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Natural Resource Stock Accounts:
Physical Data for Ontario's Timber

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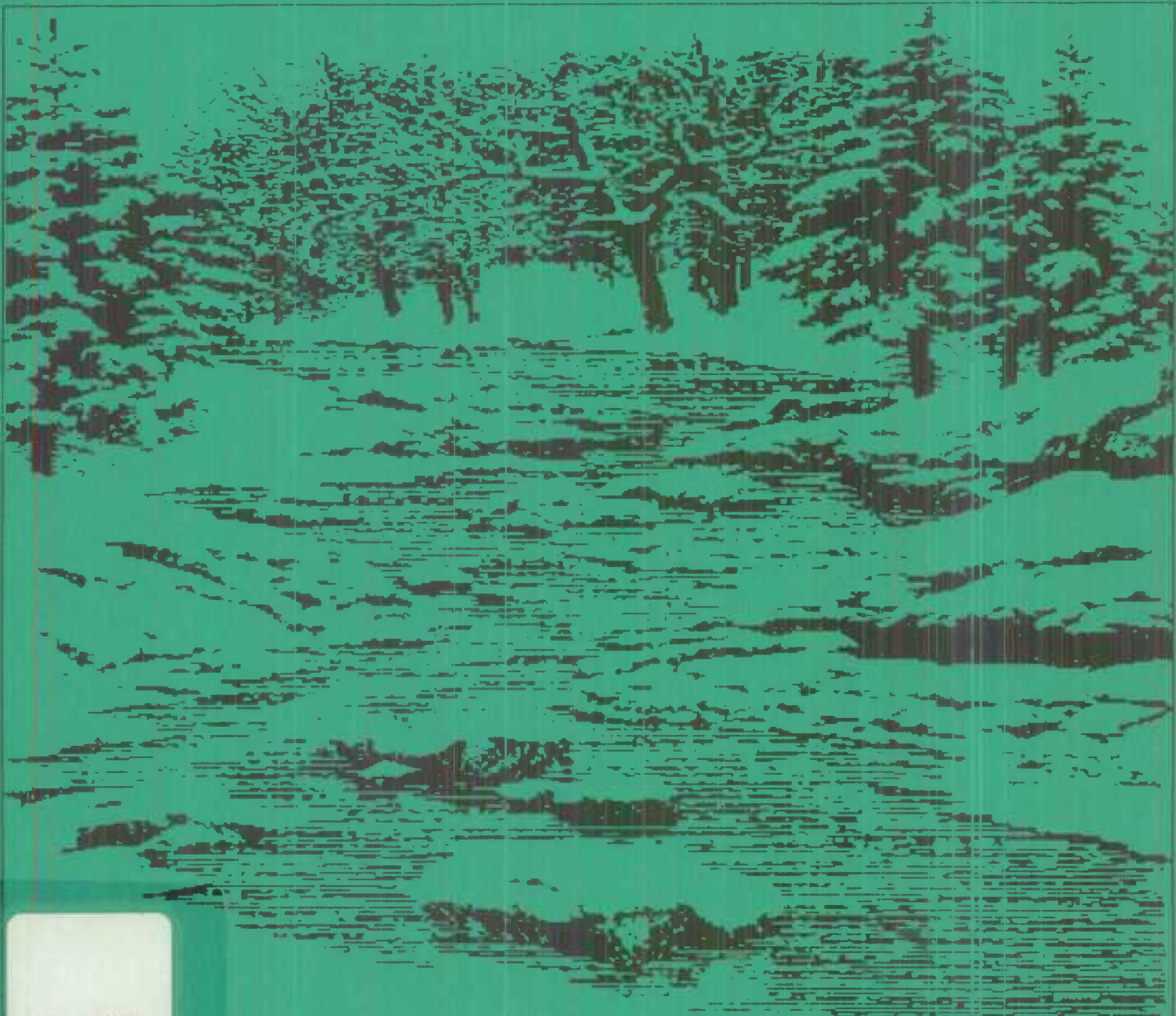

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Natural Resource Stock Accounts: Physical Data for Ontario's Timber

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This paper presents preliminary estimates of the natural resource stock accounts.

Ce texte présente les estimations préliminaires des comptes des stocks de ressources naturelles.

This paper is one in a series of internal discussion papers produced in Statistics Canada's National Accounts and Environment Division. These papers address topics related to environmental statistics and the National Accounts components which are currently under development.

Ce document fait partie d'une série de documents internes produits dans la Division des comptes nationaux et de l'environnement de Statistique Canada. Ces documents traitent de sujets reliés aux statistiques de l'environnement et composantes des comptes nationaux au stade de la recherche.

Discussion papers in this series are made available in the official languages in which they were written. Translated versions are not available in most cases.

Le documents de travail de cette série sont disponibles dans la langue officielle dans la quelle ils sont écrits. Les versions traduites ne sont pas disponibles dans la plupart des cas.

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1 Introduction

The physical timber resource account described in this paper is one of a number of natural resource stock accounts being developed by Statistics Canada.The physical timber accounts are a series of year end stock data which show the area covered by all forest land and describe its volume, age and species composition. The change in these stocks from year to year and the reasons for this change, such as growth, harvest, natural loss or change in land use, are also presented. The physical accounts are based on forest inventories produced by the province. These are carried out periodically for different land bases so that stock data are not available as a time series. To obtain a times series, missing years' data are estimated by using a model which starts with inventory data for a period and simulates the impact of growth, harvesting, natural loss and other changes.

These accounts will form an environmental component of the Canadian System of National Accounts, the major statistical framework for the measurement of economic activity in Canada. The purpose of this component is the measurement of the effect and dependence of economic activity on the environment. Four groups of accounts are being developed to cover natural resource stocks, natural resource use, waste or pollutant output and environmental expenditure.

Environment and natural resources in the Canadian System of National Accounts

Resource stock accounts will show year-end stocks of renewable and non-renewable resources and account for the changes (e.g., harvesting, growth) from year to year. Data will cover both physical quantities and monetary value. A set of monetary accounts have been developed for Canada's oil and gas reserves (Born, 1992), coal reserves (Born et al., 1995) and timber stock in Ontario (Gravel et al.,1995). The value of natural resources will be included in the measure of national wealth provided by the National Balance Sheet Accounts.

Resource use will be shown in extended input-output accounts which include physical quantity data for resource use. These accounts can provide measures of intensity of resource use, for example, the amount of energy used per dollar of output of a good or by an industry (Hamilton, 1993). Waste and pollutant output is also measured in extended input-output tables (Smith,1993). These accounts provide data on the quantity of pollutant emitted per dollar of output of a good or by an industry. Environmental expenditure accounts will show the costs associated with waste management or disposal, pollution abatement and environmental restoration.

The development of timber resource accounts started with an Ontario pilot project, carried out with the assistance of the Ontario Ministry of Natural Resources (OMNR). The first phase of this project, construction of historical time series estimates for forest stock data, is complete.

2 Timber resource accounting structure

The Ontario timber resource account involves the development of a simulation framework, ***STCMacroForest*** (Moll, 1992), which evolves an age-distributed stock (area) of forest land over time and is classed as a positive linear systems model (Luenberger, 1979).

STCMacroForest for Ontario distinguishes twenty four districts that contain productive stocked and non-stocked nonreserved forest land. Stocked forest land (Haddon, 1988) is land supporting tree growth which in this context includes seedlings and saplings. Nonstocked forest land (Haddon, 1988) is productive forest land that lacks trees completely or that is so deficient in trees, either young or old, that at the end of one rotation, the residual stand of merchantable tree species, if any, will be insufficient to allow utilization in an economic operation. Within each district, the framework distinguishes three cover types (coniferous, mixed-wood and hardwood) and 180 single year age-classes. The dynamic properties of the forest are age- and cover type- specific.

STCMacroForest attempts to integrate the processes of fire, mortality, harvesting, aging, natural and artificial (planting) regeneration with the forest inventory measurement process over a historical period 1953 to 1991. This period was originally chosen because the Ontario 1953 Forest Resources Inventory (Ontario FRI, 1953) provided the only initial condition for the simulation. However, this inventory did not provide a numerically defined age-class distribution. At first we attempted to calibrate the model using an assumed age-class distribution derived from the aggregate maturity classes given in the 1953 FRI. However, we were unable to meet the 1991 target age-class distribution using these initial conditions Therefore, a different approach was adopted. First, the 1953 inventory is estimated by running the simulation model backwards. Using the estimated 1953 age-class distribution, as the initial condition, we then ran the model forwards to meet the desired 1991 data points. This method will be described in more detail in the section entitled model validation.

The 1991 Ontario FRI was used as the end point of the simulation. As described in section 3.3 the 24 districts used in the 1953 FRI were selected as the spatial resolution for the simulation model. These boundaries, as shown in Figure 25, were maintained because most of the change data can be made to conform with this spatial resolution.

The following are the main factors which give rise to changes in the simulated forest over time:

- growth and endemic mortality due to disease and insects are absorbed in the volume per hectare as a function of age (empirical yield curves);
- catastrophic stand mortality due to fire (fire rates);
- annual volume harvested given by cubic metres of softwood and hardwood roundwood;
- aging and natural regeneration after fire;
- artificial and other natural regeneration.

These factors will be described in more detail in sections 2.2 to 2.4. First, the input and output variables are defined together with the structure of the calculation sequence during one period (a year) of the above mentioned processes.

2.1 Time loop structure

We describe ***STCMacroForest*** by reference to the following "structural diagrams" (Figures 1 to 5). These show the representation in the accounting framework of the development of a large-scale forest over time. This diagrammatic language identifies the input-output relationship of variables to and from each step (rectangles) that constitute the model. During the design process, the structural diagram approach is a useful communication medium for model development since a dynamic model may be completely described using stock/ flow variables and parameters. A stock variable is represented by a barrel, a flow variable by a pipe and a parameter by a hexagon.

Since we cannot fit the entire model on a single page, variables that are connected to processes on different pages are shown using off-page connectors which identify the source and destination process. Variables and parameters are connected to processes with arrows signifying the direction of information flow. With each graphical object is text which labels the object and describes the multi-dimensional structure of the variable.

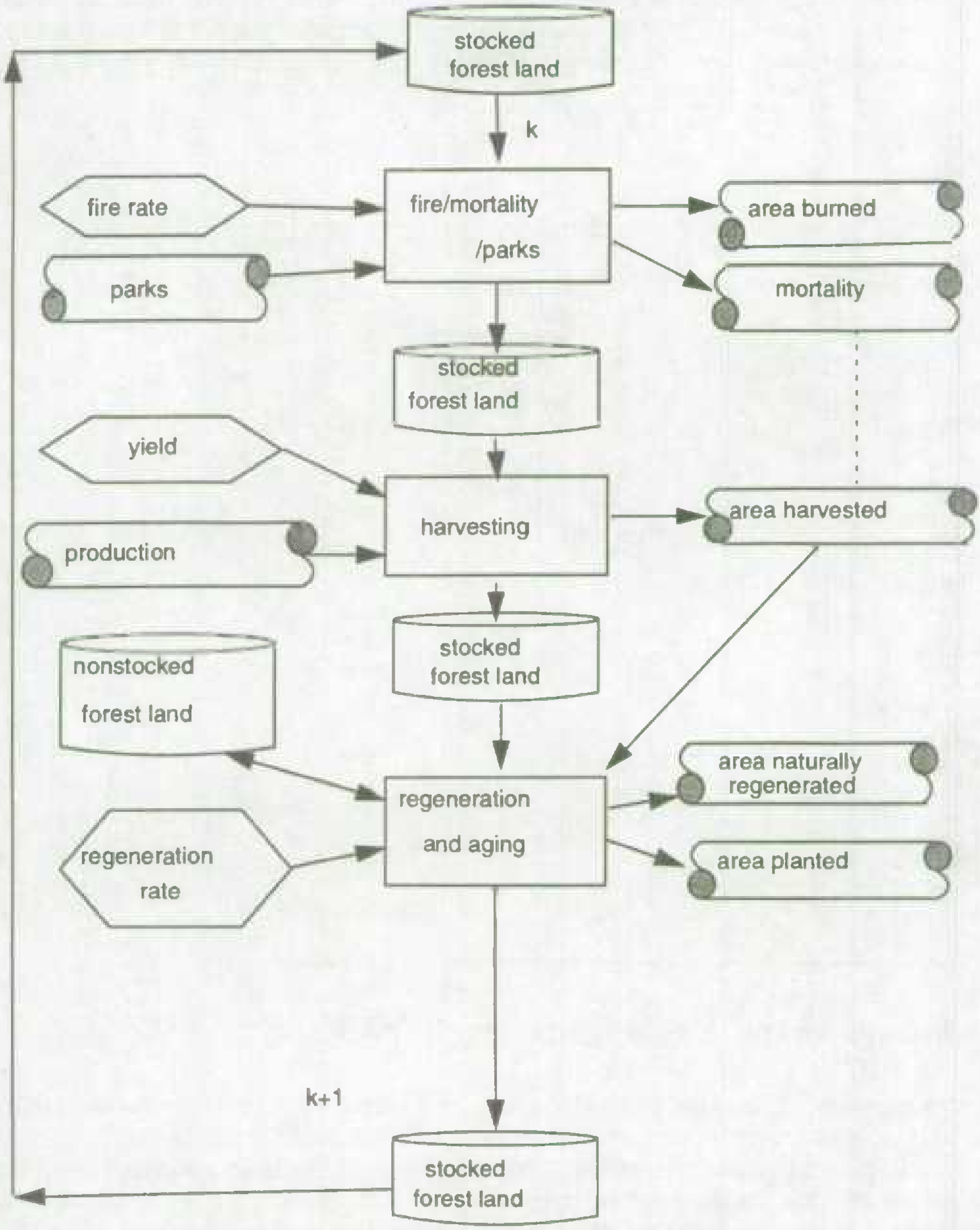
Figure 1 outlines an overview of the calculation sequence of ***STCMacroForest***. The inputs and outputs associated with the processes of fire, mortality, adjustment for parks, harvesting, aging and regeneration are shown. These show the order in which the calculations are performed during one iteration (a year) of the accounting period. As can be seen from Figure 1 the stocked forest land at the start of a period is adjusted for loss due to fires and natural mortality. Forest land area which became parkland is also removed from the exploitable forest land base. The surviving stocked forest land is input to the harvesting calculator where the annual roundwood production (m^3 of timber) is translated into area harvested from the stocked forest land.

