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# Production of regional biomass yield tables for Canada: a feasibility study

H.W.F. Bunce and G.M. Bonnor

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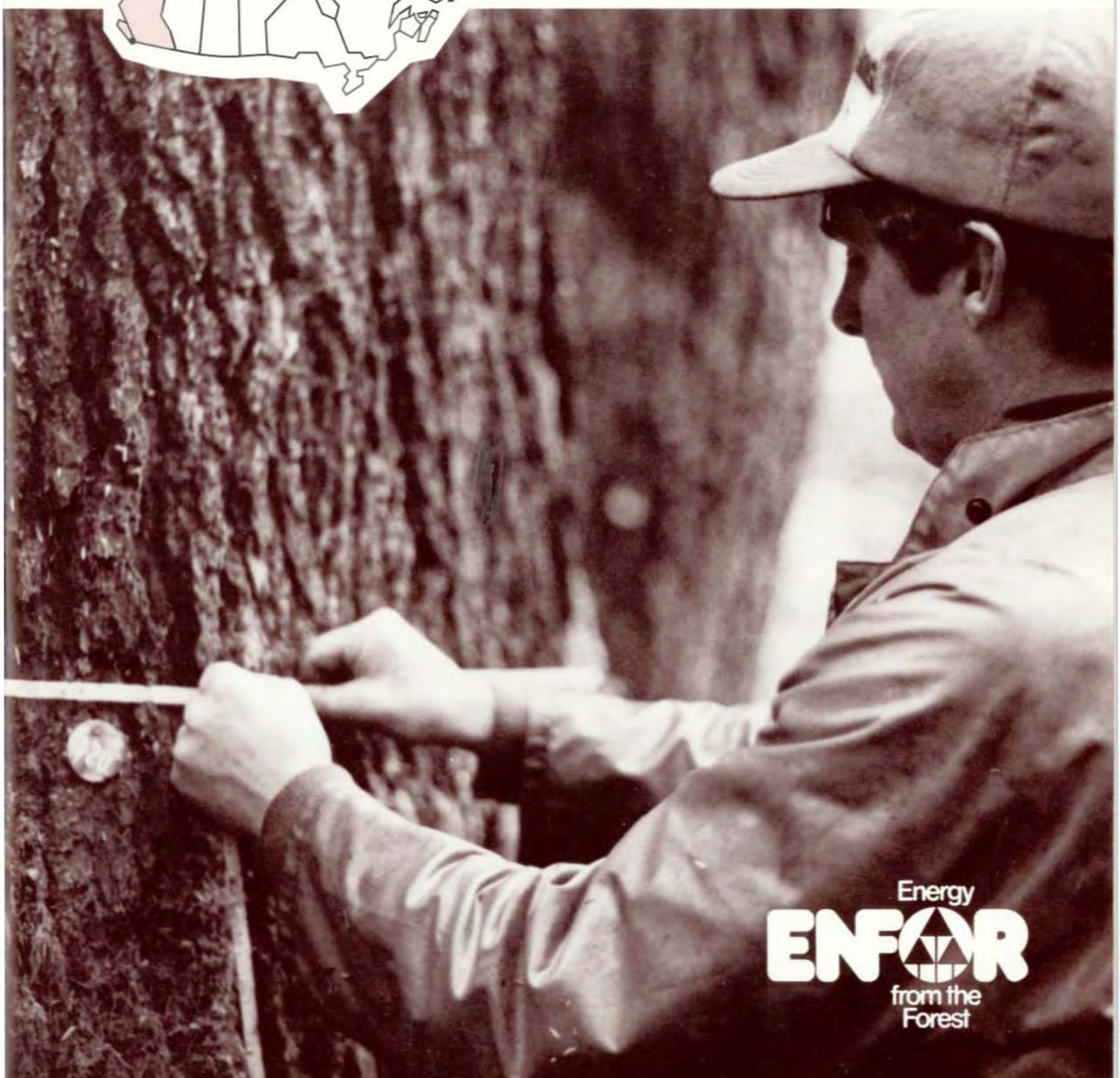

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The Pacific Forestry Centre undertakes research in response to the needs of the various managers of the forest resource. The results of this research are distributed in the form of scientific and technical reports and other publications.

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## Abstract

The production of regional biomass yield tables for Canada is feasible. This conclusion is based on the knowledge that the data bases used to construct the provincial yield tables exist and can be converted to regional biomass yield tables by the application of appropriate tree biomass equations. There also exists a set of factors produced by the ENFOR program for the conversion of gross merchantable tree volume to weight. Factors were also developed for other tree components - bark, top, branches, foliage and stump. Further factors to predict the stand volume and hence biomass for trees below the minimum size measured in permanent sample plots are available. The resulting biomass yield tables would then account for all Canadian forest biomass excluding only the biomass of roots and non woody vegetation. This study identifies the necessary data and its sources and provides a working plan for the production of the yield tables. It includes a pilot study, provides a 6-year schedule, and makes a global cost estimate of $1 120 000.

## Résumé

Des tables régionales de production de biomasse peuvent être produites au Canada. Pour les calculer, nous pouvons employer les bases de données utilisées pour la construction des tables provinciales et appliquer les équations appropriées pour la biomasse des arbres. Nous disposons également d'une série de facteurs, produits dans le cadre du programme ENFOR, qui permettent de calculer la masse à partir du volume marchand brut des arbres. Des facteurs ont également été établis pour d'autres composantes des arbres: écorce, partie supérieure non marchande de la tige, branches, feuillage et souche. Il existe aussi des facteurs qui permettent d'estimer le volume total (à l'échelle des peuplements) et, par conséquent, la biomasse pour les arbres inférieurs à la taille minimale mesurée dans les placettes permanentes d'échantillonnage. Les tables qui pourraient être produites rendraient compte de la totalité de la biomasse forestière au Canada, exception faite des racines et de la végétation non ligneuse. Le rapport indique les données nécessaires, ainsi que leurs sources, et présente un plan de travail pour la production des tables. Il comprend une étude-pilote et établit un calendrier de six ans pour la réalisation des travaux, dont le coût global est estimé à 1 120 000 $.

# Foreword

ENFOR (Energy from the Forest) is a contract research and development (R & D) program managed by Forestry Canada. It is aimed at generating sufficient knowledge and technology to realize a marked increase in the contribution of forest biomass to Canada's energy supply. The program was initiated in 1978 as part of a federal interdepartmental initiative to develop renewable energy sources.

The ENFOR program deals with biomass supply matters such as inventory, growth, harvesting, processing, transportation, environmental impacts, and socioeconomic impacts and constraints. A technical committee oversees the program, developing priorities, assessing proposals, and making recommendations. Approved projects are generally carried out under contract.

General information on the operation of the ENFOR program, including the preparation and submission of R & D proposals, is available upon request from:

The ENFOR Secretariat
Forestry Canada
19th Floor, Place Vincent Massey
351 St. Joseph Blvd.
Hull, Quebec
K1A 1G5

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# Preface

The production of biomass requires specialized new processes and equipment to convert basic biological material to useful energy. The designer of such processes and equipment must know what material will be available in the future. A knowledge of available quantity by species, nature and size of the material is required. Knowledge of the geographic location and distribution of the biomass is essential. If newly designed processes and equipment are to perform efficiently, they must have appropriate feedstocks. The purpose of this study is to relate the acquisition of forest biomass inventory data to the description of specific feedstock supply sources for the future.

Existing provincial and territorial inventories record, report, and summarize forest inventory data by species, volume and size class, sometimes by quality (defect) class.

Under the ENFOR program, the Canadian Forestry Service has produced regional biomass equations for estimating fresh and dry weights of some major tree components for Canadian tree species across Canada. They describe aboveground tree biomass in terms of fresh weight and oven-dry weight for stem and nonstem components, bark, branches, foliage and stump.

These equations have been applied by the Petawawa National Forestry Institute to provincial and territorial forest inventory data to produce an inventory of forest biomass for Canada. This biomass inventory provides summaries of total quantities of material available for conventional use - sawlogs, pulp, peelers, etc. The remaining unutilized material, found by deduction, will be available for conversion to energy or other uses.

The proposed yield tables, applied to existing forest resource inventories developed by the provincial forest services, could describe forest biomass by: (1) species, (2) parts of the tree (stem, branch, foliage, etc.), (3) forest condition (site, age, stand density), and (4) distribution according to location and availability. Costs of biomass production, handling, transportation and processing could be determined. In addition, the tables would facilitate an accurate prediction of biomass yield for future consumption.

Dave McFarlane, Director of Timber Management, Forests, Mines and Energy, in the New Brunswick government noted to the Canadian Forestry Inventory Committee, in Fredericton, New Brunswick, June, 1986, "Biomass yield tables will contribute to the transition from a forest resource data base to a forest management data base."

# Contents

# Introduction

The ENFOR program has produced a national inventory of forest biomass (Bonnor 1985). It used the same format as *Canada's Forest Inventory 1981* (Bonnor 1982). Biomass estimates have been produced by species for broad forest types (softwood, mixedwood, and hardwood) for each province. These biomass estimates have been generated by applying individual tree biomass relationships to provincial inventory data. This biomass inventory presents an image of the Canadian forest at one instant in time. Consideration of the dynamic aspect of the Canadian forest, its growth and yield, is a natural sequence to inventory. Regional biomass yield tables[1] will be a valuable addition to the ENFOR program and will have a number of uses. An understanding of the regional distribution of yield is essential to any consideration of the potential utilization of this resource.

## History and basis

The appreciation that future energy requirements could not depend forever on oil reserves, especially subsequent to the international 1973 oil crisis, renewed attention on the forest as a source of energy. The reaction of the oil consumers was twofold: they conserved oil by using existing stocks more efficiently, and they sought alternative sources of energy, especially renewable ones - such as the forest. This response was encouraged by the sharp increases in oil prices orchestrated by the OPEC countries. More recent events have led to a decline in oil prices, and the search for alternative forms of energy has become less urgent. This is especially true in those parts of Canada where natural gas is readily available for domestic and institutional heating. In other parts of Canada, there is a continued awareness of the forest as a source of energy. Chips from whole trees and logging residues as well as firewood are significant sources of heat energy in eastern Canada.

