted upon request. Numerous alternatives exist for generating stands of a specified physical structure/composition or spatial pattern. Users can employ everything from total to no control over stand specification/projection. The software is an example of the power and possibilities of an object oriented programming approach.

IBM STEM ANALYSIS MEASUREMENT SYSTEM

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ABSTRACT

A stem analysis data capture and analysis program was developed in the early 1980's by the OMNR for use with Apple IIe microcomputers. In response to user requests, a new data capture and analysis system was developed so stem analysis could be carried out on IBM compatibles, and easily linked to other growth and yield data sets. The new system runs on Lotus 123, is menu-driven and user-friendly, with built-in error checking and correction facilities. The system captures individual tree ring data, analyses and tabularly or graphically presents the captured data, and allows for the aggregation and overlay of individual tree data on a plot basis. A demonstration of the system will be presented.

DEMONSTRATION OF QUICK-SILVER, VERSION 4.0

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ABSTRACT

Quick-Silver version 4.0 is a major revision of the original Quick-Silver program released in 1984. The program is a flexible economic analysis tool for evaluation of forestry investments. It calculates common measures of financial performance using standard cash flow analysis procedures. Quick-Silver 4.0 also provides more effective analysis and output options such as a much improved batch processor (call the Stack Loader) for analyzing groups of cases and summary files of cash flows and selected financial results. A new option analyzes the sensitivity of investment performance to costs and price assumptions.

DEMONSTRATION OF TIMRET

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ABSTRACT

A micro-computer software package, TIMRET was developed to aid the forest manager in evaluating profitability of silvicultural investments, be it spacing, thinning, release, fertilization or tree improvement effects. It uses four financial criteria: 1) internal rate of return, 2) present net worth, 3) profitability index and 4) benefit/cost ratio. The returns are based on treatment costs, and on benefits such as increased harvest yield, log size premiums and logging cost reductions. Examples of use are given, and a program diskette is available on request.

INVESTIGATING THE RELIABILITY OF THE HEDONIC TRAVEL COST MODEL

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ABSTRACT

Natural resource managers are required to make decisions that imply particular values about both price and un-priced goods and services. Economists have developed a number of approaches for estimating non-market values -- contingent valuation surveys, the travel cost method and hedonic pricing. The issue of the reliability of these estimates is becoming more important as the results are used for decision making. An approach for investigating the reliability of a hedonic travel cost model is illustrated using Monte Carlo simulation techniques.

OPTIMAL THINNING AND FINAL HARVEST DECISIONS: IS THERE A ROLE FOR STOCHASTIC DYNAMIC PROGRAMMING?

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ABSTRACT

A method is presented for determining optimal economic strategies for density management in loblolly pine stands in the southern United States. A stochastic dynamic programming model employs a price state transition matrix constructed using time-series data for National Forest pine stumpage in the South. The model also incorporates WTHIN, a pine growth and yield simulator widely used in the South to support economic analyses of stand management alternatives. Results indicate that at current average prices for pulpwood and on average sites, optimal planting density decisions recommended by the stochastic model are very similar to those obtained with a deterministic price equivalent. However, optimal net present values for the stochastic model are higher due to differences in the thinning and final harvest decisions recommended by the two models.

FIRE DAMAGE APPRAISAL SYSTEM (FDAS)

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ABSTRACT

The Fire Damage Appraisal System (FDAS) is an operational tool for conducting post-fire damage studies and generating useful summary reports. FDAS consists of three major system functions : a data-base management system, net value change modules, and a report generator. FDAS operates on IBMPC - compatible microcomputers using integrated, menu-driven screen displays, prompts and visual keys.

FDAS measures the actual or potential economic impacts of wildfire at the stand level. The system considers an array of assets including mature timber, immature timber, wildlife carrying capacity, recreation values, and capital assets. The system accommodates five levels of fire intensity, multiple timber products, conversions returns reflecting specific stand attributes, and other factors related to salvageability of burned areas.