We assume that area burned regenerates as the same cover type. This is modeled by burned area regenerating in the first age-class at the start of the subsequent period. Natural mortality due to aging regenerates by prorating the oldest age-class over the other age-classes at the start of the subsequent year. This process is explained in section 2.5.

The harvesting algorithm assumes that the harvest area cut is met by proration of the cut according to the distribution of the potential volume of timber by age-class. Harvesting of two wood types "softwood" and "hardwood" is performed in three cover types. Softwood is extracted from "coniferous" and "mixedwood" cover types and hardwood roundwood exclusively from the "hardwood" cover type.

In the last block we regenerate newly harvested area either by planting or natural regeneration. Regeneration of nonstocked forest land occurs at this stage. Finally, the stocked forest land is aged by shifting area from each age-class to the next oldest age-class. The year index is incremented and the calculations are repeated for as many years as there are in the simulation time horizon.The next sections will describe the processes of fire, mortality, harvesting, aging and regeneration in more detail.

Figure 1:
Time loop structure of STCMacroForest



2.2 Indices and titlesets

The algebraic idiom of multi-dimensional arrays is used to represent the data objects which comprise the inputs and outputs of the accounting framework. First the stratification of each array dimension is defined by listing the names of each dimension as shown in Table 1. These lists are called titlesets and are fundamental building blocks in the model. They allow a model to be succintly stated.The titlesets describe the level of disaggregation while providing a notation for indexing. The elements in a titleset are the dimension labels.

Table 1:
Titleset definitions

Index	Titleset elements	Titleset name	Dimension
k	1953-1991	years	39
i	1:180	ageclass180	180
s	coniferous mixedwood hardwood	cover types	3
d	North Bay Timiskaming Cochrane Kapuskasing Geraldton Thunder Bay Pembroke Parry Sound White River Sudbury Sault Ste. Marie Chapleau Gogama Fort Frances Kenora Sioux Lookout Kemptvi;lle Tweed Lindsay Lake Simcoe Lake Huron Lake Erie PEA East PEA West	districts	24
w	softwood hardwood	woodtype	2

2.3 Forest fires, mortality and transfers to park land

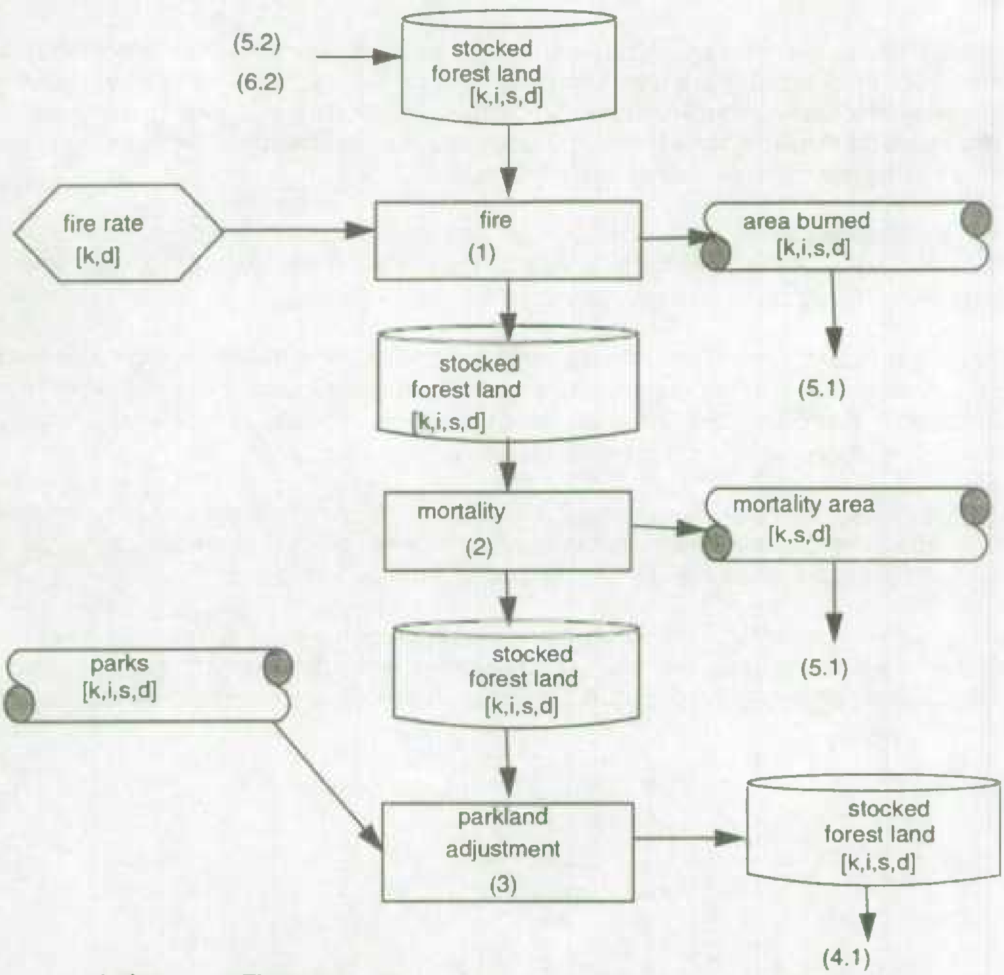
In Figure 2, three adjustments to the forest land stock during a period of the simulation (one year) are graphically represented. These are reductions of stocked productive forest due to fire (process 1), natural mortality (process 2) and newly created parks (process 3). The inputs and outputs associated with each process are described together with the structure of the arrays which represents the stratification of the data objects in the model. For example the stocked forest land is a four-dimensional array where the first dimension is time k, second dimension age-class i , third cover type s and fourth district d. The size of this array is k*i*s*d.

The object stocked forest land has 39*180*3*24 = 505,440 elements. The order of the indices is preserved throughout the documentation. That is, the order [k,i,s,d] is maintained. Consistency in ordering increases the understandability of the model structure. For lower dimensioned objects this order is also preserved. The structural diagram provides two main sources of information, 1) the calculational sequence (i.e. the order of calculation) and 2) a conception of the procedures involving input to output transformation of variables which are either stocks (barrels) flows (pipes) or parameters (hexagons).

Forest land is updated for fire by decreasing the inventory according to historical fires. Fire rates are available for the years 1953 to 1991 and were obtained for the 24 districts. At the district level the fire losses for 1953 to 1991 demonstrate considerable variability. The randomness of fires is apparent and for some years certain districts experienced very large fire losses. For example, in the district of Sioux Lookout a 500,000 hectare fire occurred in 1962. Fires of this size will have a considerable impact on the future age-class distribution of the forest. Fire data are not available on a cover type- or age- specific basis. The fire rates were calculated for each year and district as a percentage of the area burned to the total forest land area for that district. These rates were then applied uniformly for each age-class and cover type of the forest land stock.The area burned stratified by age, cover type and district is subtracted from the stock. The area bumed is summarized by cover type and district and regenerated in the youngest age-class at the start of the subsequent year in process 5.1.

Figure 2:

Fire, mortality and transfers to parks



Index	Titleset
k	years
i	ageclass180
s	cover types
d	districts

The surviving stocked forest land is input to the mortality process (2) where the area of forest which reaches the oldest ageclass (180 years) is assumed to die naturally. We then adjust the forest land inventory for transfers to park land. A historical time series of park land additions is known by district and this series is pro-rated according to the age-class and cover type distribution of forest land for each year.

2.4 Harvesting

In Figure 3 processes 4.1 to 4.3 describe how the historical production of roundwood (softwood and hardwood) are translated into area harvested so that the forest land stock can be adjusted each year. The forest is cut according to historical data for roundwood production volume (cubic metres). Two types of roundwood volume were provided as input to the harvesting algorithm: softwood and hardwood. In this accounting framework, 75 % of the softwood volume was harvested from "coniferous" and 25% from "mixedwood" stands. All the hardwood volume was met by harvesting from "hardwood" cover types. The softwood harvesting precedes the hardwood harvest in the calculation sequence.

First, in procedure 4.1 we calculate the potential volume for softwood timber in the two cover types "coniferous" and "mixedwood" by multiplying the unit volume per hectare yield for softwood timber by the forest land area and summing over the selected allowable age-classes. These are the ages from which harvesting may occur and are called the "limits of operability". This is the period in the stand's development when there is sufficient volume so that they may be economically harvested.

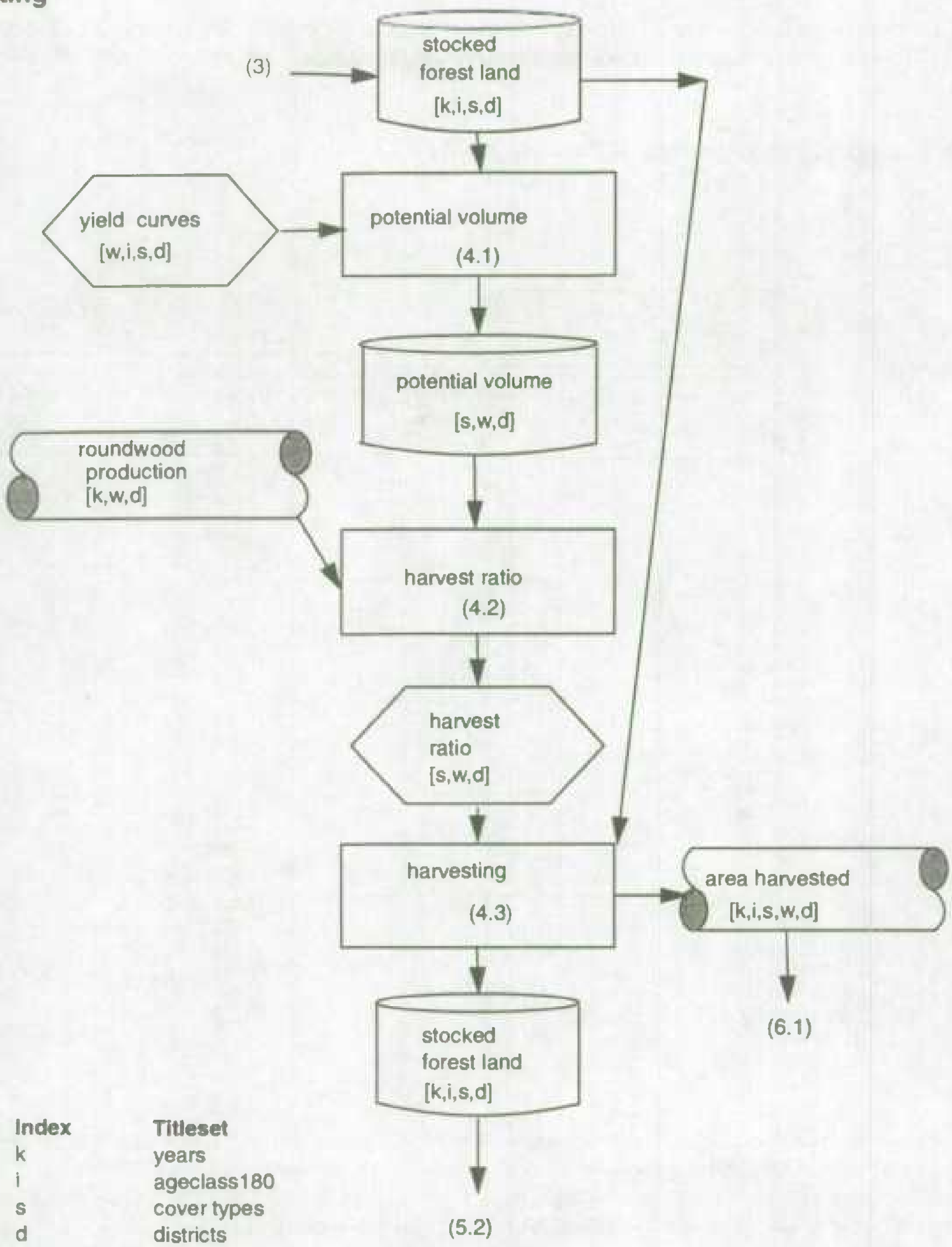
For softwood, the "limits of operability" were 60-180 years and for hardwood, 50-180 years. The potential volume was calculated by multiplying the forest land area by the unit volume per hectare and summing over the "limits of operability". Harvesting of younger hardwood stands was allowed.

Then, in procedure 4.2 the ratio of roundwood produced to the potential volume that could be harvest was calculated. This proportion (harvest ratio) was used to determine how much area of forest needed to be cut to satisfy the production in each year. In other words the harvest was allocated across age-classes by the proportion of the wood produced to the total potential volume in each cover type.