The intensification of forest management across Canada has increased the need for growth and yield studies of both managed and natural stands to measure the benefits of management. Growth and yield estimates are also required in calculating an allowable annual cut that will permit sustained yield. This is becoming more important as the proportion of the annual allowable cut derived from second-growth forests increases. This trend necessitates the production of biomass growth and yield tables and is, in part, a basis for this study.

Permanent sample plots (P.S.P.'s) are the basis of yield tables. Historically, forest inventory organizations, both provincial and federal, have installed many such plots across Canada (Candy 1938; Bickerstaff and Hostikka 1977; Reimer and Lussier 1984).

The installation of P.S.P.'s has proved very popular, more so than the compilation, analysis, and utilization of the results of the measurements. There are several reasons for this. The 5-year interval between installation and subsequent remeasurement permits the initiator of the project to be transferred, promoted, or become otherwise engaged. His successors may continue to remeasure the plots but not necessarily to process and use the results. There may also be a low demand for the end result - yield tables.

In the past, forest management has been concerned with old growth rather than second growth, and has used temporary cruise plot-based data rather than yield tables, which produces empirical curves of volume over age. These curves, if drawn back to their point of origin (zero volume at zero time), would seem usable for second-growth management planning. Unfortunately, this does not always work. Real stands may move from one productivity class curve to another in the family of curves traditionally fitted to the scatter of temporary plot data, because the stand histories differ. One temporary plot does not always relate to another such plot further along a particular curve. On the other hand, P.S.P.'s track the progression of volume over time and overcome the inconsistency that may occur with temporary plots. Excessive mortality, perhaps related to insects, disease, or windfall, may interfere. Such mortality can be accommodated by increasing the sample size, although bias may occur in either case. The sampling design is critical. Equal intensity of sampling is required for each age class and site class throughout the range of the species or species group being sampled.

The ENFOR program has generated much original work defining the relationship between volume and

[1] With the increasing use of computers in forest inventory and management, growth and yield is being expressed in the form of yield equations rather than as yield tables. Both terms are used interchangeably in this study.

weight for Canadian tree species. The factors and equations quantifying these relationships by species and by tree components are an essential part of this study.

Some work has been done in Canada towards the production of biomass yield tables. In particular, Horton (1981) produced a set of biomass yield tables for aspen in Ontario. The normal yield tables present average stand height and diameter, as well as stem frequency, basal area, and biomass (for the whole tree as well as the stem wood only) per hectare. Also, mean and current annual biomass increments are given. Smith and Williams (1980) investigated the possibility and desirability of constructing a forest biomass growth model. One of their suggestions was to use FORCYTE, which is a flexible, ecosystem-level modeling framework that simulates nutrient cycling and growth feedback (Kimmins et al. 1987).

## Purpose and scope

The objective of this study is to examine the feasibility of producing forest biomass yield tables for the various forest regions of Canada. All forested regions in Canada are considered. The field of inquiry involves the investigation of the potential of federal and provincial forest inventory operations to supply basic growth and yield data and forest biomass equations.

Volume based yield tables predict the quantity and dimension by species of merchantable wood that a forest site is capable of producing. Biomass yield tables predict the total tree weight, including stem, bark, branches, twigs and foliage. In this study, roots and other plant material below ground are excluded. Wood assigned to other forms of utilization, such as lumber, pulp, etc. could be subtracted when biomass available for fuel is the question.

## Need for regional biomass yield tables

Yield tables are essential forest management planning tool as the harvesting of the original first growth stands approaches completion. Biomass yield tables are needed so that the amount of biomass likely to be available for fuel can be calculated.

Planning fuel and energy supplies is regional in nature; the sources and forms of energy and the options available are regional. Also, biomass yield tables will have specific value for a wide range of forest management operations, including fire prevention planning, silvicultural prescriptions, residual utilization, and visual quality management. The cost of transportation of natural gas, coal and electricity limits the distribution of supply to a tributary region. There are also long-term considerations when there is only a limited supply of energy. Further, most of the habitable part of Canada has access to forest growth. Forest biomass is therefore a major consideration in regional energy supplies.

All forest management is driven by the end use of the material (wood, bark or foliage) to be delivered. The user needs to know what feedstocks to expect so that he can design his equipment to manufacture a saleable product, i.e., lumber, energy, heat, etc. In the short term, the user needs a description of the raw material in terms of quantity, size, species, quality, availability, location, and price. In the long term, the user needs to know about the future supply, and how it may change in terms of size, quality, location, species and availability. In addition, the user may have other long-term concerns: the likelihood of loss by fire, pests, disease, or disaster; regeneration delay; and price. The short-term needs are satisfied by inventory records. The long-term needs require a management plan dependent on productivity estimates, site classification, yield estimates, age-class distribution, estimates of likely losses, benefits from silvicultural treatments, protection, etc. Biomass yield tables are one of the elements a planner needs to assist the user in his decision making.

# Data bases

The major Canadian data bases are held by the forest inventory divisions of the provincial forest services across Canada. Some additional forest inventory data for federal lands are held by the Department of Indian and Northern Affairs, the territorial governments, and the Canadian Forestry Service. These data have been gathered and summarized for all of the country in cells of approximately 100-$km^2$ in the Canadian Forest Resource Data System (CFRDS). The managers of these data bases (Appendix 1) represent their services at the annual meeting of the Canadian Forest Inventory Committee (CFIC). Access to information relating to any specific area may be obtained by direct contact with the relevant manager.

The provincial forest service inventory divisions are the major producers and sources of forest inventory in Canada. They have developed and used a set of fairly comparable systems of measuring and recording mensurational data describing the provincial forest resources. The provinces own most forest land - they are responsible for about 80% of Canadian forest land and the provincial forest services are the major forest managers.

## Provincial yield data

The six biomass regions of Canada have already been defined in the ENFOR program as:

- Pacific
- The Prairies
- Ontario
- Quebec
- The Maritimes
- Newfoundland

Yield tables[2] are available within all six biomass regions. Within the regions, the Yukon, Northwest Territories, Prince Edward Island and New Brunswick are without yield tables. Prince Edward Island, Manitoba, and New Brunswick have P.S.P. data becoming available from which yield tables may be compiled. Newfoundland will also be applying more recent P.S.P. data to upgrade their present yield tables, which are based on temporary sample plots (T.S.P.'s). In the interim, substitution from adjacent provinces should give reasonable results.

[2] Unless otherwise specified, this term applies to volumetric yield tables.

The availability of yield tables by tree species and province or territory is shown in Table 1. Additional technical details are given in Appendix 2.

A more detailed description of available yield tables by region, province, and territory, follows:

### *(a) Pacific*

**British Columbia**. This province has a most comprehensive base. Yield tables are available for a full range of species, ages, sites, and zones.

Volume over age curves (known as VAC's) were the first to be produced and have been the main source for yield prediction since the 1960's. They were maintained in graphical form until 1976 when metric conversion occurred and equations were produced to represent the relationships mathematically. The Chapman-Richards generalized growth model was chosen with age as the independent variable. VAC's are available by growth type groups and site classes for utilization levels and forest inventory zones.

An enhancement of the volume over age approach uses site index to replace site class as an independent variable in the Chapman-Richards equation. In addition, volume ratios are applied to the whole stem volume (all trees greater than 7.5 cm in diameter) to obtain predictions for other utilization levels. Various levels of stocking are accommodated using adjustment factors. In use, age and height determine site index and drive the system. Yields are predicted by forest inventory type group, by forest inventory region, by utilization level, and site index. This system is based on the Ek-Payandeh Model.

Variable density yield tables (VDYT's) were developed in 1980 to account for variations in stand density. These tables use age, site index, crown closure, basal area, and diameter as independent variables, which are used to drive the modified Chapman-Richards function. They are available for pure species by inventory zone and utilization level. Coefficients specific to species are given and the equations expressed as yield tables and curves for selected crown closure, relative density and site index values. Stand statistics are projected from estimates of age, site index and crown closure, as well as from actual or calculated basal area and diameter. The yield tables include volume, basal area, diameter, and number of stems. The curves project volume. These tables are based on temporary plots or on permanent plots used as single records. Sequential P.S.P. records are available and could be used to produce yield tables free of any inherent bias that might be related to the distribution of the temporary plots.

The various available yield tables may be requested from the Director, Inventory Branch, Ministry of Forests, Victoria.

**Yukon**. There is as yet no yield table for the Yukon. Some P.S.P.'s were established in the Watson Lake area in 1961. They were remeasured in 1978, 1982, and 1987. The data will be compiled and the results published. T.S.P. data exists upon which yield tables by age class and by site class will be constructed.

### *(b) The Prairies*

**Alberta**. Alberta has recently produced empirical yield tables for even-aged natural stands based on 3131 P.S.P.'s. These tables cover three species, i.e., white spruce, black spruce, and pine, and three species groups, i.e., hardwoods (80% aspen, 16% poplar, 4% birch), mixedwood-coniferous component, and mixedwood-deciduous component. Three site classes (good, medium, and fair) are used. Ten-year age classes are represented up to 180 years.

The yield tables were derived from stem analysis data to develop site index, height-age and age to breast height equations. P.S.P. yield data were used to relate volume and quadratic mean diameter to height. Basal area was then related to volume, and number of trees related to basal area and quadratic mean diameter.

Site index was predicted from site height and age using multiple linear regression. Site height was predicted by Monserud's logistic model constrained through index height and index age.

The Alberta Phase 3 Forest Inventory Yield Tables can be obtained from the Alberta Forest Service in Edmonton.