Potential applications for FDAS include post fire damage appraisal, salvage planning, pre-fire priority mapping. In addition FDAS is ideally suited for integration with decision support systems. For example FDAS could be combined with a GIS system for simplifying data entry and providing visual displays of post-fire economic effects.

III

BUSINESS MEETING(S)

FORESTRY CANADA MODELING WORKING GROUP-BUSINESS SESSION

Minutes of meeting

by

J. Richardson

Present: B. Payandeh (chair), H. Grewal, M.F. Ker, G.M. Bonnor, M.B. Lavigne, P.F. Newton, I.E. Bella, C.H. Ung, M. Penner, P. Papadopol, G. Larocque, R.M. Newnham and J. Richardson

• National Growth and Yield Modeling Proposal.

Mike Bonnor reviewed the process whereby the proposal had been developed. It had originally been suggested as a possible project for the Working Group at the group's last meeting in Kananaskis in December 1990. A general questionnaire circulated thereafter had elicited positive responses. As a result, a small committee met June 14 to plan further strategy. This included a second, more specific questionnaire, which was circulated to the Working Group; this also drew favourable responses from all FC centres, as well as some ideas of how individual researchers might contribute to the project.

Bonnor felt it was now necessary to initiate the modeling process, but a number of questions remained to be answered. What exactly would be modelled? What would the model look like? Who would coordinate the project? Who would do what specifically within the project framework? Lengthy discussion ensued on these questions.

There was general agreement that the basic objective of the project is to develop a framework for a growth projection system which could be used by all. It was recognized that this framework would still have to be modified or adapted to specific regional needs. It is intended as a national framework rather than a national model.

Considerable discussion ensued on whether the aim should be management planning, or whether projections for silviculturally treated stands should be included, as well as crop planning and the development of prescriptions. No conclusion was reached on this topic.

Discussion also centred on potential input data for modeling. These might be good quality provincial inventory data - field data from permanent or temporary sample plots, supplemented by remotely sensed data from air photos or satellites. Alternatively, good basic yield tables might be used as the starting point.

It was agreed that the basic modular framework as outlined by Bonnor would be used, but that this was still very general and needed further elaboration. Bonnor agreed to accept the role of coordinator of the project and to prepare an elaborated model framework which would be circulated to the Working Group for comment and input. Bonnor said he would consult with others in this process. It was felt that it might be necessary to contract the services of a facilitator to help the group reach decisions on the form and future direction of the national modeling project. This might be possible with help from HQ Working Groups' budget. Jim Richardson agreed to continue to keep the Canadian Forest Inventory Committee up to date on the project development.

• Electronic Bulletin Board.

The most recent questionnaire sent out in relation to the national growth and yield modeling project had included a question about whether an electronic bulletin board should be set up for FC growth and yield modellers. There had been almost universally positive response to this question, and this was also the feeling of those present at the meeting. A bulletin board had been tried in the early years of the Modeling Working Group but had not met with success at that time, due to lack of participation. However, it was thought that with the improvement in electronic communication since then within FC, and a more focused topic ('growth and yield', rather than just 'modeling'), such a project might meet with more success this time.

Margaret Penner agreed to set up the electronic bulletin board and to send out instructions for participants. She also agreed to act as the clearing house for information, at least for the first two months of its operation.

• Quebec Presentation.

Chun-Huor Ung presented a paper entitled 'Needs for Research and Development in Growth and Yield in Quebec'. He discussed his research proposal as summarized bellow (for more detailssee Ung's article in the poster session):

One of the chief present problems in growth and yield in Quebec is that the available growth models are not suitable for management. Most Quebec yield studies are in natural unmanaged stands. Another major problem is that the Quebec forest inventory is at the provincial level, but information is needed at the regional level. The needs include inventory, yield estimations, ecological information, information on disturbances, and on many other areas.

Methods recommended to obtain some of the needed information include the use of both permanent and temporary sample plots. PSP's should involve intensive data handling; they should be established using a stratified sampling scheme; they could be established in silvicultural experiments. Temporary sample plots would involve intensive data handling until the number of plots per stratum is increased; they would generally improve the quality of the database.