An allowance of three percent of annual area harvested was made for the construction of logging roads in the forest. Stocked productive forest land is therefore reduced by three percent of the area harvested each year since newly created logging roads are not regenerated as stocked forest land.

After the harvesting has been completed the newly cut land is aggregated each year by district and cover type by summing the area cut over wood type and the age-classes in which harvesting was permitted. This newly cut forest land is then passed to procedure 6.1 which represents the regeneration process.

Figure 3:
Harvesting

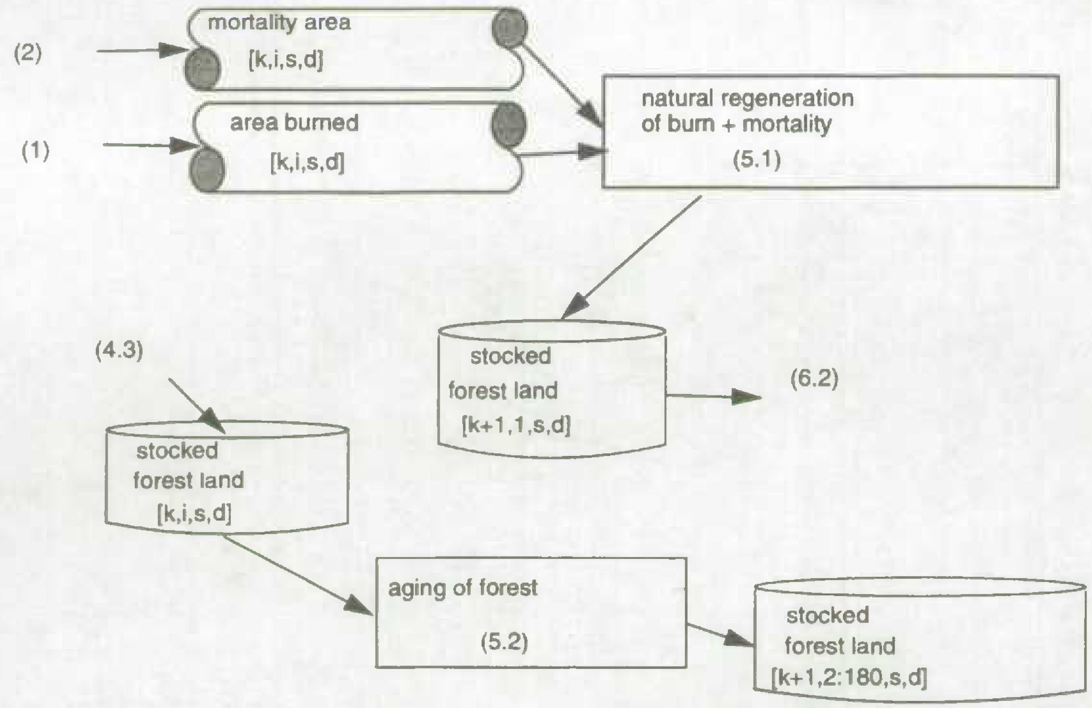


Index	Titleset
k	years
i	ageclass180
s	cover types
d	districts
w	woodtype

2.5 Aging and natural regeneration of burn/mortality

Aging of the forest and natural regeneration due to fire and natural mortality are portrayed by processes 5.1 and 5.2 in Figure 4. It is assumed that regeneration occurs immediately after fire and natural mortality.

Figure 4:
Aging and natural regeneration of burn/mortality



Index	Titleset
k	years
i	ageclass180
s	cover types
d	districts

Natural regeneration of depletions due to fire are achieved by updating the first age-class of stocked forest land in the next simulation time period. First the area burned is summarized by cover type and district in each year.Then the stocked forest land in age-class 1 for time period k+1 is updated by the area burned during period k. It is assumed that the same cover type regenerates after a burn.

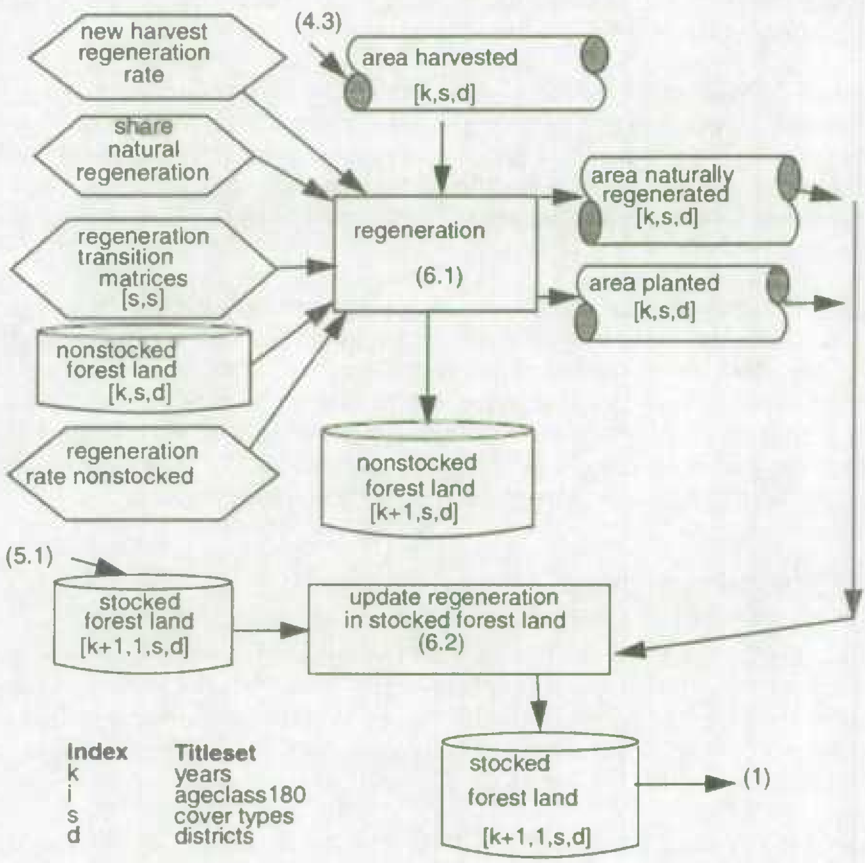
Forest that died during period k is regenerated in the following way. Rather than regenerating this area in age-class one at the start of the next year we distribute the area amongst the age classes 1 to 179 according to the current age class and cover type distribution. The reasoning behind this is that in a stand mortality is not an abrupt process. Trees do not die off as soon as they reach 180 years. There is mortality in the stand and regeneration in the form of an understorey is always present. We are trying to capture this more natural development of the evolution of the forest stand break-up by allocating the 180 year old age class amongst the other age classes. The remaining age-classes of the stocked forest land are aged by a simple shift in area from age-class i to age-class i+1 over one year.

2.6 Artificial and natural regeneration of cut

Figure 5 completes the representation of regeneration by updating stocked forest land due to both natural and artificial regeneration of newly cut and previously nonstocked forest land. Area which naturally regenerates is distinguished from artificial regeneration through planting by multiplying by the natural regeneration share. We assume 50% regenerates naturally. The regeneration rates for both newly cut forest land and previously nonstocked forest land determine how fast these area types regenerate. The regeneration rate for newly cut land was 0.7 and that for nonstocked .01. In other words the nonstocked land slowly regenerates to stocked whereas the new cut land regenerates quickly.

Figure 5:

Artificial and natural regeneration of harvested and nonstocked area



Succession in regeneration is represented by distinguishing the probability of transition to different cover types after harvest and planting. Data on regeneration after harvest and planting were available (Hearnden, Wilson and Millson, 1992) and absorbed in two regeneration transition matrices; one for natural regeneration and one for planting. The regeneration transition matrices are dimensioned 3 cover types by 3 cover types indicating by row the propensity of regenerating from one cover type to another. The outputs from procedure 6.1 are the area naturally regenerated and area planted in each year for the 24 districts classified by cover type. The nonstocked forest land for beginning of period k+1 is updated by including the proportion of newly cut forest which will be nonstocked plus the surviving nonstocked forest land from the end of the previous period k. Finally, stocked forest land is updated at the beginning of period k+1 in age-class 1 for natural and artificial regeneration of harvested and nonstocked forest land during period k. This is shown in procedure 6.2.

3 Data preparation

The final results of the project depend on the quality of data used by the model. This section focuses on the origin and characteristics of the different data used by the project, and some of the processing necessary to prepare the data for model input. Considerable effort was necessary to recode and format data for input into the model structure outlined in section 2. The principal difficulty encountered was obtaining input for each of the model's variables referenced to common geographic areas for the 40 year period.

3.1 Geographical units

Selection of the appropriate levels of spatial, temporal and categorical resolution for model elements and data is difficult. Compromises in the form of aggregation are necessary because not all data are available for the same geographic areas, in the same format, over the entire time period.

Although provincial estimates are the objective of the project, the spatial dependencies of much of the data (e.g. yield, fire, harvest) suggested that modeling at the sub-provincial level and aggregating up to a provincial total would produce more accurate results than modeling at the provincial total level. OMNR divides the province into a number of geographically defined management units for the purpose of preparing resource plans. These management units form the statistical frame for the collection and reporting of the majority of data pertaining to the resource.

Similarly, in order to efficiently coordinate forest resource management the province aggregates management units into geographically defined regions, districts, and areas. Like the management unit these administrative units are often used to define the frame for data collection and reporting. Neither the management unit or administrative boundaries have remained stable over the entire period of the historic account. The geographic boundaries with the most longevity during the 40 years of the account were those of the 22 districts of the Lands & Forest (L&F). These boundaries also coincided well with early forest inventory data which could be used as a test against the simulation model results.

3.2 Canada forest inventory

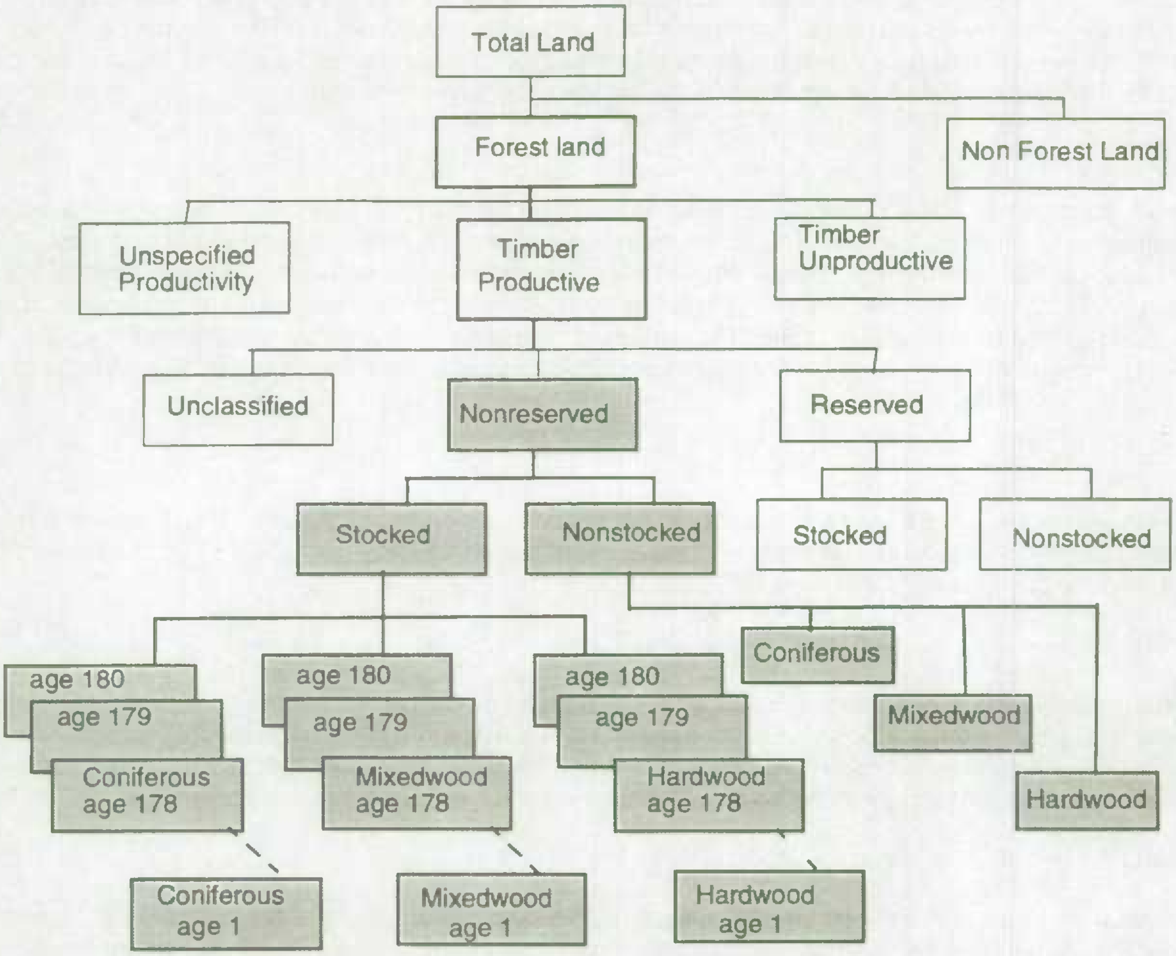
The original project plan was to use a composite 1953 inventory of the province as a starting point for the time series and evolve to the 1991 Canada Forest Inventory (CanFI91) of Ontario. However, the 1953 inventory lacked numerically defined age-classes and those that could be inferred from maturity classes were not reconcilable with model results. For a more detailed explanation of this original strategy consult section 4.1 in the model validation chapter.