**Saskatchewan.** There are 24 868 T.S.P.'s and 1830 P.S.P.'s located in even-aged natural stands, (J.A. Benson, Dept. of Tourism and Natural Resources, Saskatchewan, personal communication 1987). Empirical yield tables have been constructed for seven species in three species groups for each of eight zones (Benson 1973). Age classes range up to 95 years. Gross volume and one merchantability level are reported with height, diameter and basal area. These are based on "well-stocked stands" and have been used for the derivation of rotation ages. Their relationship to the forest inventory data base is undetermined. It should also be noted that there is no usable site class or site index (J.A. Benson, personal communication 1987). Stem analysis data of 1500 trees are also available.

These yield tables may be obtained by contacting the Department of Parks and Renewable Resources, Forestry Division, Prince Albert.

**Manitoba.** No provincially developed yield table is available. Some site index curves are available but they need improvement and addition. There are 168 P.S.P.'s available, but they are not very old. Additional plots are being established but useful results are not expected for 5 years or more.

**Northwest Territories.** Yield table data are not available, nor is any work planned.

### *(c) Ontario*

Normal yield tables produced in 1960 were revised and republished in metric units in 1981. They cover six species and two species groups for even-aged natural stands to 90 years of age in 5-year age classes for three site classes, and one plantation species on one site given one treatment. Height, diameter, basal area, gross volume, and two levels of merchantable volume are provided. Age and height determine the site class. The actual basal area per hectare is used to compute the stocking factor which is used to calculate the volume and increment per hectare. The actual basal area is usually determined in the field with a prism from a series of point samples.

In addition, various other yield tables have been made on a local basis. Empirical tables based on T.S.P.'s were produced for the Reed Tract in 1975/76. Dr. V. Smith of the University of Toronto derived yield tables from P.S.P. data for the Spruce Falls Company's limits. Mr. F. Evert (1975) has produced empirical yield tables for northern Ontario for two species and three species groups to 140 years of age based on 347 P.S.P.'s. These tables list diameter, basal area, stems per hectare, and merchantable volume. He also (1976) published variable density yield tables for one species and species group to age 90 for five levels of density and three site classes. Payandeh and Field (1986) recently published empirical yield tables for one species group to age 150 years for six site classes in northwestern Ontario. These tables list diameter, height, basal area, stems per hectare, and gross and merchantable volume as independent variables. The tables are based on Richard's growth function using the same 347 P.S.P.s' that Evert had used. Beckwith (1983) has published growth and yield tables for red pine plantations in Ontario.

The normal yield tables of Plonski may be obtained from the Ontario Ministry of Natural Resources in Toronto. The Canadian Forestry Service's regional office in Sault Ste. Marie will supply those by Evert and by Payandeh and Field.

### *(d) Quebec*

Empirical yield tables based on 7155 P.S.P.'s are available. They describe jack pine, black spruce and balsam fir in even- and uneven-aged natural stands from 50 years old up to 150 years old in 27 zones throughout the province. They relate the variables of height, diameter and basal area, stems per hectare, and gross total and merchantable volume. They are produced by and available from the Service de l'inventaire forestier, Ministere de l'Energie, Mines et Ressources in Quebec City.

### *(e) The Maritimes*

**Prince Edward Island.** Four empirical yield tables are available in graphical and tabular form for the four cover types of white spruce, other softwood, hardwood (birch and maple), and other hardwood. They predict harvestable biomass greater than 1 cm dbh, merchantable volume, and sawlog volume. They are based on 900 T.S.P.'s. The average for all sites is based on the proportion in each site class. A further 300 T.S.P.'s and 70 P.S.P.'s have been established. Normal yield tables in equation and tabular format for white spruce by five site index classes are also available. These tables list harvestable biomass, merchantable volume, total volume and diameter distribution. They may be obtained from the Manager, Silviculture Development, Prince Edward Island Forest Branch, P.O. Box 2000, Charlottetown.

**Nova Scotia.** A comprehensive set of 1765 P.S.P.'s distributed throughout the province provides the basis for variable density yield tables of ten species in three growth types of natural stands. The ages range over 100 years, with six site classes and five levels of stand density. The dependent variables reported are height, diameter, basal area and gross and merchantable volume. The records can be obtained from the Director, Resource Management, Planning and Mensuration, Department of Lands and Forests, Truro.

**New Brunswick.** Formal yield tables have not yet been produced for New Brunswick, but more than 1255 P.S.P.'s were established in 1955 and periodically remeasured until the mid-1970's. A relocation and remeasurement of 170 of these plots in 1983 encouraged plans to restore this program.

Some curves based on temporary plots have been used in the FORMAN timber supply model, but they contain a certain amount of intuitive projection. They will be replaced by yield tables that will be produced from a major growth and yield program proposed to start in 1987. Yield tables should be available for incorporation in 1992 management plans. The silviculture branch also establishes silvicultural treatment plots in the first year after logging, with remeasurement in the third and fifth years. These plots have become part of the growth and yield P.S.P. system. Because they monitor the effect of budworm and stand break-up, the growth and yield studies are confounded.

There are 90 growth curves used for the FORMAN timber supply model. These curves give the yield of spruce and balsam fir by site and species association, and by with and without protection from the spruce budworm by spraying.

### *(f) Newfoundland*

Empirical yield tables based on 1864 T.S.P.'s containing seven species and species groups in natural even-aged stands to over 100 years in age have been produced for Newfoundland. The dependent variables listed are height, diameter, stems per hectare, and gross and merchantable volume.

These tables were produced by the Canadian Forestry Service and are available from the regional office in St. John's. These are considered the best available, but curves based on P.S.P.'s would be preferred. There is a large data base of about 1400 P.S.P. records dating back over 40 years. Site curves are available but are also based on T.S.P.'s. They might be used to assist in developing new site curves. This work is currently under review by the Newfoundland Department of Forest Resources and Lands in Corner Brook.

## Federal data bases

Inventory data for federal lands (about 11% of all forest land) are collected and held by the Canadian Forestry Service, the Department of Indian and Northern Affairs, the Department of Defence, and Parks Canada. The last two agencies have only a slight interest in forest inventory and management. Major federal forest inventories have been made for the Yukon and Northwest Territories in which forests, while extensive, are not especially significant. The chief function of the Canadian Forestry Service in this discipline is in the assembly of Canada's Forest Inventory, and in providing assistance to the other agencies.

*(a) National forest inventories*

**Canada's forest inventory, 1981**. The Canadian Forestry Service publishes a national forest inventory report at approximately 5-year intervals. The latest publication is *Canada's Forest Inventory 1981* (Bonnor 1982). It is similar to its predecessors in that it focuses on the areas of wood volumes available for forest purposes, which are of greatest economic interest. The inventory data are summarized for planning and policy purposes. Emphasis is placed on objective presentation of the most pertinent data. The inventory data are summarized by national totals, by provincial and territorial totals, and by choropleth thematic maps showing the distribution of the forest resources by "cells" (see below).

This inventory is produced from the Canadian Forest Resource Data System, which is a computer-based system for the input, manipulation, and output of forest resource data. The basic data are received from the provinces and territories and are summarized by "cells" or areas used by the provinces and territories for summary purposes. Across Canada, 39 000 cells are used to store the inventory data (Bonnor 1982).

**Biomass inventory of Canada, 1985.** The availability of this Canadian Forest Resource Data System, as well as a set of tree biomass equations applicable to the major tree species across Canada, made it possible to generate a forest biomass inventory for the whole country. *Canada's Forest Inventory 1981* (Bonnor 1982) and the tree biomass equations produced by the ENFOR program were combined to produce the *Inventory of Forest Biomass in Canada* (Bonnor 1985).

This first national forest biomass inventory defined forest biomass as: the mass of the above-ground portion of live trees in oven-dry tonnes, including small-diameter trees and excluding dead trees and branches, roots, and non-woody vegetation.

The biomass data presented in *Inventory of Forest Biomass in Canada* (Bonnor 1985) were based, as much as possible, on existing inventory data. Also, existing methods and systems were used to produce the summaries. The same basic inventory data, methods, and systems were used in *Canada's Forest Inventory 1981* (Bonnor 1982), which presents data on forest areas and wood volumes. The inventory differed from the 1981 volume inventory in several respects:

• While the 1981 inventory summarized volumes of one tree component, i.e., the merchantable stemwood, the 1985 biomass inventory summarized biomass of eight components, including bark, branches, and foliage.

• Data were included from areas of forest land not previously inventoried e.g., northern Quebec, Ontario, and Manitoba.

• Data were included from areas previously inventoried but not field sampled e.g., unproductive forest lands.

• The data were classified by a measure of physical access, to give some indication of the degree of difficulty or cost of harvesting.

• Data from several provinces, particularly Alberta, were updated since the 1981 inventory.

**Canada's forest inventory, 1986.** Canada's Forest Inventory 1986 ( Forestry Canada 1988) is based on *Canada's Forest Inventory 1981* (Bonnor 1982) but is refined and has expanded information categories. These categories are listed in Appendix 3. The Canadian Forest Resource Data System is still the basic source of information which is received from the provincial and territorial forest inventory chiefs. These chiefs are the members of the Canadian Forest Inventory Committee. The cooperative attitude of the Canadian Forest Inventory Committee is essential to the development of national forest inventory definitions and its meetings provide a national forum for forest inventory issues.

This publication also describes the Canadian Forest Resource Data System use of classifiers, definitions and codes for inventory statistics. The methods of using auxiliary files where missing values are problematic is explained. The level of resolution by cell, approximately 100 $km^2$, is described, as is the system's flexibility and receptivity to new and updated information. This new information may be added at any future date to replace earlier data, making it possible to develop meaningful current inventory reports at any time within the 5-year reporting cycle. The varying standards of merchantability are described according to the source inventories to which they apply.

Of major significance in the design of the Canadian Forest Resource Data System is the geographic information system. The location of forest land by productivity class and cell will allow the application of biomass yield tables to those productivity classes. Thence, the total net annual productivity of biomass at whatever level may be obtained.