Growth and yield modeling should deal with the juvenile and adult stages of stand development separately. At the juvenile stage, there should be more experiments involving spacing and thinning. Growth modeling at the adult stage would be concerned with tactical planning and the development of yield tables for use in strategic planning.

The route to take should be, in the short term, to develop tree models and more, provisional yield tables. In the long term, what is needed are variable-silviculture yield tables, developed from data gathered from new plots. A user-oriented ecological site catalogue is required for silvicultural planning.

In the field of insect damage and the decline of old stands, entomological and pathological information should be included in the inventory. The impact of spruce budworm damage should be investigated. Natural stand decline should be studied.

Priorities for research and development in the area of growth and yield in Quebec include: 1) a forestry database system, 2) development of efficient sampling methods, 3) better user access to the database, 4) tree and stand models at the regional level. A research and development consortium in growth and yield is proposed in the boreal, mixed and southern forests. This would involve all agencies in sharing information. Data needed especially are from experimental silvicultural plots. Such plots need to be on a regional basis, but coordinated through a strong central organization.

Inventory by sampling is proposed, in order to improve yield prediction in the boreal forest. This would be optimized sampling, with an optimized procedure for plot establishment. Inventories have different objectives, which might include determining the current state of stands, estimating the impact of silvicultural treatments, or predicting the future state of the forest. It is assumed that the plot form does not affect the accuracy of the sampling. Above a certain minimum level, the individual plot area is not important. Efficiency increases with the number of plots.

Modeling growth in the boreal forest requires yield tables at the regional level, and tree growth models of the impacts of modern silvicultural methods. Present yield tables cannot provide this type of information. They do not include mixed stands, or the effects of 'new silviculture', and they are not available at the regional level.

Methods for producing this information will include the development of yield tables for three Quebec regions. Stem analysis will provide new height growth information and better site information. Tree models should be developed for the same three regions. Finally there should be better use of the presently available data.

• Election of Chair

Mike Bonnor accepted the nomination by Payandeh, seconded by Newnham, to serve as chair of the Working Group for the next term. The nomination was endorsed by all present, and will become effective January 1, 1992.

• Next Meeting

It was agreed to hold the next meeting of the Working Group in Quebec during the winter of 1992-93. Huor Ung agreed to organize the meeting, including inviting other speakers. He thought that simultaneous translation would be beneficial. Guy Larocque offered to help with the organization in any way necessary.

SUMMARY UPDATE OF MODELING ACTIVITIES FOR ONTARIO REGION
by
Bijan Payandeh

Entomology:

Members of the entomology modeling group consisting of Don Wallace, Vane Nears and Barry Lyons are continuing their work in entomological modeling as reported last year with minor changes. Jens Roland was the successful candidate for the insect population dynamics position vacated by Tim Lysyk about two years ago. Jen joined us recently from the Northern Region, Forestry Canada and is mainly interested in studying population dynamics of saw flies mainly via application of GIS. Much of the work of the group, however, remains pretty much the same as reported in the last meeting.

Forest Fire:

Tim Lynham has been involved in a joint effort with Dave Martell of University of Toronto regarding a national database of experimental fires and reports that: Canadian forest fire researchers have collected over a million observations on weather, fuel moisture and fire behaviour related to a massive test-fire program that was conducted from 1931 to 1961. Approximately 20,000 test fires were conducted at 11 field stations. across Canada. In 1960 a project began to transfer the original field notes to computer files so that the data could be analyzed on mainframe computers. Late in 1989, PNFI provided a tape copy of the above information at GLFC and the initial work began in preparing a national database on such information. The objectives were:

- bring together all the 1931-1961 test fire data,
- fill in missing data,
- merge the fire and weather data,
- calculate and add the current fire weather indices from the CFFDRS, and
- re-archive the 9-track tapes.

Lynahm and Matrell have analyzed the database and concluded that although many comparisons between fire behaviour and fire weather indices have been carried on small experimental data sets and on some wildfires, we do not have another data set of this magnitude that addresses the spatial nature of fire occurrences in Canada. Another significant advantage of these data is that all 20,000 test fires can be associated with weather observations taken at nearby weather stations. Therefore these data are well suited to answer some questions about fire behavior based on reliable, observed weather.