The project now exclusively uses the Canada Forest Inventory (CanFI) for Ontario, maintained by the Canadian Forest Sevice. This inventory is a collection of over 100 inventories of different parts of Ontario, conducted by the provincial and federal governments over a time-span of 25 years.

The majority of the inventories which comprise the CanFI for Ontario were originally carried out to facilitate resource planning on geographically defined management units. These management unit inventories, known as forest resource inventories (FRI), are conducted at approximately 20-year intervals. This means that the average age of the inventories held in the CanFI is close to 10 years. Unfortunately, the names and boundaries of the management units are frequently changed so it is very difficult to track the state of the resource through time.

For the purposes of the account the CFI recorded area, and softwood and hardwood net merchantable volume over 24 districts, 3 broad cover types (coniferous, mixedwood or hardwood) and nine 20-year age-classes. The inventory area classification for the 1991 inventory may be represented hierachically as shown in Figure 6. Out of a total area of forest land of 57.4 million hectares 41.9 million hectares were timber productive and 15.5 million hectares were timber unproductive. The timber productive forestland was further broken down into reserved (1.5 million hectares) and nonreserved (35.3 million hectares), parks (2.15 million parks and 3.0 million hectares of nonstocked forest land). The nonreserved and the nonstocked timber productive forestland areas were used in the simulation model. These area classifications are highlighted in Figure 6 by the shaded boxes. The stratification of the nonreserved stocked and nonstocked forest land is also given.

Figure 6:
Area classification 1991 Canada Forest Inventory



3.3 Aggregation of forest inventory to 24 districts

Since much data were not available at the 24 district level a means to convert to and from this geographic level was necessary. A digital map of the 22 L&F districts was developed, supplemented by two additional northern districts (PEA[1] East & West), using various background coverages[2] and hard-copy inventory maps for guidance. This districts map is illustrated in Figure 25.

CanFI data is referenced to an irregular geographic grid which divides the province into approximately 4500 cells as shown in Figure 24. These data were aggregated to the L&F district level (24 districts) through a process of overlaying the boundaries of the 24 districts on the centroids of the CanFI cells. A cross-reference table linking the cells to the districts was then created and used to aggregate the cell level data up to a district level using a relational database.

3.4 Forest fire data

The simulation framework was designed to require estimates of area by cover type and age consumed by fire in each district/region during a year. It is not difficult to obtain provincial level fire records as far back as 1917, however, the reporting categories and geographic units have changed considerably over this period.The following notes detail the availability of data over the modeling period:

1953-55

Area burned statistics at a sub-provincial level could not be located for this period. However, the volume of standing timber burned (cu.ft), and its value, was recorded in the annual statistical reports, by each of the 22 L&F districts. Using these volume loss estimates the provincial area burned was apportioned among districts. Provincial estimates (1951-1961) of the distribution of the area burned by cover types and land classes (eg. non forest, cutover, plantation) were used to to reduce the area burned statistics (by 6% to account for non-forest area burned) and to estimate the portion of the area burned occurring in stocked forest vs. nonstocked forest (79% vs. 21%).

1955-72

Area burned, by each of the 22 L&F districts, was recorded in the annual statistics. These statistics do not classify the area burned by cover type or land class, assumptions derived from 1951-61 data, were used as stated in the previous section.

1973-75

Area burned in each of 8 regions were available. The area burned in the three northern regions were reduced because the extent of forest inventory used by the model is south of the northern boundaries of these regions. This was done by applying a factor to the area burned statistics equal to the total area burned in the intensive and measured zones relative to the regional total, based on a twelve year average (1976-88).

1975-91

Area burned in each of 8 regions were available by protection zone. Data for the intensive & measured protection zones were chosen because this area most closely corresponded with the inventory extent.

For the years 1973-1975 the total forest fire area reported within a region was used after being reduced by a factor meant to predict what proportion of that area would fall within the intensive and measured protection zones (ie. the area under timber management which is coincident with the inventory). This factor was based on a ten year (1976-1988) average of the proportion of total area burned in these zones relative to the regional area.

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1. Potentially Exploitable Area
2. Coverage = digital map file used by a geographic information system (GIS).

3.5 Yield tables

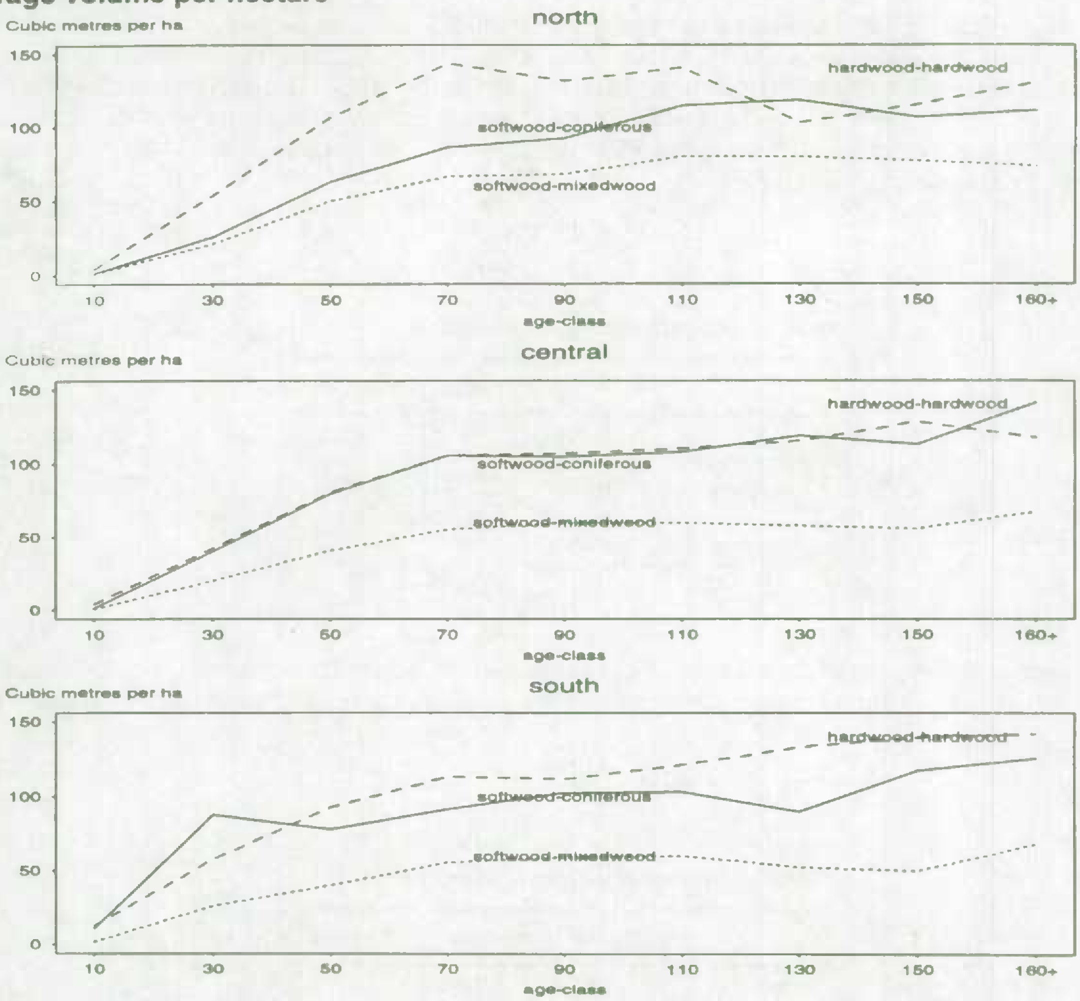
Yield tables establish the yield, usually in volume, which an area of forest normally provides at a given age. Yield tables were created using empirical methods to determine the average volume yield of softwood and hardwood woodtypes for three regions in Ontario (north, central and south) as shown in Figure 7.

Empirical volume tables were created by totaling the inventory volume and area by age-class and dividing the volume by the area. Regional aggregate yield tables were used because at the district level the data suggested yields could be aggregated into three distinct regions as graphed in Figure 7

The districts which comprise these regions are: **north** = districts 3,4,5,6,9,14,15,16, 23 and 24; **central** = districts 1,2,7,8,10,11,12,13; and **south** = districts 17,18,19, 20,21,22

These tables provide the connection between the harvest data (a volume) and the area harvested. Volume at individual ages was determined by interpolation of the 20 year age-class based data over 180 single years

Figure 7:
Average volume per hectare



3.6 Harvesting data

It was difficult to obtain accurate, comprehensive harvest data. Problems included,

- incomplete time coverage.
- no coverage of private wood.
- non-convertible units, time lags.
- no geographic labeling or changing geographic framework.
- incorrect values from mis-reporting or poor measurement unit conversion.
- no specification of method of harvest.

The following principal sources of harvest data were used: timber management planning annual reports, timber scaling and mill license returns.

3.7 Regeneration data

Post fire regeneration is represented by an immediate retum of the stock affected to an age-class of zero. Prediction of post harvest regeneration is based on success rates found by a regeneration survey for the Ontario Independent Forestry Audit (Hearnden, Wilson and Millson, 1992) . The regeneration transition matrices are shown in Tables 2 and 3. Different success rates are assigned based on whether regeneration was artificially assisted or occurred naturally. Planted and seeded areas by year are taken from provincial statistics and applied equally across districts.

Table 2:
Natural regeneration transition matrix

	coniferous	mixedwood	hardwood
coniferous	0.43	0.411	0.159
mixedwood	0.21	0.580	0.210
hardwood	0.07	0.360	0.570

The accuracy of the regeneration predictions are subject to the assumption that changes in harvesting methods, stock, regeneration method, sites and climatic condition have no effect on regeneration predictions.

Table 3:
Planting regeneration transition matrix

	coniferous	mixedwood	hardwood
coniferous	0.44	0.397	0.163
mixedwood	0.194	0.598	0.208
hardwood	0.150	0.620	0.230

4 Model validation

Traditional model validation involves devising a test that the model, if false, would fail to pass. If the model fails the test then we must reject it. If it passes, then we should devise a more stringent test and so on until we are satisfied with the degree of validation. As pointed out by Mesterton-Gibbons, 1989 the model is accepted if it explains all the facts that we would like it to explain. In other words there is always a degree of subjectivity in model validation in deciding when to stop testing its validity.

In the next two sections we briefly describe the procedures used for validating the simulation framework. In section 4.1 we outline a method of reconstructing the forest inventory by backward simulation of the 1991 inventory. In section 4.2 a visualization process is set up to compare predicted inventories with actual. Our closeness criterion was determined visually i.e by comparing the graphed age-class distributions for the simulated and actual inventories.

4.1 Estimation of 1953 age class distribution by reverse calculation method

Since the model is forward stepping it was necessary to establish an initial condition from which to commence the simulation. Our original intention was that this initial condition would be based on the 1953 inventory. Unfortunately, this inventory did not categorize the forest by numerical age-classes, but it grouped it into broad maturity classes. While an attempt was made to project the maturity classes into numerical age-classes, an age-class distribution which would provide an adequate initial condition could not be created.

As an alternative, the model was rewritten to run in reverse and approximate an initial condition from the 1991 inventory. The reconfiguration proved somewhat problematic since many of the processes in the model require a cover type, age class distribution to predict the changes which will take place in a period. For example, the fire losses in any one period are spread amongst the cover types and age-classes according to their relative occurence in a district. The cover type, age classes distribution at the end of a period (t+1) was shifted backwards one year and used as a substitute for the occurrence distribution for the beginning of a period (t).

Another difference in the reverse-order model is the handling of the regeneration phase of fire. When a fire occurs in the forward stepping model the area burned is placed in the first year age-class at the start of the next period. The direct opposite would be to remove all of the area burned from this first age-class and distribute it amongst the other ages. In the case of large fires this may not be feasible where there is inadequate area in the first year age-class to cover the fire loss. To avoid this difficulty the reverse-order model takes area from all of the first 20 age-classes. Since the areas in the single-year age-classes were originally taken from an inventory which grouped them into 20 year classes, this is a reasonable solution.

These slight differences in the forward and reverse models mean that there are some differences in the original 1991 and the predicted 1991 inventory. In "some aspects" the predicted inventory may be more precise than the original, particularly with regard to the youngest (first) 40 age classes predicted by the forward model processes.

4.2 Data visualization

In order to test whether the simulation model was a reasonable representation of reality the area of provincial stocked forest by single year age was plotted for the 1953 predicted, 1991 predicted and 1991 inventory as shown in Figure 23. This was one of our principal "views" on the performance of the model. We were able to detect problems in data and model structure by checking the predicted with the actual age-class distribution for 1991. We also plotted the evolution of the stocked productive forest age-class structure for total forest land (Figure 22). This gave us an indication of how the simulation was developing over time.

5 Results

The physical accounts are a series of year end stock data showing the area and volume of forest land as provincial totals. The stock data, which include both the growing stock in cubic metres and the forest land area, are estimated by cover type. The changes to these stocks from year to year and the reasons for this change, such as growth, harvest, natural loss due to fire and mortality, change in land use due to area withdrawn for roads or parks are summarized in the next sections as provincial totals.