**Table 1.** Availability of yield tables by tree species and province or territory

| Species[a] | B.C. | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EMP | VDYT | Yukon | Alta. | NWT | Sask. | Man | Ont. | Que. | PEI | N.B. | N.S. | NFLD |
| Douglas-fir (coastal) | x | x | - | - | - | - | - | - | - | - | - | - | - |
| Douglas-fir (interior) | x | x | - | - | - | - | - | - | - | - | - | - | - |
| Western hemlock | x | x | - | - | - | - | - | - | - | - | - | - | - |
| Western red cedar | x | x | - | - | - | - | - | - | - | - | - | - | - |
| Sitka spruce | x | x | - | - | - | - | - | - | - | - | - | - | - |
| Pacific silver fir | x | x | - | - | - | - | - | - | - | - | - | - | - |
| Subalpine fir | x | x | - | - | - | - | - | - | - | - | - | - | - |
| Lodgepole pine | x | x | - | x | - | - | - | - | - | - | - | - | - |
| White birch | x | x | - | - | - | x | - | x | x | x | - | - | x |
| Black cottonwood | x | x | - | - | - | - | - | - | - | - | - | - | - |
| White spruce | x | x | - | x | - | x | - | - | - | x | x | x | - |
| Larch, western | x | x | - | - | - | - | - | - | - | - | - | - | - |
| Engelmann spruce | x | x | - | - | - | - | - | - | - | - | - | - | - |
| Red alder | - | x | - | - | - | - | - | - | - | - | - | - | - |
| Trembling aspen | - | x | - | x | - | x | - | x | - | - | - | - | x |
| Black spruce | - | - | - | x | - | x | - | x | x | - | x | - | x |
| Jack pine | - | - | - | - | - | x | - | x | - | - | x | - | - |
| Larch-Tamarack | - | - | - | - | - | x | - | - | - | - | - | - | x |
| Balsam poplar | - | - | - | - | - | x | - | - | x | - | - | - | - |
| Eastern white pine | - | - | - | - | - | - | - | x | - | - | x | - | - |
| Red pine | - | - | - | - | - | - | - | x | - | - | x | - | - |
| Oak | - | - | - | - | - | - | - | - | x | - | - | - | - |
| Maple | - | - | - | - | - | - | - | - | x | - | - | - | - |
| Ash | - | - | - | - | - | - | - | - | x | - | - | - | - |
| Elm | - | - | - | - | - | - | - | - | x | - | - | - | - |
| Balsam fir | - | - | - | - | - | - | - | - | - | - | x | x | x |
| Yellow birch | - | - | - | - | - | - | - | - | - | - | - | - | x |
| Total | 13 | 15 | 0 | 4 | 0 | 7 | 0 | 6 | 7 | 2 | 6 | 2 | 6 |

Total Species - 27

[a] Single species stand, or cover type in which that species is dominant.

### *(b) Yield data*

The Canadian Forestry Service has a wide variety of growth and yield projects in progress across Canada at its six regional forestry centres. A list of current projects and studies is included in Appendix 4. These concentrate on the study of the effects of various forest management procedures on the growth and yield of the forest. They also include studies of growth and yield of particular species, e.g., black spruce in Newfoundland and Ontario, and balsam fir in New Brunswick.

A major contribution to Canadian growth and yield study was made by Bickerstaff and Hostikka in their publication *Growth of Forests in Canada, Part 1, An Annotated Bibliography* (1977). This bibliography was a preliminary step in the preparation of a national estimate of the productive capacity or growth of Canadian forests. It contained 600 references, and attempted a complete coverage to the end of 1975 of Canadian literature related to the increment or yields at known ages of naturally established unmanaged stands. The bibliography included some data summaries.

### *(c) Tree biomass equations*

The individual tree biomass growth and yield equations assembled by the ENFOR program will be required for application to existing provincial and federal growth and yield equations or tables. The available tree biomass equations appear sufficient for the purpose. An additional component for small trees will need to be added, which may be done according to the procedure used in the ENFOR Canadian forest biomass inventory project. The addition of the small tree component on a percentage basis will be somewhat imprecise. Because it comprises such a small proportion of the total biomass in most cases, any variation from the absolute figure should not be critical. It may be reasonable to use the biomass inventory project figures. These will need to be confirmed, improved, or added to the existing data using additional field samples or sub-samples.

A tree biomass equation is typically of the form:

$$M = a + bD^2H$$

where

$M$ = oven-dry mass (kg);
$D$ = tree diameter at breast height (cm);
$H$ = tree height (m); and
$a,b$ = equation coefficients

The equations are usually derived for individual species, for geographical regions or provinces, and for tree or stand components (foliage, top, branches, merchantable stem wood, merchantable stem bark, stump wood and stump bark). These seven components relate to merchantable trees; an eighth component is a stand component and includes all the small trees that have no merchantable wood, i.e., the submerchantable trees.

A major effort of the ENFOR program has been the collection of tree data for the construction of such equations: equations have now been developed for all principal species in Canada, by region or province (Bonnor 1985).

The equation format is different in each province or territory. Table 2 lists the availability of tree biomass equations.

**Table 2.** Availability of biomass equations by number and location of sample trees

| Species | Location | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | B.C. | Yukon | Prairies | NWT | Ont. | Que. | N.B. | N.S. | NFLD | |
| Coastal Douglas-fir | 49 | - | - | - | - | - | - | - | - | 49 |
| Sitka spruce | 40 | - | - | - | - | - | - | - | - | 40 |
| Western red cedar | 70 | - | - | - | - | - | - | - | - | 70 |
| Interior Douglas-fir | 41 | - | - | - | - | - | - | - | - | 41 |
| Ponderosa pine | 42 | - | - | - | - | - | - | - | - | 42 |
| Western hemlock | 70 | - | - | - | - | - | - | - | - | 70 |
| White spruce | 105 | 368 | 60 | 61 | 75 | 79 | - | 44 | 169 | 961 |
| Engelmann spruce | 43 | - | - | - | - | - | - | - | - | 43 |
| Pacific silver fir | 45 | - | - | - | - | - | - | - | - | 45 |
| Grand fir | 40 | - | - | - | - | - | - | - | - | 40 |
| Western larch | 41 | - | - | - | - | - | - | - | - | 41 |
| Western white pine | 40 | - | - | - | - | - | - | - | - | 40 |
| Lodgepole pine | 98 | 149 | 60 | - | - | - | - | - | - | 307 |
| Mountain hemlock | 39 | - | - | - | - | - | - | - | - | 39 |
| Black spruce | 60 | 302 | 60 | 51 | 115 | 734 | - | 49 | 318 | 1 689 |
| Subalpine fir | 89 | - | 60 | - | - | - | - | - | - | 149 |
| Yellow cedar | 41 | - | - | - | - | - | - | - | - | 41 |
| Black cottonwood | 40 | - | - | - | - | - | - | - | - | 40 |
| Red alder | 41 | - | - | - | - | - | - | - | - | 41 |
| Trembling aspen | 40 | 201 | 60 | 56 | 224 | 133 | - | 46 | 70 | 830 |
| White birch | 40 | - | 60 | - | 135 | 101 | - | 45 | 275 | 656 |
| Shore pine | 40 | - | - | - | - | - | - | - | - | 40 |
| Jack pine | - | - | 60 | 56 | 139 | 136 | - | 42 | - | 433 |
| Balsam fir | - | - | 60 | - | 74 | 177 | - | 50 | 296 | 657 |
| Larch-Tamarack | - | - | 60 | 56 | 79 | 97 | - | 47 | 243 | 582 |
| Balsam poplar | - | - | 60 | 56 | 90 | - | - | - | - | 206 |
| Largetooth aspen | - | - | - | - | 96 | - | - | - | - | 96 |
| Yellow birch | - | - | - | - | 95 | 130 | 50 | - | 53 | 328 |
| Sugar maple | - | - | - | - | 112 | 62 | 45 | - | - | 219 |
| Red maple | - | - | - | - | 63 | 61 | - | 49 | - | 173 |
| Silver maple | - | - | - | - | 37 | - | - | - | - | 37 |
| White ash | - | - | - | - | 74 | - | 47 | - | - | 121 |
| Black ash | - | - | - | - | 26 | - | - | - | - | 26 |
| Red ash | - | - | - | - | 28 | - | - | - | - | 28 |
| Basswood | - | - | - | - | 76 | - | - | - | - | 76 |
| American beech | - | - | - | - | 76 | - | - | - | - | 76 |
| Black cherry | - | - | - | - | 72 | - | - | - | - | 72 |
| White elm | - | - | - | - | 77 | - | - | - | - | 77 |
| Hickory | - | - | - | - | 73 | - | - | - | - | 73 |
| Ironwood | - | - | - | - | 14 | - | - | - | - | 14 |
| White oak | - | - | - | - | 61 | - | - | - | - | 61 |
| Red oak | - | - | - | - | 114 | - | - | - | - | 114 |
| Eastern white pine | - | - | - | - | 77 | 56 | 47 | - | - | 180 |
| Red pine | - | - | - | - | 66 | 53 | - | 47 | - | 166 |
| Eastern white cedar | - | - | - | - | 84 | - | 47 | - | - | 131 |
| Eastern red cedar | - | - | - | - | 26 | - | - | - | - | 26 |
| Eastern hemlock | - | - | - | - | 140 | - | 49 | - | - | 189 |
| Red spruce | - | - | - | - | - | 55 | - | - | - | 55 |
| Beech | - | - | - | - | - | - | 47 | - | - | 47 |
| Grey birch | - | - | - | - | - | - | - | 44 | - | 44 |
| Total | 1154 | 1020 | 600 | 336 | 2418 | 1874 | 332 | 463 | 1424 | 9621 |

# Yield tables

As Assmann (1970) says so well: "Production techniques in forestry depend on the utilization and systematic control of growth processes. In the course of these processes, smaller or larger quantities of vegetable substance are produced, of which, in the case of a forest, we are mainly interested in the woody substance. It is the task of yield studies to examine the quantitative extent of growth processes in the forest in relation to time, site and the economical and technical measures available to man... ."