Silviculture:

● Art Groot reports that he is currently developing a numerical model to investigate aspects of the forest clearcuts environment. The model comprises a solution the one dimensional transfer equations describing the transfer of heat and water in the air and soil near the surface. The model is applicable to flat, unvegetated, horizontally-homogeneous forest clearcuts. The model has been validated on three forest clearcuts Bias in predicted soil temperatures was less than 1 C on all three sites. Air temperature, water vapour pressure and saturation deficits at 20 cm height were predicted with small bias on two of the validation sites; on the third site bias was larger, possibly because of heterogeneity of the surface. soil water content predictions were sensitive to soil hydraulic conductivity. The model is useful for examining the effects of boundary, surface and soil conditions on the seedling physical environment.

● Rob Fleming's current modeling initiatives are centred on two areas 1) plant water relations and 2) black spruce seedling establishment following direct seeding. The plant water relation work involves the development of a phenomenological model relating seedling stomatal conductance to environmental variables such as solar irradiance, air and soil temperature, soil moisture and atmospheric humidity. The approach taken is to solve a multiplicative model using nonlinear regression techniques and subsequently employ modeled outputs to estimate daily and seasonal transpiration rates. The work on black spruce seedling establishment is now focused on selecting appropriate probability density functions relating seedling establishment ratios to stocking levels for spot seeding. Further developments will involve using modifying and/or creating appropriate stochastic models to predict stocking and density following aerial seeding as a function of site type, seedbed, seedling rate and climate. These studies are currently being undertaken. No publications relevant to these topics have been produced as yet.

● Growth and Yield and Regeneration: Calibration of the "ONTWIGS" model continued on both peatland and upland black spruce, white spruce, jack pine, balsam fir poplar, white and yellow birch from northern Ontario Mixedwood types and also with thinned and control plot of red pine plantation from the Ottawa valley. Results of the „ an economic feasibility of forest drainage fertilization and/or thinning will be conducted as a "wrap up" work on this study by next year. Although Mike Punch, COFRDA contractor on "PLANTPC" left suddenly to take a position with Ontario Lottery Corporation, considerable progress has been made in finalizing the model and completing its users manual."FIDMEPC" has been modified somewhat to allow for input file editing and manipulation. It will be used for the final economic analysis for the growth and yield study wrap up and yield study. Following restructuring of two research projects: Black Spruce and Reforestation Silviculture, proposals for developing forest management advisory systems for major forest types in Ontario are underway. In addition about ten new proposals related to various aspects of growth and yield, forest management advisory systems, climate change, decision support system, etc. were prepared for the various Green Plan Project initiatives. So far little if any progress has been made toward undertaking any of them.The basically summarizes Modeling activities at Ontario Region during last year. I have noted a number of related publications and reports in my summary.

Related Publications

Nealis, V. G. 1990. Jack pine budworm populations and staminate flowers. Can. J. For. Res. 20: 1253-1255.

Payandeh, B. 1990. Equations describing attributes of major tree species in north central Ontario. For. Ecol. Manage. 36: 245-252.

Payandeh, B. D. Basham and R. A. Haig. 1991. Forestry Investment Decisions Made Easy on Personal Computers (FIDMEPC). Frontline Forestry Research Applications, FCOR, Tech. Note 3.

Payandeh, B. and R. A. Haig. 1991 A management-oriented model for assessing early stand establishment. Frontline Forestry Research Applications, FCOR, Tech. Note 5.

Payandeh, B. 1991. Development of a model for planting stock production evaluation in Ontario. New Forests. 4:309-317.

Payandeh, B. Plonski's yield tables (metric) formulated. The Forest. Chon. (67(5)545-546).

Payandeh, B. Composite site productivity functions for northern Ontario black spruce. New Forests. In Press.