5.1 Growing stock

One indicator of forest development is total growing stock, calculated as the product of the area of forest and the yield or the net merchantable volume per hectare. Yield tables are derived as a function of age for both softwood and hardwood woodtypes specific to the cover type defined. Figure 8 shows the total growing stock (cubic metres) by three cover types for the historical period 1953 to 1991. These derived data are the result of simulating the changes to the estimated 1953 inventory over the 38 years which constitute the simulation time horizon. In Figure 8, we see that the simulated growing stock did not meet the target 1991 inventory (represented as points).

The difference between simulated and actual growing stock may be explained by reference to the evolution of stocked productive forest age-class structure (Figure 22). The simulated age-class structure for 1991 is younger over all than the 1991 actual. This can be seen in Figure 22 by comparing the last two plots.

Figure 8:
Growing stock by cover type

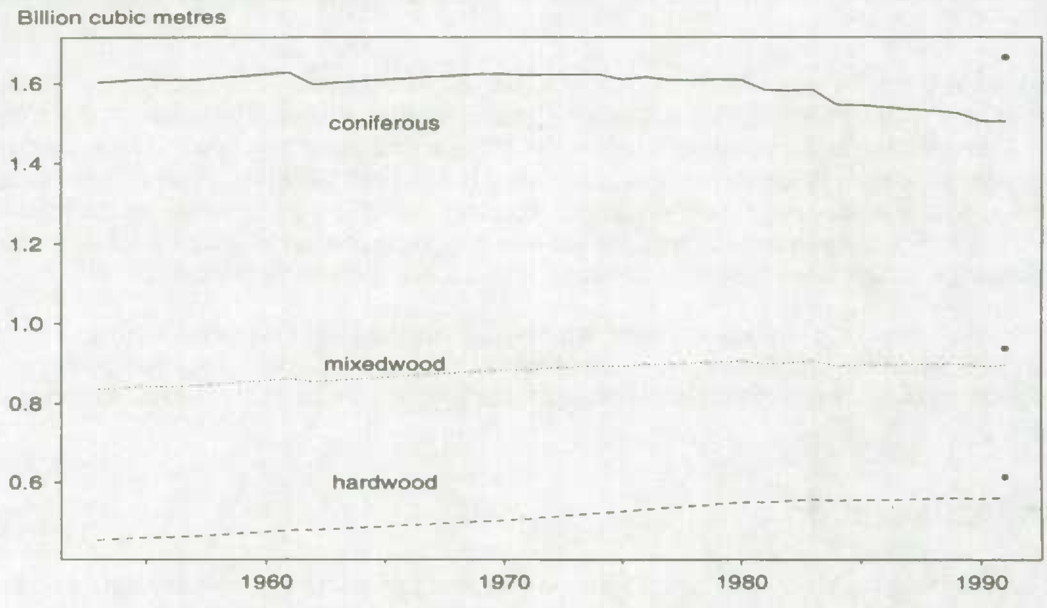
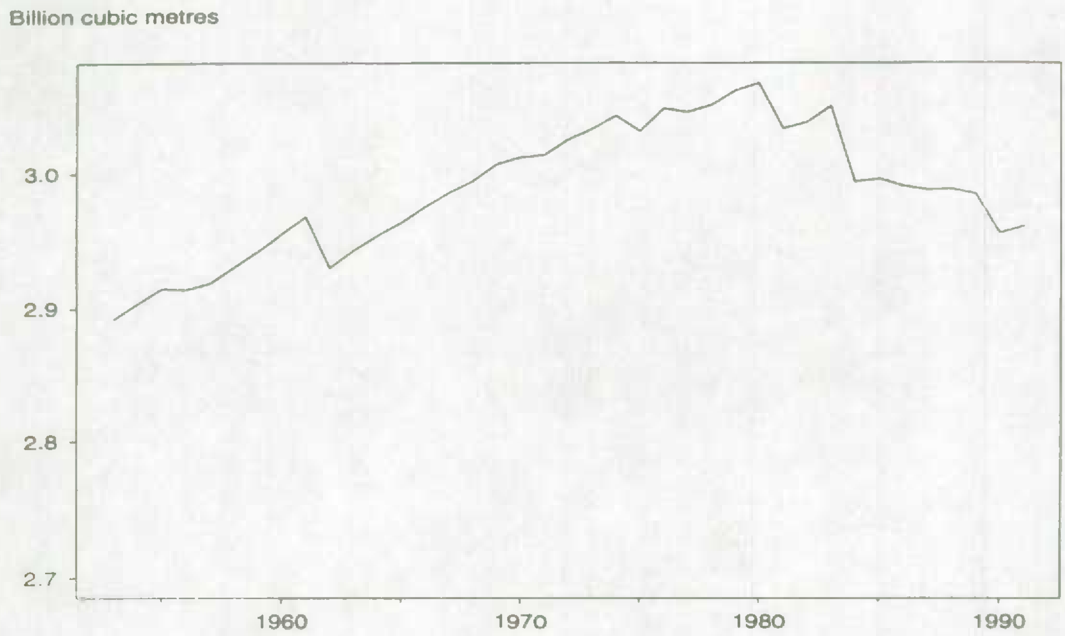


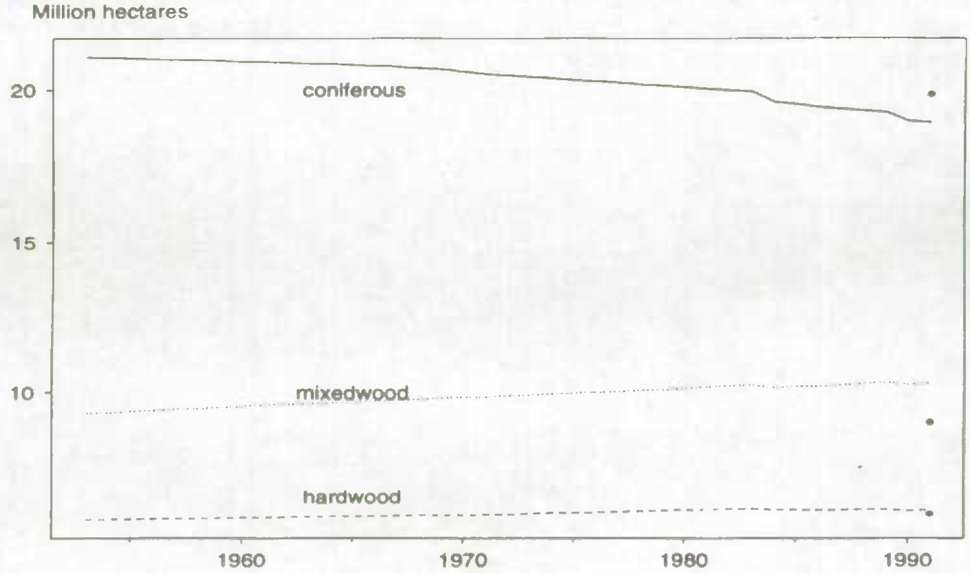
Figure 9 shows the total growing stock for the same period such that the y-axis is scaled between 2.7 billion cubic metres and the maximum value. Bearing in mind this scale, the growing stock shows a rise over the period 1953 to 1980 and for the remaining period declines at a similar rate. The reasons for these changes are numerous and depend on the evolution of the age-class distribution of the forest and the extent of both natural and harvesting disturbances to the forest.

Figure 9:
Total growing stock



The stocked forest land area over time, as depicted by Figure 10, shows that the model overestimates the area of mixedwood cover type and underestimates the area of coniferous cover type. However, the difference between the total 1991 inventory in area and that projected from **STCmacroforest** model is small. The evolution of the forest by cover type depends on several factors. First, we assume that forest area burned or died regenerates to the same cover type. Second, the regeneration transition matrices are not defined on a district basis. We apply these regeneration assumptions to all districts. There are two matrices (as discussed in section 3) one defined for regeneration of recently harvested forest land and the other for the regeneration of nonstocked forest land. Lack of district specific regeneration transition data will introduce error over time in the distribution of forest land by cover type. Our main concern is that the forest area is constant over time

Figure 10:
Stocked forest land area



5.2 Fire loss

Reported annual fire loss by volume and area are given in Figures 11 and 12, respectively. Both barplots show the contribution of fire loss by the three cover types. What is evident from these charts is the extreme variability of forest fires from year to year. We see that catastrophic fires occurred in 1961 and 1980. The variability of these disturbances becomes visible in the age-class distribution of the forest originating as a large regenerated area in the first age-class. For example, the huge fire in 1961 appears as a spike in the evolution of the stocked production forest age class structure as shown in Figure 22.

Each time series plot shows the single year age-class distribution for the province total at approximately four-year intervals during the simulation time horizon. We see in the plot for 1964 the emergence of the burned area in 1961 as a regeneration spike. This is a spike in the regeneration age-class. This huge fire necessitated a rescaling of the plot in 1964. By 1991 38 years of disturbances to the forest (i.e. fire, mortality and harvesting) are reflected in the first 38 age classes.

In the model validation section (4) we explained how the evolution of the age-class structure, as depicted in Figure 22, was used as a principal data visualization tool to check the validity of the simulation framework.

Figure 11:
Volume burned by cover type

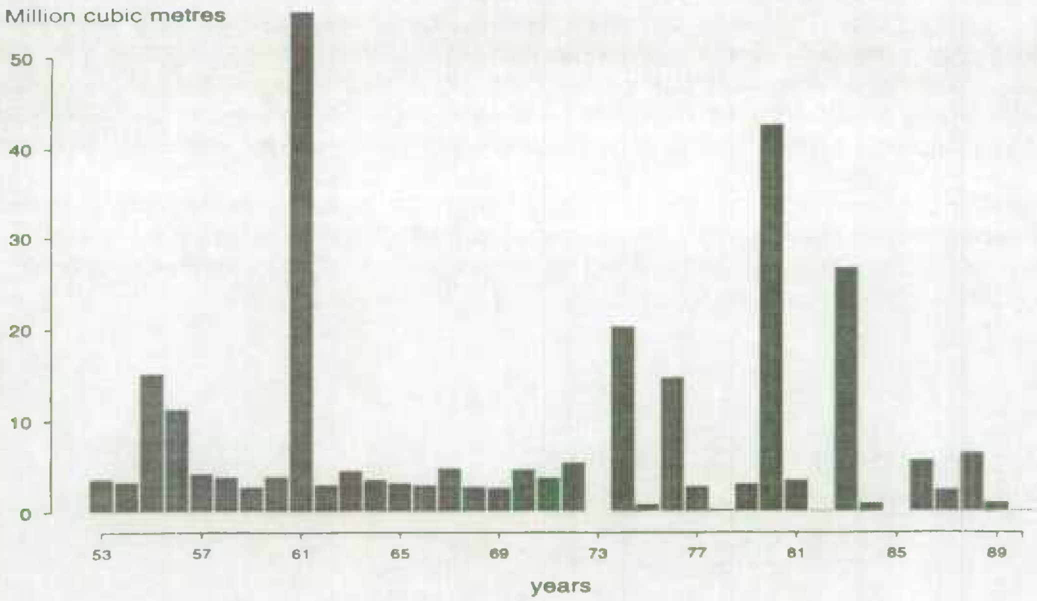
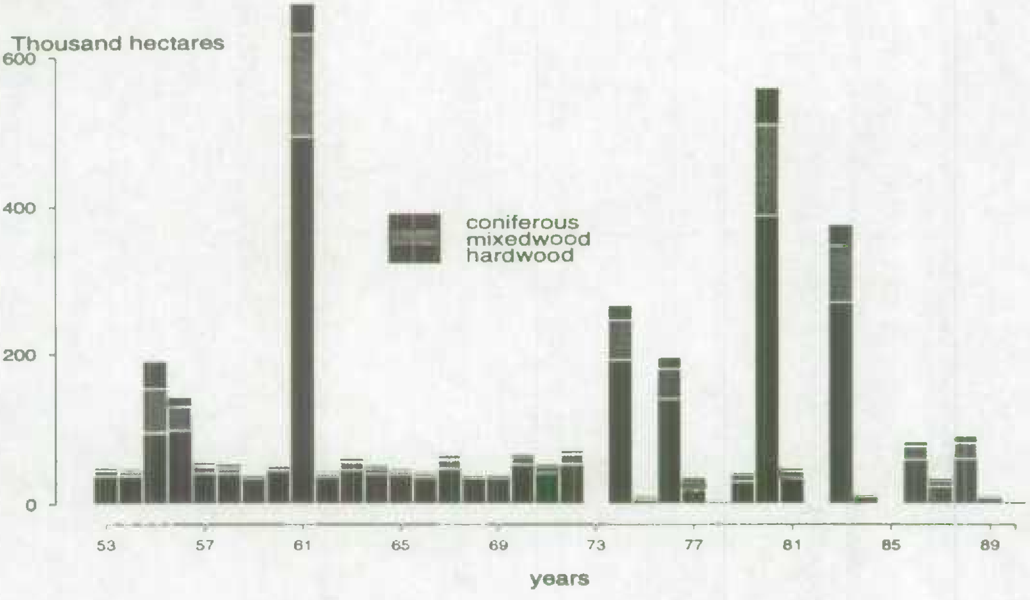


Figure 12:
Forest land burned by cover type



5.3 Mortality

Natural mortality is represented (in **STCmacroforest**) by assuming that the area of the oldest single year age class (180 years) dies. The pattern of mortality seen in Figures 13 and 14 displays the volume and area of forest that is lost to mortality over the historical period 1953 to 1991. The drop in mortality for both mixed and hardwood cover types is explained as a result of the way in which the age-class structure evolves over time. Since mortality is represented in the model as all area that reaches the oldest age-class regenerates in the next year, discontinuities in the age-class structure will be reflected in the shape of the mortality curve.