The forest is an ongoing, renewable, growing resource. The forest is not just an inventory of timber that once cut has no future value. The potential of forest land to produce crops of trees in perpetuity has to be recognized and the potential production of the forest land estimated by means of yield tables. Yield tables may be put to use in various aspects of forest management.

Yield tables serve a variety of essential purposes in good forest management where profitability is a primary objective. Where management is primarily for protection, recreation, wildlife, water, or other non-consumptive forest-use, then yield tables may well be unnecessary. Again, "...sustained forest management requires not only a knowledge of the existing stock of a forest but also a knowledge of the yields to be expected in the future... ." (Assmann 1970).

Yield tables present a summary of a set of stand characteristics for one or more species on one or more sites for a series of ages of the stand. The characteristics may include gross and merchantable volume and stems per hectare, basal area, height, and mean diameter.

Three variations of yield tables based on stocking have been developed: empirical yield tables are based on actual stocking; normal tables on a theoretical fully stocked stand; and variable density tables which represent several possible levels of stocking for each site.

## Standard yield tables

Yield tables are presently constructed to predict the merchantable or total wood volume at some specified time in the future. This prediction is made according to site quality, the time elapsed since the stand was established, the tree species, the present stocking (by number of tree stems or basal area per hectare), and the forest management regime practiced or intended in respect to relevant regeneration, cleaning, fertilizing and thinning schedules.

The net merchantable wood volume is the volume of wood in logs that is cut from the tree between the top of the stump and the smallest acceptable top diameter inside bark, less allowances for decay and defect as locally appropriate. Total wood volume is all inclusive from tip to ground level not considering decay and defect, excluding bark.

### *(a) Purpose and use*

**Annual Allowable Cut.** The most important use of yield tables is in the calculation of Annual Allowable Cut. The determination of the Annual Allowable Cut is the most significant, critical management control in forestry. The calculation of the Annual Allowable Cut determines the quantity of wood to be cut each year in a given forest management unit. All other aspects of forest management are dependent upon this central calculation. The yield table defines the rate at which the productive forest land can reproduce wood as it is logged. This productivity, annually stated, is the basis of the determination of the long-term Annual Allowable Cut. In the short term, previously accumulated growth (old growth) can contribute significantly to the total Annual Allowable Cut. The accuracy of the yield table used is therefore significant. The yield table is generally used to define rotation length. This is usually taken as the length of time required to reach the point at which the mean annual increment and the periodic annual increment intersect. The rate of increase of the stand's growth rate is then at its maximum. This definition of rotation provides the maximum yield.

**Timber inventory.** In one part of Canada, yield tables are used in timber cruising to produce forest inventories. Normal yield tables are adjusted on a factorial basis for actual stocking. Accurate, sensitive tables are essential if correct inventories are to be produced.

**Silvicultural management.** The site-specific selection of the species to regenerate, the spacing to choose, the site preparations to recommend, fertilization, cleaning, and thinning to apply, depend on anticipated yields according to the schedule of treatments chosen. Accurate variable density managed stand yield tables by species are required for this purpose.

**Planning.** The potential for productive land to contribute in the long term to the national, provincial, regional or local good is determined by the application of the appropriate yield tables to areas previously classified from ground or photographic inspection. Forest policy decisions depend on the total perceived potential future production estimated with the application of yield tables.

In the short term, yield tables provide essential estimates for the planned utilization of productive forest that is approaching utilizable age. They indicate merchantable wood sorts by quantity, species, size, and quality. The accuracy of such information can be critical to the success of planned industrial ventures.

Yield tables also provide essential estimates for the planning of the utilization of productive forest land by government officials. Economists determine local or regional short-term development potentials, and these require yield estimates to predict future wood supplies.

**Appraisal.** The economic value of productive forest land appraised for sale, purchase, or exchange depends on the present standing timber inventory and the land's future ability to grow trees. Yield tables provide a sound basis for determining the productive monetary value of land.

A different type of appraisal is required when fire destroys existing young stands. Estimates of what would have been on the ground are then required. Additionally, it may be necessary to predict the lost yield at rotation and discount its final value back to the present time. Without yield tables these appraisals are not possible.

### *(b) Construction*

Forest yield depends on the tree species present, the age of the stand, the number of trees per hectare, the site quality and the management regime. These are the independent variables. The yield may be expressed in volume, basal area, or mass (biomass to be discussed later) per unit area. The units will be cubic or square metres or tonnes, per hectare. Height and mean diameter are other dependent variables usually reported.

A prerequisite of yield table construction is the definition of site index. It reflects the combined attributes of age and height in the dominant and codominant trees of a stand. Knowledge of site index is basic to the allocation of the P.S.P.'s across the range of productive forest sites in the region. It is therefore necessary to confirm the validity of existing site curves before proceeding.

The validation of site index curves may be done using stem analysis data from dominant and codominant trees of the relevant species. Height over age curves of trees at least as old as the age used for classifying the site index classes can be tested as to "goodness of fit" against the site index curves. This requires stem analysis of trees at least 50 years old for most Canadian species. In coastal British Columbia, 100 years is also commonly used for site index curves. Stem analyses have very commonly been made in most parts of Canada. If necessary, additional samples could be obtained, but few are likely to be needed.

The construction of yield tables requires a definition of the tree species or species groupings (forest cover types) to be measured. It requires definition of the maximum age of interest for the trees and the dimensions of the proposed age classes. A decision must be made whether the tables are to be normal, or variable density. The site quality in height classes or as a site index must be quantified. The forest under study may be natural, planted, or under some level of forest management, such as thinning or fertilization. If variable density tables are to be produced, a measure of density is required which would be based on crown closure or basal area or some measure of stand density. Merchantability limits must also be decided.

Upon completion of the yield tables, it is necessary to validate them against a second set of independent data. This may reveal deficiencies which require reworking of the tables or a different method of preparation.

Fortunately, Canadian forests tend to be coniferous and uniform in age. They usually consist of trees of one species or of a few ecologically similar species. They are managed under a uniform system, without intermediate cutting or thinning. Regeneration (natural or artificial) following clearcutting produces even-aged stands. There exist many examples of the various stand conditions available for study. This situation lends itself readily to mathematical modeling of stand growth. The major steps for yield table construction include a well designed sampling plan, its implementation including the establishment of P.S.P.'s and the analysis of data obtained from the P.S..P's. It is also essential that yield table construction be related to forest inventory procedures for the region in question.

### *(c) Site classification*

Even-aged stands provide the opportunity to obtain accurate representative measurement of stand age and height. Height over age curves make it possible to classify site with precision (though lodgepole and jack pine can cause problems when overly dense) and give a good indication of the potential productivity of the site. Mean height is dependent on the number of trees per hectare: therefore dominant height is used to define the height of a stand. Dominant or top height is the average height of a specified number of dominant and codominant trees in the stand.

Site indices for site classification may be developed from tree height and age measurements from temporary or permanent plots. Permanent plots are preferable as successive remeasurements can be joined by straight lines if a graphical method is used. Data from temporary plots may not equally represent different sites and ages. This can introduce error. Graphically represented curves can also be expressed in the form of equations. The weibull function is often used as a model for that purpose.

The manual, curve drawing method is simple, but the results can be interpreted by different people in different ways. If there is a large amount of data it is tedious, and should be done by computer. Statistical methods can be used, but these may be less accurate than hand-drawn curves. A basic height growth model is Schumacher's equation (Schumacher 1939), but more recently other non-linear equations such as the Chapman-Richards functions have been used. Methods of fitting site class curves include multiple regression, nested regression, linear regression, and the minimum-maximum method. These are well described by Alder (1980).

Site assessment may be based on environmental factors, but no great success has yet been achieved in Canada with this approach. It is more relevant to exotic species at the time of introduction or to mixed natural forests.

The recent work of Zeide (1978) with the standardization of site index curves may have application to this proposed project. Zeide demonstrated that a wide selection of site index curves (site height over stand age) could be standardized into a common series of normalized curves. He examined site index curves from 118 yield tables and developed a standardized height over age table that can be applied with two height over age measurements from a given tree or sample plot.

Zeide (1978) developed these tables in the following way.

"All series were normalized in such a way that the values would be 1.00 (or 100) at the age of 50 years. This means that the values of each series were divided by the value at the age of 50 from the same series. The normalized values are expressed as relative heights: heights in relation to the height at 50 years. Thus, all series were combined at the age of 50 without disturbing the original shape of the curves."

Zeide's approach has been further examined by the Washington State Department of Natural Resources on many of the tree species that grow in western Canada (Hoyer and Swanzy 1986). They concluded that Zeide's approach is equivalent to the site index curves normally used, and can be successfully used to model the development of site height over time. In terms of this proposed project, the Zeide approach could be used to assign a common site index to sample plots that will be obtained from various provincial and federal agencies and pooled by biomass region. In many cases, separate provincial or federal agencies may use different site index curves for the same species growing in a biomass region. Sample plots that have the same real height growth potential may not be assigned the same site index using the various site index curves that are available. The Zeide approach may offer a method to remove this artificial difference in estimated height growth potential.

### *(d) Yield prediction*

The present yield of a forest is determined by using temporary sample plots in which the species of each tree is tallied, as are the measurements of height, diameter at breast height, and, in older stands, decay and defect. These are used in association with volume equations and merchantability factors to determine gross and net volume per hectare. If the plots are permanent, the trees are individually numbered and remeasured at regular intervals, usually every 5 years. In this way the growth of a stand may be found. Considerable care in the acquisition and compilation of data is needed to maintain consistency. Ingrowth of trees which were below the minimum size of measurement when the stand was last measured as well as mortality of previously recorded trees, must be accounted for.

The records of temporary and permanent sample plots can be analyzed to produce predictive yield tables. The plots must be selected or located to be equally representative of the range of site and age classes. This often produces the apparently incongruous result that some minor site and age classes are sampled very intensively. Such classes are sampled with such intensity because it is important to mathematically define the limits of the class ranges.