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SUMMARY UPDATE OF MODELING ACTIVITIES FOR FOREST PEST MANAGEMENT INSTITUTE

by

Rich A. Fleming

The Forest Pest Management Institute (FPMI) is one of Forestry Canada's two national research institutes. FPMI provides national leadership and capability in the development of new or improved pest management products and strategies for their use. Environmental quality and public health and safety are major considerations in this endeavour. The Institute's program is broad and complex and involves a wide range of discipline specialists.

The Biological Systems Analysis project (FP-23) conducts most of the modeling work at FPMI. The project also cooperates with scientists from other Forestry Canada establishments and with scientists outside Forestry Canada on a national and international basis. Systems analysis techniques are developed and applied to the design, conduct, interpretation, and synthesis of a broad range of experiments that cut broadly across FPMI's research program. In particular, expertise in experimental design, statistics, and modeling is provided in many studies related to the effectiveness and environmental impact of pest control materials and methods. In this way the project tries to develop important information and interpret results in a form promoting application. Through modeling, FP-23 also promotes an integrated approach to pest management by helping to develop ecologically sound and cost-effective strategies for combining the use of new pest control products with those currently in use. Thus FP-23 has a major role to play in bringing potentially new options for forest pest management into operational use.

The main thrusts in modeling at FPMI in 1990-91 fell in four main areas:

- **Environmental Impact Interlab comparison of songbird ChE data.** Studies of the association between aerial applications of Zectran and cholinesterase levels in songbird brains and of the consistency of results between two labs.

- **Climate change.**
A mathematical analysis of the potential influence of age structure and sudden climatic shifts on the dynamics of forest-pest systems in simple dynamical models. (2) During a development leave, learned some statistical techniques for studying pest phenology-climate relationships. These techniques are being applied in a statistical analysis of long term climate-pest phenology interactions.

- **IPM / Decision Support** using FIDS-type survey data to test large scale spruce budworm-forest simulation models which were developed as decision support tools for forest management.

B.t. respray decisions. Recently some operational sprays of B.t. have had inconsistent effects. This study aims at determining whether appropriate decisions about applying a second B.t. application (for greater consistency) could be based on field measurements of the B.t. dose ingested by spruce budworm larval populations 48 hr after the initial spray.

- Pest Damage Thresholds and Assessment Jack pine cone crops. Development of sampling plans for monitoring damage and estimating crop size. Study to determine the impact of spruce budworm defoliation on subsequent balsam fir foliage and wood production. One objective of this work is to develop damage thresholds for budworm defoliation of balsam fir. As a first step, period and cohort models of needlefall in spaced, protected stands are under development.

- Pest Control Vegetation management. Study to develop improved-use strategies for glyphosate.

Related Publications

Fleming, R.A., P. de Groot, A. Obarymskyj, and T. Burns. 1990. Devising sampling methods for inventory of receptive seed cones of jack pine. Can. J. For. Res. 20: 1704-1713.

Antonovsky, M.Y., R.A. Fleming, Y.A. Kuznetsov, and W.C. Clark. 1990. Forest-pest interaction dynamics: the simplest mathematical models. Theor. Popul. Biol. 37: 343-367.

Fleming, R.A. 1990. Population dynamics of the eastern spruce budworm: inferences and model performance examination using survey data. Pages 381-392 in A.D. Watt, S.R. Leather, N.A.C.Kidd, and M. Hunter (eds.), Population Dynamics of Forest Insects. Intercept, Andover, U.K.

Payne, N.J., B.V. Helson, K.M.S. Sundarum, and R.A. Fleming. 1989. Estimating buffer zone widths for pesticide applications (abstr). Page 51 in G.K.M. Smith and D. Bates (eds.), Forest Research Marketplace, OFRC Symposium Proc. O-P-18. Forestry Canada, Ontario Region. Sault Ste. Marie, ON. 151p.

SUMMARY UPDATE OF MODELING ACTIVITIES FOR PACIFIC AND YUKON FORESTRY REGION

by

Mike Bonnor

Mike Bonnor:

● Continuing the development of the w. hemlock growth model: data acquisition and cleanup were completed; data summaries were completed and the data bases (stand, tree and tree percentiles) were created; terminology was established; model architecture was approved and described in a report; initial component equations were identified, and testing was initiated by fitting the data to the equations and calculating coefficients.