Discontinuities in the age-class structure in this framework arose because a single year age-class distribution was created from twenty year age-classes. Therefore, these drops in mortality are in part an artefact of the model structure.The abruptness of this effect was smoothed by running the time series through a simple linear time invariant filter (a convolution filter) .

Figure 13:
Volume lost to mortality

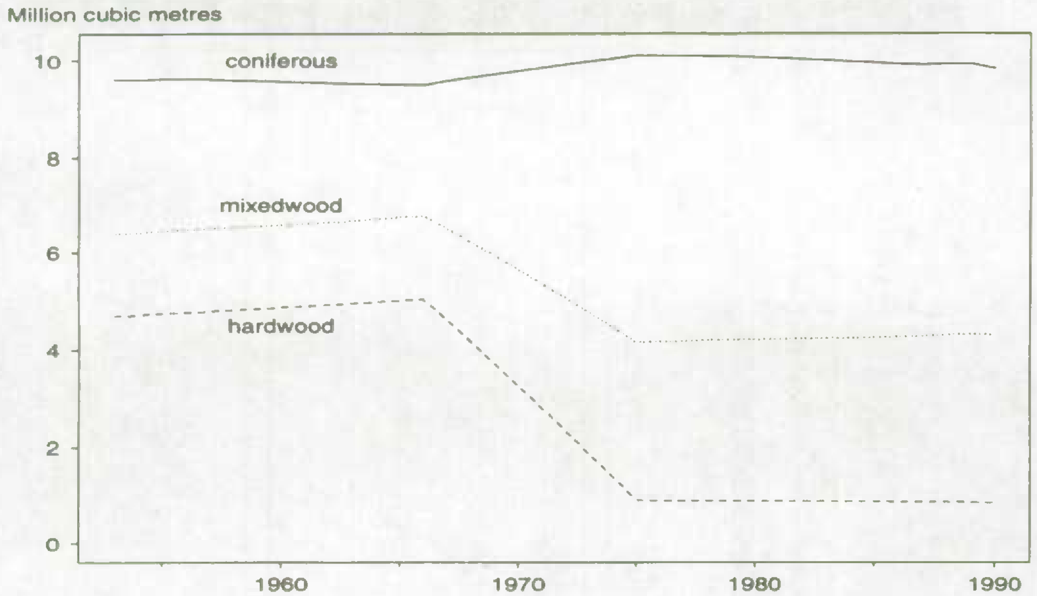
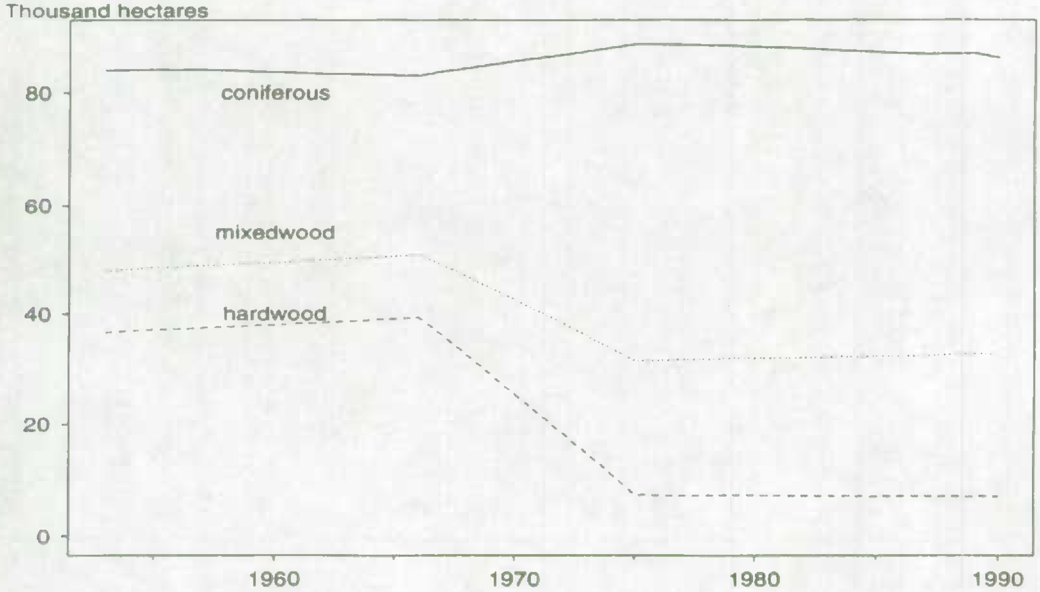


Figure 14:
Forest land area mortality



5.4 Roads and parks

Each year a certain amount of stocked productive forest land is withdrawn from the exploitable landbase. The first withdrawal is the logging roads required for harvesting. We assume that 3% of area harvested are required for logging roads.

The second withdrawal of forest land from the exploitable landbase is the creation of new parks. We display in Figure 15 and 16 the volume and area, respectively, of forest withdrawn for parks. The volume and area withdrawn from the production forest as a result of constructing logging roads are shown in Figures 17 and 18 respectively.These barplots show the annual withdrawals by cover type.

Forests set aside for parks has increased considerably recently.Two particularly large parks were created in 1983 and 1989. The pattern of volume and area withdrawn for logging roads follows that of the area harvested by cover type in Figure 20.

Figure 15:
Volume withdrawn for parks

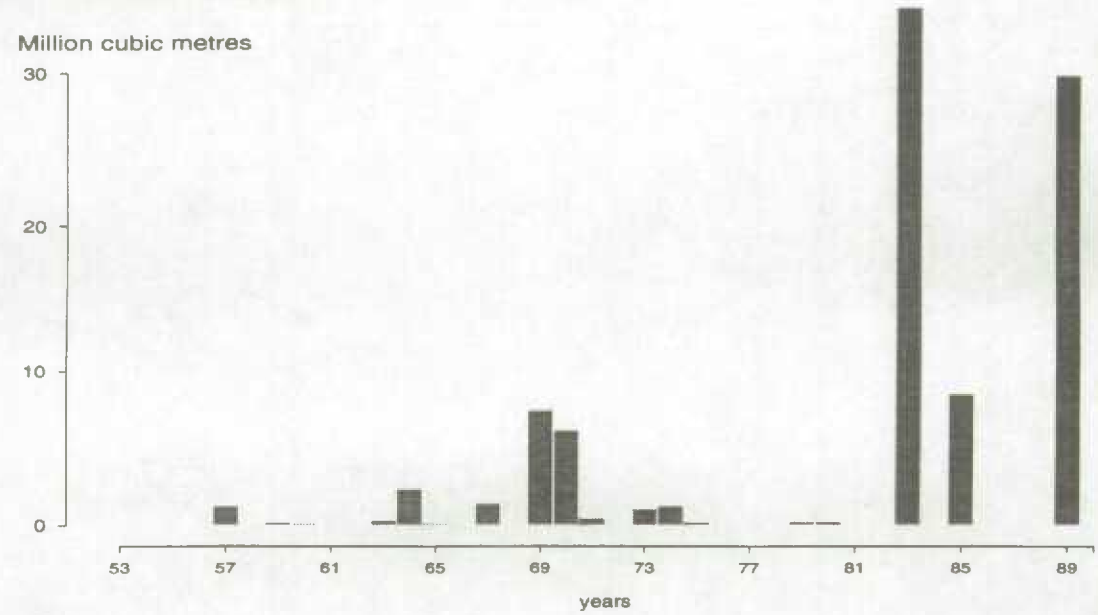


Figure 16:
Area withdrawn for parks by cover type

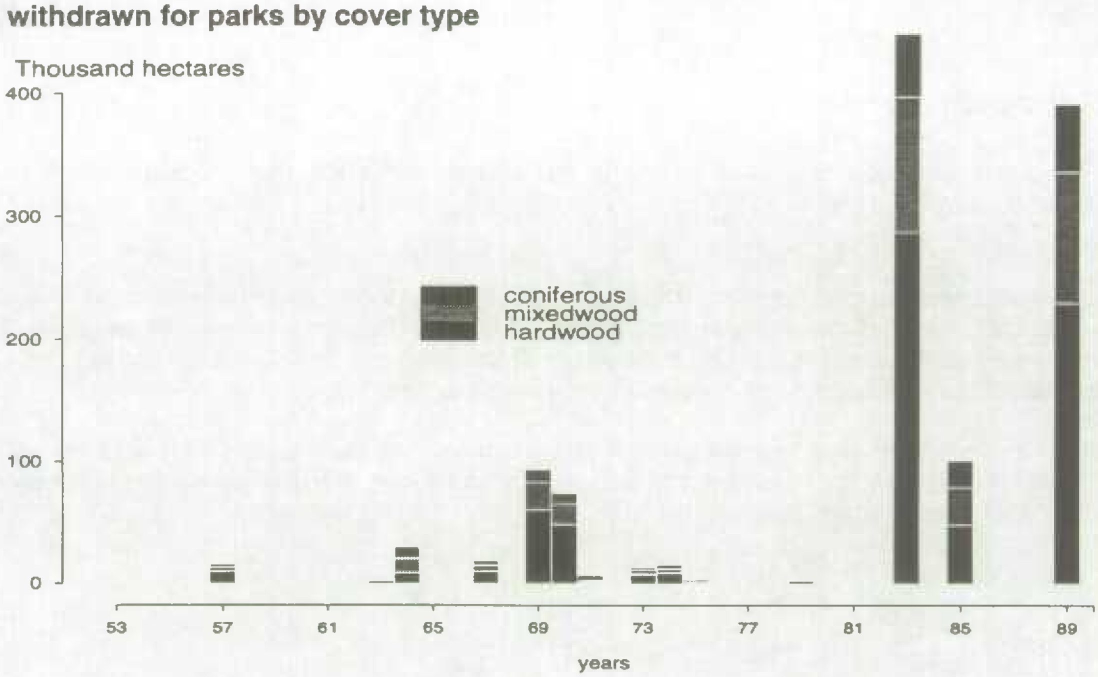


Figure 17:
Volume withdrawn for logging roads

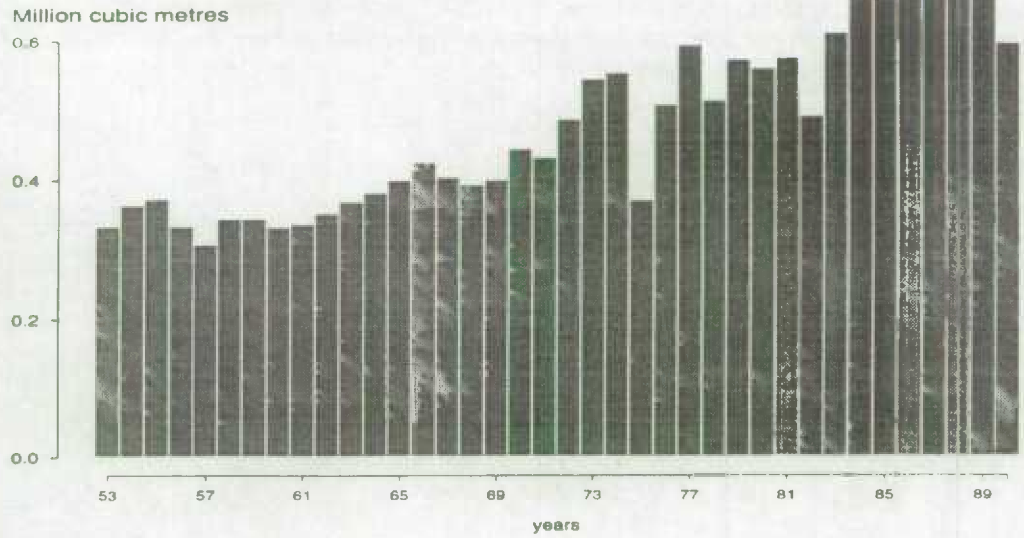
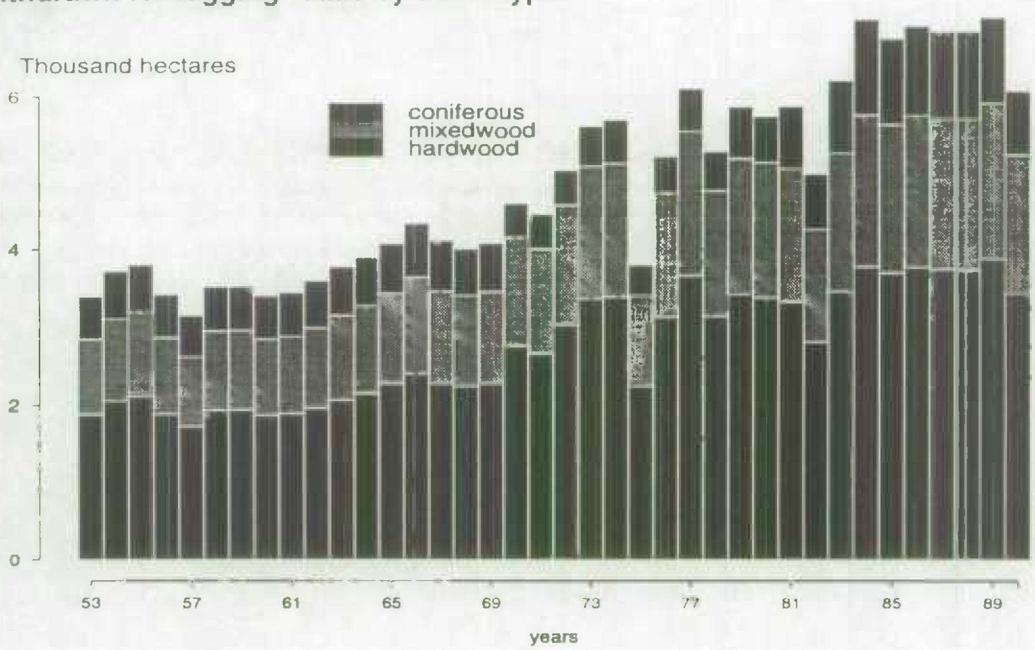