Static models analyze the components of volume (yield) in terms of height, diameter, and stems per hectare to give total volume. They may be constructed by developing the mean diameter over height relationship for each age and site class. These can be found by means parallel to those used for height and age in the site classification, such as nested or multiple regression, or hand graphing. Stocking classes may also be used to improve the efficiency of the estimate (Alder 1980).

Dynamic models predict the rate of change (growth) in terms of the increment in diameter, basal area, or volume. They more realistically represent the effect of the number of stems per hectare on stand yield than do static models. They can be used to combine data from various sources.

Growth models contain functions that represent the increment of mean diameter, basal area, and volume over short periods in relation to stems per hectare. Yield predictions are produced from growth functions either by mathematical integration or by summation iteratively over a series of years. This is done using a computer to simulate growth.

The techniques available can use mean diameter or volume or basal area. Basal area is easiest to model. These techniques are described elsewhere (e.g. Alder 1980; Clutter et al. 1983).

### *(e) Procedures*

A modification of the method of analyzing permanent sample plot and temporary sample plot records to produce yield tables was recommended by Reimer and Lussier (1984). Their method is logical and is the best way to proceed in the case of the Canadian regions. The relevant section is provided in the Phase I Report found in Appendix I of Reimer and Lussier (1984). Some especially relevant passages are abstracted in the following two sections.

**Basic model format.** The basic model format suggested (by Reimer and Lussier) is that of a static, multiple-equation, component forecasting system. The system suggested includes separate estimating equations for the following components of stand yield:

1. Stand top height
2. Stand density
3. Stand diameter
4. Stand volume

Such a format would enable the development of models with good predictive behavior for a wide variety of species and available data. In practice, each equation in the linked set attempts to describe the mensurational relationship of a parameter of interest; the more complex parameters, such as volume, are functions of the simpler parameters, such as stand top height and basal area.

Reimer and Lussier (1984) propose stand top height as the basic driving parameter of the system, as it is the parameter least affected by changes in stand density. All stand descriptions and parameter relationships would be tied directly or indirectly to stand top height. Age and basal area are the other two independent parameters.

Yield tables, as noted earlier, represent a static rather than a dynamic growth model in the sense used by Alder (1980).

**Specific model format.** The basic data bank will be required to supply volume classified by species, site, age, and stand density. The stand structure is to be described by average DBH, stem frequency, and basal area, which are functions of species, site, age, and stand density.

The specific model format suggested for this study is as follows:

Site: Height = f (age)
Average Stand Density: BA = f (site, age)
Volume: Volume (or weight) = f (site, age, BA)
DBH: DBH = f (site, age, basal area)
SPH: Defined by BA and DBH

Where:
Height = site height in metres (from site curves)
BA = basal area in $m^2$/ha
Volume = volume per hectare in $m^3$ (gross or net merchantable to any standards for which data are available.
DBH = average stand diameter, perhaps in the form of a quadratic mean diameter, or another expression of average stand diameter.
SPH = stems per unit area (hectare)

Because DBH is expressed as the quadratic mean DBH, stems per hectare are defined by basal area and DBH.

Several levels of stand density should be specified according to experience, perhaps 75%, 100% and 125% of average stocking (average stand density).

Currently, this model could be applied to all provincial inventory systems except that used in New Brunswick, but most provinces would still have to derive the component equations required for each species of commercial or management importance in their land base.

If a growth model is required, it could be achieved by using a net basal area growth function instead of average stand density. This basal area growth model would then be: the increment of basal area = f (site, age and starting basal area).

**Summary.** Multiple-equation systems which forecast yield in terms of components have been widely used since the development of computer-based simulation models. While most component simulation models have been developed specifically for use in analyses of intensive forest management regimes, component forecasting systems are equally beneficial for natural stand forecasting.

The recommended standard static yield model to be used as a basis of comparison for other growth and yield models currently in use in Canada and the United States, is a component model. The model is a whole stand model, predicting stand average parameters. However, it can easily be modified for stand table projection or for managed stand simulation, as dictated by management requirements and data availability.

The model suggested is a height-based forecasting model. Height is used as the driving parameter as it is the parameter least affected by variations in stand density. In addition, the use of height can simplify model construction and field application if only a single set of mensurational relationships need be derived which are to be equally applicable to all heights and site indices for a particular species.

In presentation of yield tables, the British Forestry Commission uses yield classes which provide a clean, simple and straightforward format. They define a yield class as a method of classifying crop growth in terms of the potential maximum mean annual increment (maximum rate of production) which can be obtained by a given species on a given site, expressed in steps of 2 $m^3$/ha•yr (Horne and Whitlock 1984).

## (f) Growth and yield cooperatives

The establishment and remeasurement of permanent sample plots is a time-consuming and expensive job. The design of the sampling plan, and the determination of which age classes, site classes, species, and species groupings should be sampled is not easy. The compilation and analysis requires reasonably competent mathematical skills and computer availability. The successful production of regional yield tables requires talent and dedication maintained over time. Higher levels of management must be persuaded that the work is valuable so that budgets are maintained. Observation of the variable results across Canada indicates that a favorable combination has seldom been maintained for the requisite period of time.

One suggested solution is growth and yield co-ops. They help to foster commitment and continuity of effort, and members benefit by sharing information and data.

Co-ops have been established, most notably on the west coast. Permanent sample plot records have been submitted and productive exchanges of raw data have occurred.

In 1981, Frank Hegyi, as Chairman of the Forest Growth Projects Subcommittee of the Canadian Forest Inventory Committee and as Project Leader of the co-op COSMADS (Committee on Standards of Measure and Data Sharing of the Western Forestry and Conservation Association) proposed that a catalogue of permanent sample plots across Canada be established. Since that time, he has worked in close cooperation with the Canadian Forestry Service to assist and guide them in that task. The resulting Canadian Permanent Sample Plot Catalogue and manual is identical in most respects to the COSMADS catalogue and manual.

Two other cooperative organizations are the British Columbia Coastal and Interior Productivity Councils, which have a joint Technical Advisory Committee.

The regional offices of the Canadian Forestry Service are also in an ideal position to encourage and promote the formation of co-ops, and to provide central facilities, secretariat, and basic services in each region. The software for the Canadian Permanent Sample Plot Catalogue has been installed in five Canadian Forestry Service regional offices.

## (g) Discussion

There is undoubtedly a wealth of data in Canada that has been or could be utilized to develop yield tables. Bickerstaff and Hostikka (1977) have documented much of this and there is probably more, especially work done by individual forest companies that could be discovered and utilized. Most of this work is local in scope or the study designs, fieldwork, compilation or analysis are incomplete. While it would theoretically be possible to complete and utilize this work, it could be difficult. A more efficient way to stimulate their use might be to offer extension services. Sample designs, field instructions, analytical packages (including mathematical procedures and computer programs) could be made available and promoted for local use across Canada. This would encourage the use of yield tables in Canadian forest management, and would improve the quality of yield tables.

At the provincial management levels, yield tables are appreciated and used to varying degrees. There are some notable gaps, for example in Manitoba and Prince Edward Island. In some cases, such as Newfoundland and New Brunswick, the type of yield tables in use is not fully satisfactory to the users, who would like to upgrade it. There are cases where the yield tables in use are sophisticated and advanced, but still do not represent the forest in the best possible way. For example, Ontario uses normal tables with their inherent problems in application; and British Columbia uses tables based on

T.S.P.'s, whereas P.S.P.'s would give more truly characteristic results.

The proposed tables would present the dependent variables of volume (total and merchantable, by utilization standard), basal area, mean diameter, top height, and number of trees per hectare for each age class by top height class. Tables would be produced on a regional basis for all major species present. Stands of mixed species would be treated as single species stands of the leading species or as single species stands of a species association. Corresponding biomass yield tables would be produced presenting tree components by oven-dry and green mass. The tree components would be bole, bark, branches, and foliage. Branches may or may not be broken down into size classes depending on the size of the trees in the region. These yield tables would be a joint production of the provincial and territorial inventory services in cooperation with the regional offices of the Canadian Forestry Service.

The basis of the yield tables would be existing records of permanent sample plots. Validation of site curves would be a first step in the preparation of the tables. In some cases, some or much of the work has been done and is available. In the Prairies region, Alberta and Saskatchewan have good yield tables. These tables might be validated for Manitoba and the Northwest Territories using the limited permanent sample plot data presently available. The biomass tree component equations are available and can be applied to these two sets of yield tables. The Prairies region might well be considered appropriate for a pilot project.

While it is possible to collect general information about the availability and status of yield tables across Canada, it is not possible to assemble detailed accounts of exactly what is available in each case. This should not be necessary to proceed to the next stage of this project. If the principles and general practices proposed are reasonable and the expected results and outcome seem to be of value, the details can be left to a later stage.

## Biomass yield tables

Biomass (total tree mass above ground) yield tables parallel standard yield tables. They report the tree mass in kilograms by component parts: main stem wood, bark, branches, and foliage. They aid forest management and forest utilization planning, as do standard yield tables.

### *(a) Purpose and use*

The major use of biomass in the future will be as fuel. Predictions of the future supply of biomass by species, tree component, size, age, and location will be required. These will provide a basis for calculating delivered cost, processing machinery specifications and costs, and the quantity of energy that could be produced. Other information required will include the specific heat and moisture content of the biomass by tree species and tree component. This will be used to calculate the gross quantity of available energy. The operating efficiency of the generating equipment will be used to determine the net quantity of energy available. A cost-benefit analysis will then show whether to proceed with any biomass-related energy project.

Biomass yield tables are essential in planning alternate energy generating schemes where, either out of choice or necessity, a renewable resource is to be used. Like regular yield tables, they are required to determine and control the annual allowable cut. As and when biomass utilization becomes a regular practice and the value of biomass is confirmed, appraisal of biomass for sale, purchase, barter or compensation for loss will become necessary.