Al Thomson:

● Developing a prototype expert system for diagnosis of forest seedling nursery problems.

● Modeling of seed orchard and nursery practices in relation to genetic diversity and genetic gain.

● Completing a variable-density lodgepole pine growth and yield system, including mountain pine beetle effects, for use on PC's.

● Completing a forest-level mountain pine beetle spread and impact model for use by BCMF.

Hugh Barclay:

● Modeling pheromone trapping for male annihilation in combination with various other pest control methods to determine possible synergistic control combinations.

● Cleaning up the mountain pine beetle model and doing a sensitivity analysis on the effects of two sources of mortality.

Eugene Hetherington:

Has finally obtained a UNIX version of the HSPF (Hydrologic Simulation Program Fortran) model that works on the DEC workstation. Objective is to develop a calibrated version of the model using Carnation Creek data. Is currently working on preparing the Carnation Creek data for use with the model. This massive undertaking includes getting data off charts and estimating missing values for a number of climatic parameters. Hopes by this time next year to have the calibrated model ready for use.

SOME OF RECENT MODELING ACTIVITIES AT PETAWAWA NATIONAL FORESTRY INSTITUTE

A) Marg Penner

The main projects involving growth and yield modeling that I am involved with are the Spruce Falls Power and Paper Co. (SFPP) project with the OMNR and a proposal to be involved in the ForCan Boreal transect.

The SFPP project is looking at the stand development of black spruce in the Ontario claybelt and the influence of site. The forest ecosystem classification (FEC) system for the claybelt region 3e is used to stratify the SFPP permanent sample plots (PSP's). The most important influence that site has on these forests is through species composition and in timing of breakup. This project is funded mainly by the northern TDU with support from SFPP and NSERC.The boreal transect study is still in the proposal stage and is part of the greenplan climate change initiative. Work will be concentrated on a transect running from Prince Albert, Sask. to Nelson House, MB and look at the forests along this climatic gradient from moisture stress in the south to temperature stress in the north. I am particularly interested in the above-ground production and hope to link up with Mike Lavigne from Newfoundland to develop a physiological model linked to climate variables.

B) Monty Newnham

- Project PI-19 - Forest Management Modeling

Since December meeting of the Working Group, progress on LOGPLAN has gone more or less as projected. A recent graduate of the school of Computer Science at Carleton University was hired on contract to develop a user-friendly input interface for the model using the Object Oriented Programming System, Smalltalk. Using a window/menu based system the flowchart of the logging operations can now be constructed on the terminal screen. Data for each store are entered by "double-clicking" on the store icon and then entering values on the menu that appears. Data for each activity are loaded from previously created machine "libraries". Modifications can be easily made at any time to the flowchart or any of the data. The project is initiating the process of hiring a Smalltalk programmer to continue this work and other applications of Smalltalk in forest management planning.

Within the next year the project expects to have on staff an experienced wildlife scientist. This will improve our ability to integrate wildlife requirements into our planning models.

SUMMARY UPDATE OF MODELING ACTIVITIES FOR NORTHWEST REGION
by
H. Grewal

M.J. Apps is involved in modeling the role of northern forests and forestry in the global carbon cycle in a changing climate. This is being undertaken within a quantitative modeling framework - the CBM-CFS (Carbon Budget Model of the Canadian Forest Sector) which has been developed in partnership with ESSA Ltd.

H. Grewal, T. Varem, and R. Mair are working on ecosystem-based dynamic gap models. LINKAGES, ZELIG, and other models are being examined for possible adaptation to suit regional requirements and needs. H. Grewal is also involved in the FORCYTE-11 model project. A model evaluation workshop is being planned for next year.

K. Charter, visiting scientist D. Price, staff members to be hired, and NeFC's M. Lavigne are working on ecophysiological response models. PFC's T.Trofymow and NeFC's B. Titus and others are working on the development of soils sub-models. S. Zoltai and several external contributors) are working on a peatland sub-model.