Figure 18:
Area withdrawn for logging roads by cover type

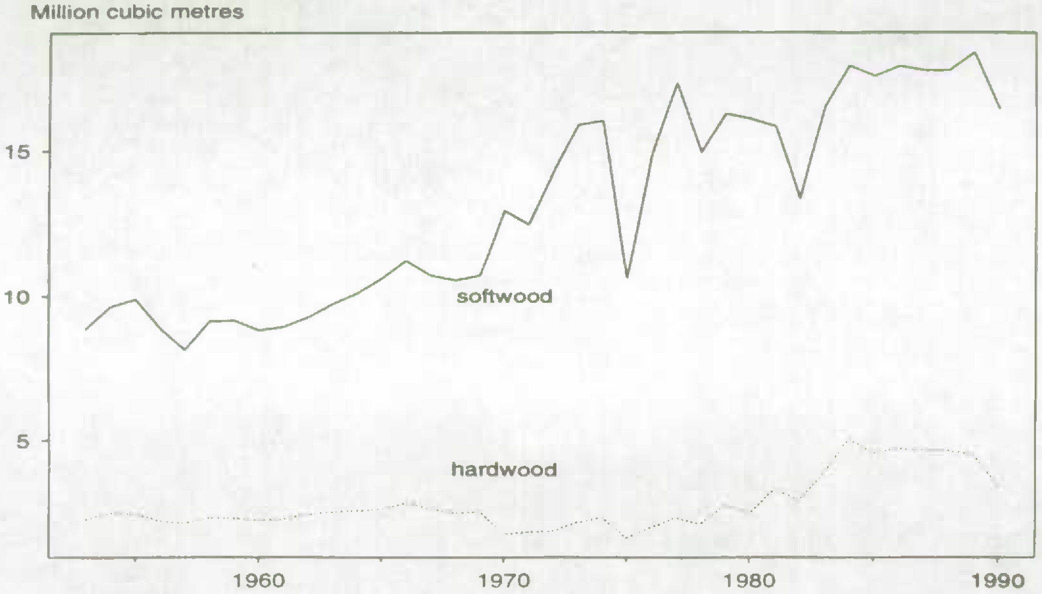


5.5 Harvesting

As mentioned in the data section of this report, time series of harvesting volume for two wood types: softwood and hardwood were reconstructed for the 24 districts from several provincial sources. Figure19 shows the provincial total volume harvested by woodtype.

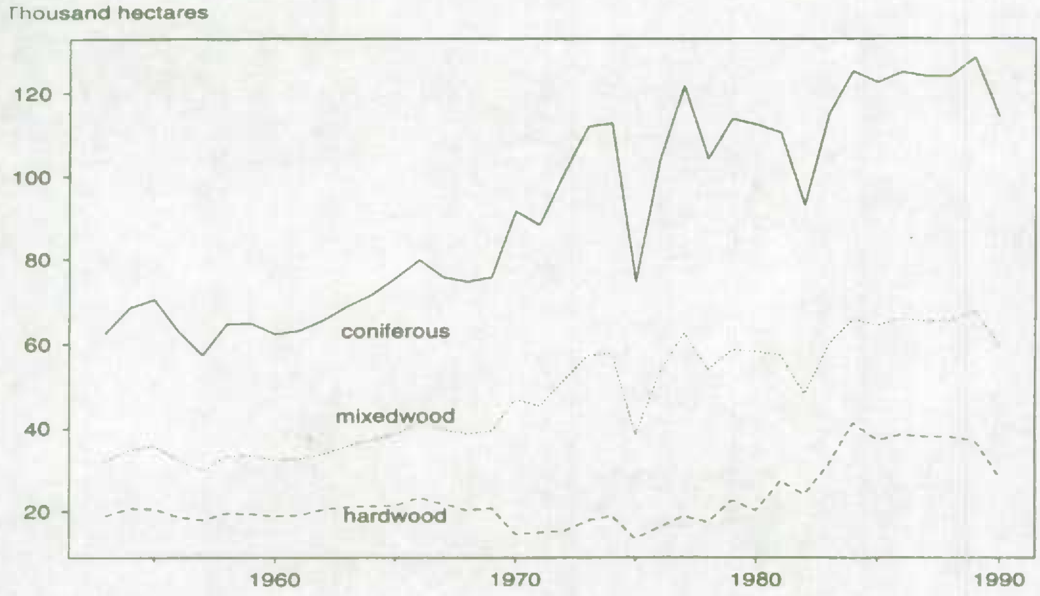
Figure 19:

Volume harvested by woodtype



One objective of the simulation of forest development was to translate this historical timber production back into the forest area required to meet this production. We show in Figure 20 the area of each cover type required to meet the historical production volume. We recall, in our model framework, that softwood is harvested from coniferous and mixedwood stands whereas hardwood woodtype is harvested only from hardwood cover type. The reduction in volume harvested in 1975 was due to a loggers strike and the down tum in production in 1982 was a result of the recession.

Figure 20:
Forest land area harvested

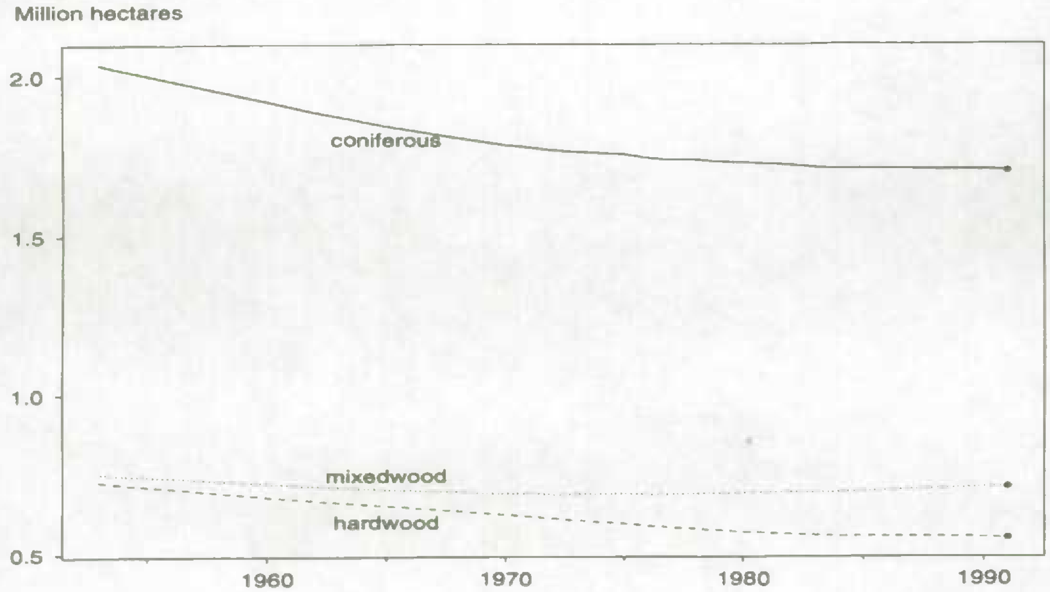


5.6 Nonstocked forest land

We also keep track of timber productive forest land which is nonstocked. After harvesting a certain proportion of cut forest land becomes nonstocked and stays in this state until regeneration occurs. We represent a regeneration delay after harvesting by modeling nonstocked forest land. Each year regeneration of nonstocked to stocked forest land occurs. The transfer of area between stocked and nonstocked forest land is simulated over the historical period 1953 to 1991. We show, in Figure 21, the time path of nonstocked forest land by cover type. By definition nonstocked has no observable volume.

We observe a decline in overall nonstocked forest land. The points signify the 1991 data points of total provincial nonstocked forest land by cover type. The solid lines indicate the result of simulating this nonstocked variable over the period 1953 to 1991. If we compare the nonstocked with stocked forest land (Figure 10) nonstocked is about 8% of the stocked area for 1991.

Figure 21:
Nonstocked forest land area



5.7 Timber volume and area account

The physical stock/flow accounting for Ontario net merchantable timber volume is shown in Table 4 in tabular form :

Closing Stock =

Opening Stock - Volume Lost (due to harvest, fire, mortality and road and park withdrawals) + Net Growth.

Net Growth[t] =

Growing Stock [t+1] - Growing Stock [t] - Fire Volume Lost [t] - Mortality Volume Lost [t] - Volume Withdrawn for Roads/Parks [t] - Harvest Volume [t].

Where :

Growing Stock [t] = Opening Stock for year t

and

Growing Stock [t+1] = Closing Stock for year t which equals the Opening Stock for year t+1

The reason for this imputation is that growth is not calculated *per se* since we are using an age-structured forest development approach which ages forest area from year to year. The volumes are calculated by multiplying the areas removed by the appropriately defined unit volumes (yield tables).

Table 4:

Ontario Timber Resource Volume Account

Year	Opening Stock	Harvest	Fire	Mortality	Parks	Roads	Growth	Closing Stock
1953	2,892,058	11,081	3,695	20,668	0	332	47,442	2,903,724
1954	2,903,724	12,099	3,464	20,632	0	363	47,509	2,914,675
1955	2,914,675	12,360	15,217	20,720	5	371	47,934	2,913,937
1956	2,913,937	11,083	11,308	20,730	0	332	48,307	2,918,791
1957	2,918,791	10,217	4,253	20,815	1,315	307	48,716	2,930,602
1958	2,930,602	11,434	3,937	20,837	49	343	48,729	2,942,732
1959	2,942,732	11,452	2,839	20,873	232	344	48,927	2,955,919
1960	2,955,919	11,049	3,975	20,909	165	331	49,201	2,968,691
1961	2,968,691	11,187	55,319	20,952	0	336	49,621	2,930,518
1962	2,930,518	11,698	3,096	21,002	0	351	49,523	2,943,895
1963	2,943,895	12,251	4,585	21,055	374	368	49,583	2,954,845
1964	2,954,845	12,684	3,659	21,108	2,465	381	49,612	2,964,160
1965	2,964,160	13,261	3,332	21,162	169	398	49,678	2,975,516
1966	2,975,516	14,127	3,076	21,221	70	424	49,645	2,986,244
1967	2,986,244	13,400	4,847	20,620	1,489	402	49,191	2,994,677
1968	2,994,677	13,059	2,891	19,967	66	392	48,625	3,006,927
1969	3,006,927	13,289	2,777	19,304	7,512	399	47,831	3,011,477
1970	3,011,477	14,759	4,753	18,636	6,260	443	46,666	3,013,292
1971	3,013,292	14,354	3,850	17,954	539	431	48,193	3,024,357
1972	3,024,357	16,169	5,466	17,266	38	485	47,201	3,032,134
1973	3,032,134	18,093	160	16,570	1,159	543	46,058	3,041,667
1974	3,041,667	18,384	20,291	15,868	1,315	552	45,287	3,030,544
1975	3,030,544	12,282	946	15,167	254	368	45,493	3,047,017
1976	3,047,017	16,830	14,766	15,145	131	505	44,491	3,044,131
1977	3,044,131	19,744	2,918	15,153	78	592	43,783	3,049,430
1978	3,049,430	17,064	470	15,165	0	512	44,111	3,060,330
1979	3,060,330	19,051	3,210	15,175	284	572	43,701	3,065,740
1980	3,065,740	18,598	42,588	15,164	280	558	43,706	3,032,258
1981	3,032,258	19,194	3,603	15,152	0	576	43,406	3,037,139
1982	3,037,139	16,323	253	15,140	16	490	43,721	3,048,839
1983	3,048,639	20,393	26,740	15,128	34,238	612	42,507	2,994,035
1984	2,994,035	23,116	1,123	15,112	0	693	41,965	2,995,956
1985	2,995,956	22,244	79	15,100	8,511	667	41,766	2,991,120
1986	2,991,120	22,769	5,771	15,087	0	683	41,541	2,988,350
1987	2,988,350	22,542	2,627	15,074	0	676	41,451	2,988,881
1988	2,988,881	22,542	6,508	15,115	0	676	41,415	2,985,455
1989	2,985,455	23,051	1,169	15,155	29,833	692	40,780	2,956,335
1990	2,956,335	19,872	340	15,032	0	596	41,047	2,961,543

Note: Units are 1000s of cubic meters of net merchantable volume.

Finally, the forest land area account is shown in Table 5. This states the opening stock in hectares of non-reserved stocked timber productive forest land and the areas harvested, lost to fire and mortality together with area withdrawn from this landbase due to parks and construction of logging roads. The next column gives the area regenerated due to planting or natural means and the closing stock for nonreserved stocked timber productive forest land. We also show the closing stock of timber productive park land which is also nonreserved and timber productive. The next column provides the closing stock for the nonreserved timber productive forest land which is nonstocked.

Finally the CanFI91 estimate for the stock of reserved timber productive forest land which is both stocked and nonstocked is provided together with in the final column the area (CanFI91 estimate) of timber unproductive and unspecified productive forest land. The sum of these closing stocks for each year provides a total picture of forest land for Ontario.