### *(b) Construction*

Biomass yield tables differ from conventional yield tables in that they express mass instead of volume. This has already been done in the development of the biomass tree equations. These equations, in conjunction with yield table equations, can be used to generate biomass yield tables or equations.

There are several ways in which these biomass tables can be produced. Four approaches are discussed below:

1. One approach would be to take a standard yield table preparation format and apply the permanent sample plot data base (Appendix 2). This could be done in a central location such as the Petawawa National Forestry Institute. Sufficient communication and computer services would be required. Cooperation of the members of the Canadian Forest Inventory Committee would be needed, as they are the major holders of the base data. Minor data sources resident in the Canadian Forestry Service would be readily accessible.

   This approach would produce completely standardized and compatible national biomass regional yield tables. The work of Evert (1983 and 1985) on national systems to develop equations for estimating the oven-dry mass of aspen and 18 other Canadian species has shown this approach to be feasible and efficient. The broader data base has considerable advantages in producing regional and national tables. Minor gaps and inconsistencies can be filled or resolved when a large data base is available to manipulate. Experience with the development of the national biomass inventory (Bonnor 1985) should provide a strong basis for such a project.

2. If the P.S.P.'s data prove to be unavailable or difficult to process then a complete, self-contained study could be mounted. It would involve the production of a national and regional sampling design, the establishment and remeasurement of P.S.P.'s, and the compilation and analysis of the data to produce regional biomass yield tables. This approach is amenable to strong, central control for consistency, accuracy and compatibility with existing inventory, although measurements could be conducted regionally. The regional centres of the Canadian Forestry Service are capable of conducting this type of project. Preliminary biomass yield tables could be compiled centrally using the first measurements of the P.S.P.'s as temporary plot data. On remeasurement after five years, revised yield tables could be computed and published. These would be based on growth trends.

3. A combination of the first and the second approach might be preferred. All permanent sample plot records could be scrutinized vigorously and only those satisfying certain criteria might be accepted. A comprehensive sampling design would then be produced to include all major species, sites and age classes. Unsampled or incomplete sample strata would be identified and a listing of required additional P.S..P.'s would be developed; these plots would be established and measured. Analysis to produce preliminary biomass yield tables would be followed by revised biomass tables when the remeasurement of all additional plots was completed.

In each of the preceding cases, it would be necessary to add elements for trees smaller than the minimum tree size tallied in the data base used. This was done for the 1985 forest biomass inventory using factors. These same statistics could be used or their accuracy and efficiency confirmed by additional subsampling. The percentages involved are small.

Some P.S.P.'s data base records may be deficient in nonmerchantable tree sizes or in noncommercial species. Again, it may be possible to adjust the totals by the addition of an appropriate component using factors, from additional field samples or from existing temporary sample plot records.

A final step is to apply the appropriate energy equivalents per cubic metre of wood in joules per oven-dry tonne by species or species group. Bark and foliage would have different calorific values than wood. The basic data required were mostly assembled for the 1985 forest biomass project. Additional information may be required for species not included in previous studies.

4. Another approach is to collect existing yield equations. These equations or tables could be converted to a common compatible base by mathematical interpolation, substitution, or approximation. In the case of missing equations, substitutions could be made between regions or between species. This would produce the equations required for all six regions.

The tree mass equations (green and oven-dry mass) would be assembled, including small tree factors and nonmerchantable tree factors for each of the six biomass regions. Necessary additions to the data already assembled for the 1985 biomass inventory (Bonnor 1985) should first be identified. Similarly, any additional calorific values for green and oven-dried wood, bark, and foliage by species would be assembled as necessary.

Application of the tree mass equations to the yield equations would produce regional biomass equations. The calorific values of species would be applied, and the biomass yield equations would be published.

## Differences between standard and biomass yield tables

There are differences between biomass yield tables and standard yield tables. Standard yield tables describe the forest stand in gross and merchantable volume by species or species group, age, site, and perhaps by some measure of stocking or density. They can also report height, diameter, basal area, stems per hectare, and occasionally crown size. Biomass tables give the (oven dry) mass of the forest by species or species group, by age, by site and stocking or density in the tree components: bole wood, bole bark, branch wood plus bark, foliage, and sometimes roots.

# Working plan

A suggested working plan to develop and produce regional biomass yield tables for Canada is outlined in the following sections.

## Method

The first of the four approaches outlined previously will be followed: a representative subset of the basic permanent and temporary plot data that were used to generate the various regional standard yield tables will be obtained. These basic data will be obtained in the form of a tree list for each plot giving the species, height, and diameter of each tree on each plot. In addition, other relevant parameters such as site index and location will be added to the records of each plot. This tree list will then be converted to the various biomass components using tree biomass equations. An estimate of the biomass represented by trees less than 7 cm in dbh and noncommercial tree species will also be added to each plot; this may be done according to the procedure used in the ENFOR Canadian forest biomass project (Bonnor 1985). Once the basic data are assembled, the methods suggested by Reimer and Lussier (1984), discussed in a previous section, will be applied to generate biomass yield tables.

This approach will require the pooling of plot data from various provincial and federal sources. As the proposed biomass yield model is driven by height as expressed by site index, special care will be required to ensure that the site index relationships used by various agencies are consistent. In some cases, this may require the use of standardized height age curves, as discussed in a previous section.

## Schedule

### *Stage 1: Pilot study - one species, one region*

*Phase 1 - (2 months).* Assemble tree mass equations (green weight and oven-dry), as well as small tree and non-merchantable tree factors and calorific values for all species for each of the six biomass regions.

*Phase 2 - (12 months).* Assemble available yield data from permanent sample plots and temporary sample plots that was used to generate yield equations for each biomass region of Canada.

Develop yield equations from the assembled data using a common model. When data are missing, use data from another region or species.

Phase 3 -( 6 months). Apply tree mass equations to yield data developed in Phase 2 to produce regional biomass yield equations for green and oven-dry wood, bark, and foliage by species. Apply calorific values to produce estimates of available energy.

Phase 4 -( 4 months). Publish biomass yield equations and estimates of available energy per unit area for all six regions of Canada in English and French. In some cases, it may also be advantageous to publish the regular yield tables that were generated in Phase 2.

### *Stage 2*

Phases 1 to 4 for the remaining species in the first region.

### *Stages 3 to 7*

Phases 1 to 4 for all species in the remaining regions.

This schedule recommends a pilot study for one species in one region. It could be jack pine or black spruce in the Prairies region, or white spruce in Prince Edward Island or Nova Scotia. It would provide the opportunity to test the technical ability to project acceptable results to Manitoba and the Northwest Territories from the Alberta and Saskatchewan records, or to P.E.I. from New Brunswick and Nova Scotia.

The pilot study should be completed in 12 months. It would be followed by completion of that region's remaining commercial species, and then region by region until all are completed. This repetitive process will vary in difficulty and cost. It could take 5 to 6 years to complete the entire series.

Data bases, whether computerized or not, often contain some inconsistencies. These can cause unpredictable delays, so this schedule is approximate. There are, of course, ways to minimize the effects of these problems. There are forest mensuration analysts who have the ability to foresee and unravel the complexities inherent in stored data. The selection of the most appropriate technical personnel is essential for successful completion of the project. Skill, dedication, and patience will be needed.

At the conclusion of the project, both regular and biomass yield tables would be available for all major commercial Canadian tree species.

## Cost estimate

This estimate will, if necessary, have to be adjusted according to the base location of the technical personnel responsible:

Stage 1: Pilot Study: One region one species

| | | |
|---|---|---|
| Phase 1 | | |
| 8 man days @ $500/day | $4000 | |
| 2 man days @ $250/day | 500 | |
| Expenses | 500 | $5000 |
| Phase 2 | | |
| 120 man days @ $500/day | $60 000 | |
| 40 man days @ $250/day | 10 000 | |
| Travel and expenses | 15 000 | |
| Computer costs | 10 000 | $95 000 |
| Phase 3 | | |
| 20 man days @ $500/day | $10 000 | |
| 20 man days @ $250/day | 5000 | |
| Expenses, computer time, etc. | 10 000 | $25 000 |
| Phase 4 | | |
| | | $35 000 |
| Sub-Total | | $160 000 |
| Stage 2: Phases 1 to 4. Remaining species in pilot study region | | $160 000 |
| Stages 3 to 7: Phases 1 to 4. Remaining five regions @ $160,000/region | | 800 000 |
| TOTAL | | $1 120 000 |

## Conclusion and recommendations

The production of regional biomass yield tables for Canada is feasible and is recommended. It will require an estimated $160 000 over a 1-year period for the pilot study and a global cost of $1 120 000 over a 5- to 6-year period to develop such regional biomass tables for all of Canada.

The most difficult part of this project will be Phase 2. It will require remarkable skill to take the yield data and produce compatible equations and tables from what is available across Canada. It will need intelligent transfer and substitution, using the best and closest approximations from region to region and species to species to fill the gaps such as those in Manitoba, the Northwest Territories, and Prince Edward Island.

The proposed method of developing biomass yield tables is to apply the ENFOR program's individual tree component biomass equations to selected provincial yield data. This method should give regional biomass tables that would cover Canada, and at the same time reveal opportunities to upgrade the provincial yield table base. Biomass yield tables will complement regular yield tables expressing weight by components rather than volume and tree dimensions. They will describe the forest and its productivity more completely. They will not be an alternative to regular yield tables.

In more specific terms, it is recommended that the work of Reimer and Lussier (1984) be used as a basis and that those parts of the country that require assistance be aided in bringing their yield tables up to a basic standard by the method recommended.

It is also recommended that this process be assisted by regional co-ops based on the six regional Canadian Forestry Service centres. Further, we recommend that smaller forest agencies, including private ones, be assisted in developing yield tables from local data for local use.

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# Appendix 1.