The climate change group collectively is involved in a major modeling development and verification effort which will be associated with the BOREAS international project. FC's Boreal Forest Transect Case study (involving participants from NeFC, PNFI, GLFC, NoFC and PFC) will link to the BOREAS project and be used both to develop and verify productivity models and their incorporation in a regionalized version of the Carbon Budget Model for the Boreal Forest Transect (CBM-BFT). Scoping back up to the national scale (and possibly international scale) both within the CBM-CFS (for what-if scenario analysis) and within the interdisciplinary, interagency Northern Biome Observation and Modeling Experiment NBIOME (for monitoring and linkages with national scale data collection systems through remote sensing, gas flux surveys, etc.).

The fire management systems group at the Northern Forestry Centre has continued the development of the Intelligent Fire Management Information System (IFMIS). IFMIS is a PC based decision support system that models the current fire danger in the forest and aids the protection officer in efficiently placing fire suppression resources. The latest enhancement is the optimizer - a linear programming tool used to optimally place resources to maximize coverage while minimizing costs. IFMIS and the optimizer are being used operationally in Alberta, Saskatchewan, and Manitoba while other agencies are evaluating IFMIS and considering incorporating it into their operations.

"D.L. Booth and Mark Messmer have been workingon National Wood Supply Study Phase II: An Empirical Analysis of Regional Industrial Wood Supply and Demand" and state that:

Over the last year, a simulation model originally ,developed by Dr. Doug Williams(Cortex Consultants, Inc.) known as the Price Responsive Timber Supply Model(PRTSM) has been developed to produce supply curves for industrial roundwood for six regions in Canada, namely the B.C. Coast, B.C. Interior, Prairies, Ontario, Quebec, and Atlantic.

The PRTSM simulates over time, the responses of industrial wood supply to a variety of cost, value, and regional policy variables. PRTSM can be "linked" with final product demands, to produce an overall supply-demand balance over time.

Currently we are using PRTSM to analyze the B.C. Coast, B.C. Interior and Atlantic regions. Initial results from base runs with PRTSM in the two B.C. regions will be complete later this year. For the Atlantic region, we have produced an "economic stock picture" which is simply a total dollar value of the existing industrial wood inventory based on delivered wood costs. We are also implementing a new version (version 6) of the model for the Atlantic provinces of the analyses.

Over the next year the study will begin producing results from the use of PRTSM. We hope to publish the results from the B.C. and Atlantic regions some time this year, and possibly begin discussions with the prairie provinces for analysis of their region.

R. Yang and A. Chow are developing a Microsoft Windows-based aspen growth and yield model for the prairie provinces using object-oriented programming approach. This model will be a growth component of our aspen DSS.

C. Cieszewski is working on a new lodgepole pine height-density model based on the Czarnowski's stand dynamics theory.

T. Singh (Risk Modeling and Climate Change Modeling) and B. Swanson (Hydrology modeling) have retired this summer.

SUMMARY UPDATE OF MODELING ACTIVITIES FOR QUEBEC REGION

(See Ung's article in the Poster Section and refer to J.Richardson's minutes of Business Meeting)

SUMMARY UPDATE OF MODELING ACTIVITIES UPDATE FOR MARITIMES REGION

by

Mike Ker

Dave MacLean continues modeling the impact of the spruce budworm, in cooperation with provincial foresters and researchers at the University of Moncton at Edmunston. Merv Morgan is evaluating the effects of spacing on conifers in several Nova Scotia spacing studies, and also the combined effects of fertilizationand thinning on young hardwoods in New Brunswick. Tom Royama recently finished writing a book on theoretical population dinamics. Mark Messmer and Darcie Booth, an economist at ForCan HQ, are working on a national wood supply study, using a modified version of the price Responsive Timber Supply Model which was originally developed by Dr. Doug Williams of Cortex Consultants, Inc. Mike Ker recently published a set of polimor.

SUMMARY UPDATE OF MODELING ACTIVITIES FOR NEWFOUNLAND AND LABRADOR REGION

by

Mike Lavigne

Report on Modeling Activities in Newfoundland Region

- An interagency group has formed to give direction and impetus to growth and yield activities in Newfoundland. This group is very interested in yield models and wood supply modeling. Efforts have begun to improve yield predictions in managed stands, and predictions of the developments in overmature stands. Existing permanent sample plot programs are being reviewed and the results of this review will be used to coordinate and improve these activities.

- Peter Newton is engaged in extensive yield modeling activities as part of his doctoral work at U.B.C. This work includes application of principles of growth analysis and the self-thinning rule to yield predictions of black spruce stands.

- A model of the population dynamics of pine martin developed by Ian Thompson is being used by the wildlife management agency in New Brunswick.

- Modeling activities for integrated resource management were initiated this year with Green Plan funds.

- A paper discussing the use of process models for predicting stand development of mixed stands is in press.

- Researchers from this Region have become involved in the BOREAS Project which will include modeling of soil processes and tree growth to assess possible impacts of climate change.

MINUTES - GLFGYC Business Meeting

D. Walters

● Review of Key Accomplishments in Last Year

▸ Co-sponsored meeting in Sault Ste. Marie with Midwest Mensurationist Group.

▸ Growth Implementation Package (GIP) improved and prepared a paper describing the system which is to be published in the FORS Compiler. A second paper describing the model development is in preparation.

▸ A request for proposals was submitted to members. The decision to fund/not fund proposals will be made by general membership (see new motions below).

▸ An organizational meeting of the Minnesota subgroup was held and a plan for this subgroup was organized.

▸ Several projects have been funded by external organizations. At least partial success in obtaining funding for these projects can be attributed to the judicious use of the Coop's goals, data sources, and membership as justification for the importance of the projects.

● New Business

▸ It was proposed that a general membership meeting be held in Duluth, Minnesota sometime in early 1992. Topics could include: Minnesota GEIS, PRO-WEST/HLFGYC project implementing GIP into GIS, Annual Forest Inventory System being proposed by NCFIA and the Minnesota DNR, and possibility of an Ontario subgroup, presentations on various aspects of forest growth modeling similar to the overview sessions at the Tools to Take Home Workshop, Business items (budget/etc.).

▸ The terms of office expire for 6 of the Coop's elected officials: Alan Ek(Administrators), Tom Burk (Research Chair), Dave Heinzen (Advisory Committee), Don Perala (Advisory Committee). The GLFGYC would like to thank all of these members for their active participation and involvement.

▸ Nominations for filling these positions were taken and a ballot will be sent to the general membership.

● Three proposals under consideration for funding by GLFGYC were:

DEVELOPMENT OF A BIBLIOGRAPHY OF GROWTH AND YIELD MODELS.
Submitted by Dave Walters, University of Minnesota.

USING ARTIFICIAL NEURAL NETWORKS TO DEVELOP INDIVIDUAL TREE MORTALITY COMPONENT FOR TWIGS.
Submitted by George Gertner, University of Illinois.

SYNTHESIS OF WHITE PINE GROWTH AND YIELD INFORMATION.
Submitted by Don Perala (USFS-NCFES) and Dave Walters (University of Minnesota).

The advisory committee recommended funding these proposals with the minor changes. A motion was made and passed to allow the membership to vote by mail to fund/not fund these proposals.
A ballot will be sent out later in 1991 to decide on funding of proposals, elect new officials, and select a good date for the 1992 meeting.
Meeting was adjourned.

MIDWESTERN FOREST MENSURATIONISTS GROUP

B. Payandeh

The only business related item discussed for the above group was that of location and timing of the next year's meeting. John Moser volunteered to organize the next annual meeting which will coincide with the 25 anniversary of the establishment of the group. He suggested an early summer meeting at Grand Hotel, Mackinac Island, Michigan, with as many of the pioneer members present as possible. John's proposal was graciously approved by the membership. John has already contacted the hotel and invited several of the original members such as Ken Ware and Bruce Bare and others to attend.

Harry Wiant volunteered to organize the 1993 meeting in Williamsburrg, Virginia. His proposal will perhaps be confirmed during the next meeting in Mackinac Island.

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