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# Appendix 2

Estimated status of growth and yield data base by biomass region

| Biomass region | Province or territory | Type | Management regime Age Even | Uneven | Natural | Plantation | Data source P.S.P.'s | T.S.P.'s | Format Table | Equation | Analysis | Author |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pacific | B.C. | Empirical | x | - | x | - | 4739 | 50 000 | x | x | Chapman-Richards Ek-Payandeh | B.C.F.S |
| | | Variable Density | x | - | x | - | 4739 | 50 000 | x | x | Chapman-Richards | B.C.F.S. |
| | Yukon | None | | | | | 16 | | | | | |
| Prairies | Alberta | Empirical | x | - | x | - | 3131 | 119 | x | x | Monserud | A.F.S. |
| | N.W.T. | None | | | | | | | | | | |
| | Sask. | Empirical | x | - | x | - | 1830 | 24 868 | x | - | - | D.P.R.R. |
| | Manitoba | None | - | - | - | - | 168 | 135 000 | | | | |
| Ontario | | Normal | x | - | x | - | - | - | x | - | - | Plonski(1981) |
| | | Normal | - | - | x | - | - | - | x | - | - | Plonski(1981) |
| | | Variable Density | x | - | - | x | 59 | - | x | x | Least squares | Evert (1976) |
| | | Empirical | x | - | x | - | 347 | - | x | - | - | Evert (1975) |
| | | | | | | | 347 | - | x | x | Richards | Payandeh (1976) |
| Quebec | | Empirical | x | x | x | - | 7155 | | x | - | - | S.I.F. |
| Maritimes | P.E.I. | Empirical | x | | x | | 70 | 900 | x | | | D.E.F. |
| | | Normal | x | | x | | | | x | x | | D.E.F. |
| | N.S. | Variable Density | x | - | x | - | 1765 | - | x | x | - | D.L.F. |
| | N.B. | Empirica | - | x | x | - | 1255 | x | - | x | - | D.N.R. |
| Newfoundland | | Empirical | x | - | x | - | - | 1864 | x | - | - | C.F.S. |
| Totals | | | | | | | 20 535 | 212 751 | 14 | 8 | | |

*Does not add up since some plots have been used to construct several tables.

| No. of zones | No. of species | No. of species groups | Age ranges | No. of site classes | No. of density levels | Output Variables | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Height | Diameter | Trees per hectare | Basal area | Crown class | Volume | |
| | | | | | | | | | | | Total | Merch. |
| 12 | 13 | 17 | 0-250 | 4 | - | - | x | - | - | - | 1 | 4 |
| 12 | 15 | 6 | 0-140 | 7 | 3 | - | x | x | x | x | 1 | 4 |
| - | | | 0-250 | 4 | - | | | | | | | |
| - | - | - | - | - | - | - | - | - | - | - | - | - |
| 1 | 3 | 3 | 0-180 | 3 | - | x | x | x | x | - | 1 | 4 |
| - | - | - | - | - | - | - | - | - | - | - | - | - |
| 8 | 7 | 3 | 0-70 | - | - | x | x | - | x | - | 1 | 1 |
| - | | | 0-95 | - | - | | | | | | | |
| - | - | - | - | - | - | - - | - | - | - | - | - | |
| 1 | 6 | 8 | 0-90 | 3 | - | x | x | - | x | - | 1 | 2 |
| | - | | 0-190 | - | - | x | - | - | x | - | 1 | 1 |
| 1 | 1 | - | 0-65 | 1 | - | x | x | - | x | - | 1 | 1 |
| 1 | 1 | 1 | 30-90 | 3 | 5 | - | x | x | x | - | - | 1 |
| 1 | 2 | 3 | 30-120 | - | - | x | x | x | x | - | 1 | 1 |
| | - | | 30-140 | - | - | | | | | | | |
| 1 | - | 1 | 20-150 | 6 | - | | | | | | | |
| 27 | 7 | - | 0-50 | - | - | x | x | x | x | - | 1 | 1 |
| | - | | 0-150 | - | - | | | | | | | |
| - | - | - | - | - | - | - | - | - | - | - | - | - |
| 1 | 6 | 3 | 0-100+ | 6 | 5 | x | x | - | x | - | 1 | 1 |
| 1 | 2 | 30 | 0-100+ | - | - | x | x | - | - | - | 1 | 1 |
| 1 | 6 | 6 | 0-100+ | - | - | x | x | x | x | - | 1 | 1 |

# Appendix 3

## Information categories in Canada's forest inventory, 1986

### A. MAIN FILE

**1. Location**

1.1 Province or Territory
1.2 Cell Reference
• code which identifies a cell or mapsheet used by the managing forest agency for data aggregaton.

**2. Classification Codes**

2.1 Data Source (Reconnaissance; Management; Operational Inventory)
2.2 Ownership
2.3 Status (Reserved; Non-reserved; Assigned; etc.)
2.4 Land Class (Productive, Unproductive)
2.5 Site Quality
2.6 Stocking Class
2.7 Cause of Disturbance (refer to auxiliary file for stocking mixture for areas having unproven stocking following disturbance)
2.8 Age Class
2.9 Maturity Class
2.10 Forest Type (Softwood; Mixedwood; Hard wood)
2.11 Predominant Genus

**3. Numerical Attributes**

3.1 Year of Information
3.2 Area (ha)
3.3 Volume ($m^3$/ha) by species group

### B. AUXILIARY FILES

1. Stocking Mixture - give the mixture of non-stocked, partially stocked, and fully stocked land
2. Conversion of Age Class to Maturity Class
3. Policy Constraints on Wood Harvest
4. Cull
5. Tree Size-volume Relationship

# Appendix 4.

## Canadian Forestry Service projects and studies in growth and yield by region, 1987

### Newfoundland Forestry Centre

Project 24: Tree and stand growth

Study 01 -Influence of stand density and fertility on productivity - R.S. van Nostrand, M.B. Lavigne.
Description - Study to investigate productivity gains through spacing and fertilization in natural and planted stands

Study 04 - Tree and stand growth prediction - M.B. Lavign
Description - Investigations of biological and physical factors influencing tree growth and predicting the effect of perturbations on growth and yield.

Study 05 - Stand density model - black spruce - P. Newton.
Description - Development of a stand density model for pure black spruce in central Newfoundland.

Study 06 - Advisory services - growth and yield - M.B. Lavigne, P. Newton.
Description - Provision of professional expertise and advice in the discipline of growth and yield to client agencies.

### Canadian Forestry Service - Maritimes

Project 32: Forest Productivity

Study 19 - Mathematical models: tree and stand growth - M.F. Ker.
Description - To develop mathematical models of tree and stand growth for balsam fir.

### Centre de foresterie des laurentides

Project 41: Croissance et production en forêts feuillues amenagées

Study 01 - Production des stations forestières - R. Zarnovican.
Description - Dispositifs experimentaux et analyse quantitative et qualitatives de peuplements boj, ers, fra.

### Great Lakes Forestry Centre

Project 04: Black spruce ecosystem silviculture

Study 02 - Growth and yield - B. Payandeh.
Description - Growth and yield of black spruce on peatlands in Ontario.

### Northern Forestry Centre

Project 04: Stand productivity & forest inventory.

Study 01 - Growth & yield of native tree species - I.E. Bella.
Description - Evaluate effects of site quality, species, stand density, pests & environmental agents.

Study 01 - Stand modelling of growth and development of important forest species - H. Grewal.
Description - Assess stand growth & development for different treatments by modelling.

### Pacific Forestry Centre

Project 41: Growth and biology of coastal Douglas-fir

Study 02 - Pilot fertilization - thinning trials in coastal Douglas-fir - E. Gardner
Description - Set up to provide annual stand growth information for fertilization and thinning effects on a Douglas-fir ecosystem at Shawnigan Lake for input into growth models.

Project 43: Systems studies in regional forest management problems

Study 04 - Quantitative study of site productivity and competition effects - H. Barclay
Description - To investigate the quantitative effects of thinning on tree growth which will allows the formulation of explicit prescriptive management guidelines for improving tree growth.

Project 42: Forest growth and measurement

Study 02 - A model for projecting stand volume in forest inventories - G.M. Bonnor

Description - To investigate how the accuracy of the estimates can be improved using existing data, using additional variables, or by increasing sample size.

Study 03 - Growth models of unevenaged stands of Douglas-fir of the B.C. Interior - G.M. Bonnor

Description - To develop operational growth prediction model by stem diameter distributions for stands managed under the Faller Selection Method.

Study 04 - Response of W. hemlock to fertilization and spacing Part I: Review of existing information - H. Brix and E. Gardner

Description - To gather and review existing information on the responses of western hemlock to spacing and fertilization so that future trials can be designed to provide an optimum of new information.

Study 05 - Forest pest damage and assessment research - R. I. Alfaro

Description - To determine relationships between the level and duration of pest infestations with the loss of growth or mortality of trees and stands. To investigate new technologies for the measurement of damage caused by forest pests. To understand and describe the damage caused by insects and diseases to the forest resource.

Study 06 - Application of remote sensing to pest damage detection and appraisal - Y.J. Lee

Description - To determine if damage due to root rot and spruce budworm defoliation can be reliably detected and assessed using air photos and satellite data.

Study 08 - Levels of growing stock (LOGS) study in Douglas-fir - J. Arnott

Description - To determine how the amount of growing stock retained in repeatedly thinned stands of Douglas-fir affects cumulative volume production, tree size development and growth/growing stock ratios. The combined data from all cooperators will provide the basis for improved Douglas-fir stand tending methods.

**Petawawa National Forestry Institute**

Project 12: Silviculture - growth and yield

Study 57 - Growth and yield - red pine plantations - D. Brand.

Description - Development of thinned and unthinned red pine plantations at various spacings.

Study 58 - Growth and yield - white spruce - D. Brand.

Description - Growth and yield of thinned and unthinned white spruce plantations at various spacings.

Study 64 - Successional growth and yield - (Vacant)

Description - Growth and successional trends of common forest cover types. Development of various forest types under specific site or treatment conditions.