Table 5:
Ontario Forest Land Area Account

Year	Nonreserved Opening stock	Harvest	Fire	Mortality	Parks	Roads	Regeneration	Nonreserved Closing stock	Parks Closing stock	Nonstocked Closing stock	Reserved Closing stock	Unproductive Closing stock
1953	36,144	113	49	169	0	3	361	36,170	915	3,489	1,485	15,521
1954	36,170	124	47	169	0	4	367	36,194	915	3,461	1,485	15,521
1955	36,194	127	191	170	0	4	514	36,217	915	3,435	1,485	15,521
1956	36,217	114	143	170	0	3	455	36,242	915	3,406	1,485	15,521
1957	36,242	105	57	170	16	3	362	36,253	932	3,376	1,485	15,521
1958	36,253	117	53	171	1	4	368	36,276	932	3,349	1,485	15,521
1959	36,276	117	40	171	3	4	355	36,296	935	3,322	1,485	15,521
1960	36,296	113	54	172	2	3	366	36,318	937	3,295	1,485	15,521
1961	36,318	115	672	172	0	3	985	36,341	937	3,268	1,485	15,521
1962	36,341	120	43	171	0	4	359	36,363	937	3,243	1,485	15,521
1963	36,363	126	62	171	5	4	383	36,378	942	3,219	1,485	15,521
1964	36,378	130	51	172	30	4	375	36,366	972	3,197	1,485	15,521
1965	36,366	135	47	172	2	4	375	36,381	974	3,176	1,485	15,521
1966	36,381	144	44	173	1	4	380	36,395	975	3,158	1,485	15,521
1967	36,395	137	66	174	19	4	397	36,392	994	3,138	1,485	15,521
1968	36,392	133	42	175	1	4	370	36,407	995	3,117	1,485	15,521
1969	36,407	136	40	175	93	4	371	36,330	1,088	3,098	1,485	15,521
1970	36,330	153	66	176	74	5	410	36,267	1,162	3,082	1,485	15,521
1971	36,267	148	53	130	7	4	348	36,273	1,168	3,065	1,485	15,521
1972	36,273	167	73	127	0	5	379	36,280	1,169	3,052	1,485	15,521
1973	36,280	187	2	127	13	6	324	36,269	1,162	3,044	1,485	15,521
1974	36,269	189	267	127	15	6	591	36,256	1,197	3,036	1,485	15,521
1975	36,256	126	11	127	3	4	285	36,269	1,200	3,016	1,485	15,521
1976	36,269	173	196	127	2	5	507	36,273	1,202	3,005	1,485	15,521
1977	36,273	203	35	127	1	6	370	36,271	1,203	3,001	1,485	15,521
1978	36,271	176	6	128	0	5	319	36,275	1,203	2,991	1,485	15,521
1979	36,275	195	42	128	3	6	371	36,272	1,206	2,985	1,485	15,521
1980	36,272	191	559	128	3	6	884	36,270	1,209	2,978	1,485	15,521
1981	36,270	195	49	127	0	6	377	36,270	1,209	2,973	1,485	15,521
1982	36,270	165	3	127	0	5	307	36,276	1,209	2,961	1,485	15,521
1983	36,276	206	376	127	447	6	712	35,826	1,657	2,958	1,485	15,521
1984	35,826	232	15	126	0	7	371	35,817	1,657	2,960	1,485	15,521
1985	35,817	224	1	126	101	7	350	35,709	1,758	2,960	1,485	15,521
1986	35,709	229	83	126	0	7	437	35,701	1,758	2,962	1,485	15,521
1987	35,701	227	34	126	0	7	387	35,693	1,758	2,963	1,485	15,521
1988	35,693	227	90	127	0	7	443	35,685	1,758	2,964	1,485	15,521
1989	35,685	233	13	127	390	7	371	35,285	2,148	2,966	1,485	15,521
1990	35,285	202	5	126	0	6	336	35,283	2,148	2,962	1,485	15,521

Note: Units are in 1000 hectares.

6 Discussion

Forest inventory and timber resource accounting

The primary purpose of the simulation modeling efforts in this project was to estimate a physical, historical time series of Ontario's forest estate. If the estate had been fully inventoried on a regular basis, and all of the changes from both natural events and human interventions were estimated and recorded in conformable units of measure, simulation would not have been necessary.

The past 30 years has seen the the arrival of a number of key technologies for updating and maintaining forest inventories. These new technologies include: computerized databases, satellite imagery, geographic information systems, and global positioning systems. Through the application of these technologies, inventories are becoming more current and comprehensive every year. It is now possible to envision inventory information which is no more than a year or two out of date at any time.

Original forest inventories in Ontario are currently updated at district and area offices on a five-year recurring basis for the purpose of management planning. These updated inventories are rarely aggregated back to a provincial level due to differences in standards, computing environments and inventory boundaries. Work on provincial data management and information systems now underway should make provincial compilations simpler and easier.

The 1991 Canadian Forest Inventory (CanFI91), used by this project, is compiled on a five year cycle from original provincial forest inventories which are anywhere from 1 to 20 years old. It will be possible to update the resource accounts with new inventory data every 5 years once the new data management systems are in place. By using CanFI data for resource accounting it will not be necessary to predict more than four years of inventory estimates. This will keep divergence between estimates from the model and the inventory to a minimum.

Change data

The other side of forest resource accounting is tracking the changes which occur to the forest as well as their origins. The compilation of harvest and artificial regeneration statistics is improving in Ontario, with documentation requirements for timber management plans and the environmental assessment driving the process.

The information now available at the provincial level within the National Forestry Database is similar to that required for resource accounting. It would make an excellent starting point and would provide the provinces with a means of making this information available to a wider audience with minimal effort.

Related iniatives

The OMNR has provided the public with statements on forest inventory through the release of the publications Forest Resources of Ontario in 1953, 1986 and 1991 and the provision of data to the Canadian Forest Inventory in 1981,1986 and 1991. OMNR has also produced Annual Statistical Reports and financial reports since its formation. Over the past 4 years Ontario has joined with other provinces to jointly release statistics through the National Forestry Database program.

In part due to the heightened awareness of environmental issues a considerable effort has been made over the past five years to obtain better information. The province of Ontario has spent the last 6 years undergoing an environmental assessment (E.A) of its forestry practices on public land. As part of the conditions for granting approval the E.A. board demanded that the province provide a 'State of the Forest Report' on a continuing basis.

The Canadian Forest Service has been delivering an annual report on the state of Canada's forests to parliment since 1990. This report which undergoes regular revisions contains numerous social and economic statistics meant to describe the resources physical properties and the social and economic activity associated with its use. This report has since 1991 included a National Forest Account similar to that desired for the CSNA satellite. The CFS also published a report entitled Canada's Forest Area and Wood Volume Balance 1977-1981 (Honer and Bickerstaff, 1985).

As a result of the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 numerous cooperative international efforts have commenced to establish frameworks which can be used to demonstate sustainable forest management. Canada, through the Canadian Council of Forest Ministers, is now working with a forum of non-European countries with boreal and temperate forests to establish a common criteria and indicators framework. These quantitative indicators of social, economic and environmental qualities will be tracked and regularly compared with baselines and historic data to show trends and provide the international community with a view of Canada's resource management.

7 Conclusions

The modeling methodology was successful in resolving a time series estimate of the physical stock of Ontario's forest estate over the 39 year historical period. Despite the flexibility of the modeling software considerable effort was required to transform and translate the raw data available into the structures necessary for simulation. We believe the resolution of the model and its outputs represent the best compromise given the resources and data available.

Over the 39 year period the total forest stock as shown in Figure 9 increased to 3.07 million cubic metres in 1980 and then declined to 2.98 million cubic metres in 1990. This change in stock level depends on several factors. First the evolution of the age-class distribution as shown in Figure 22 shows a decrease in area in the older age-classes. By 1990 the total growing stock is distributed such that most area/volume is centred around the 60-year old class. This young forest has considerable potential for growth because the average volume per hectare is an increasing function with age as seen in Figure 7. Therefore the growth rates are greater in the younger age classes.

The major influences have been harvesting and natural mortality as shown in the volume account of Table 5. Volume lost to fire is a random process with losses as large as 55.3 million cubic metres in 1961 and as small as 79 thousand cubic metres in 1985.

The level of detail required for the timber accounts should be reviewed prior to commencing additional projects. We expect that future calculations will be made at a more aggregate spatial level due to the computational complexity that resulted from this pilot project.

Further discussions of project linkages between the various agencies (STC, CFS, MNR) involved with the production and use of these statistics should be encouraged and attempts made to improve the sharing of responsibilities, costs and information.

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9 Glossary

Canada forest inventory. Through the Canadian Forest Inventory Committee, the Canadian Forest Service works in close cooperation with provincial and territorial forest management agencies to make recommendations on forest inventory procedures, and to acquire data for national area and volume summaries on topics such as ownership, status, productivity, site quality, stocking, disturbance, age, forest types and species groups. Data on forest inventories are available from the Forest Inventory and Analysis Project, Petawawa National Foresttry Institute.

Coniferous cover type contains cone-bearing trees with needle or scale-like leaves belonging to the botanical group Gymnospermae.

Coverage in remote sensing terminology is the area covered by overlapping aerial photos or by maps.

Cover type is a group of forested areas or stands of similar composition which differentiates it from other groups.

Endemic mortality due to insects and diseases is mortality reflected in the empirical yield tables.

Empirical yield table is a summary table showing, for stands (usually even-aged) of one or more species on different site qualities, characteristics at different ages of the stand. The characteristics usually include average diameter and height and total basal area, number of trees, and volume per hectare. Empirical tables are prepared for actual average stand conditions.

Externalities by definition are costs or benefits that are imposed on others as the result of a particular economic activity.

Financial flow accounts reveal the financing of economic activity by focussing on transactions in assets and liabilities for a number of institutional sectors. The transactions are classified by type of financial instrument and shows the way in which funds move beween the lending and borrowing sectors.

Growing stock is the sum by number, basal area or volume of trees in a forest or specified part of it

Hardwood cover type contains trees belonging to the botanical group Angiospermae with broad leaves usually all shed annually.

Input output accounts measure productive activity occurring in the economy, focussing particularly on commodity transactions of industries and the role of producers and purchasers in the economy.

Linear filter in the engineering sense is a filter in which the relationship between the input series x_t and the filtered output series is described by a constant coefficient linear difference equation. There are two main types of linear filters: (1) Convolution Filters and (2) Recursive filters. We used a convolution filter : if the original time series is x_t and a vector $a = (a_0 ..... a_q)$ is a set of filtered coefficients, then the filtered series y_t is related to the original series x_t by the convolution equation $y_t = sum(j, a_j.x_{t-j})$ for t=0, +- 1 etc

Limits of operability define the range of ages from which harvesting may occur.

Mixedwood cover type contains a approximately equal mixture of coniferous and hardwood trees

Model validation is the scientific method of of proposing a test that the model , if false, would fail to pass. If the model does fail such a test , then it must be rejected.

Multi-dimensional array is the generalization of a matrix. Where matrices have two subscripts, arrays may have one, two, three or more subscripts.

National balance sheet accounts are structured in the same way as the financial flows but are intended to show the level rather than the change in assets and liabilities. At the aggregate level the national balance sheet provides an estimate of net national wealth by summing the net worth of each domestic sector.

Nonreserved forest land is forest land that, by law or policy, is available for the harvesting of forest crops.

Assigned nonreserved forestland is crown-owned no longer under the direct control of the Crown

Retained nonreserved forest land is crown-owned under the direct control of the Crown

Other nonreserved forest land is privately owned and controlled.

Nonstocked forest land is productive forest land that lacks trees completely or that is so deficient in trees, either young or old, that at the end of one rotation, the residual stand of merchantable tree species, if any, will be insufficient to allow utilization in an economic operation.

Positive linear system is a linear system in which the state variables are always positive (or at least non-negative) in value.

Production forest is productive forest land where harvesting may occur

Productive forest land is forest land that is capable of producing a merchantable stand within a reasonable length of time.

Regeneration transition matrices are tables of probabilities which define the propensity of regeneration by cover type from harvesting a particular cover type. These are defined for both natural regeneration and planting.

Reserved forest land is not available for the harvesting of forest crops

Roundwood is the section of tree stems, with or without bark.

Silviculture is the science and art cultivating forest crops... the theory and practice of controlling the establishment, composition ... and growth of forests.

Stocked forest land is land supporting tree growth which includes seedlings and saplings.

Structural diagram is a flow diagram graphical language to describe the input output relationship of a dynamica multi-varible process model. The diagrammatic language contains symbols for stock variables, flow variables and parameters.

Titleset is a collection of character labels which describe the elements in each array dimension.

Timber productive forest land c.f productive forest land.

10 APPENDIX A: STCmacroForest program

All computations are performed using the new S Language; a programming environment for data analysis and graphics S is a very high-level language for specifying computations. It is part of an interactive environment and so encourages the programmer to compute, look at data such that quick feedback enables the user to learn and understand complex data analysis problems.

We chose the S language since it satisfied three important criteria for the development of the timber resource account:

- interactive language (interpretive compilation);
- data objects may be represented as multi-dimensional arrays; and
- data objects may be visualized using graphics.

The visualization of the data played an important role in the verification of the simulation framework over the historical period. In the next sections we document the transformations associated with the processes identified in the structural diagram representation of the framework (sections 2.3 to 2.6) using a pseudo-code slightly different to S since it avoids certain functions which are not immediately obvious to the reader. We have used the = instead of the <- for assignment. Summation over a dimension of an array is the more obvious sum(i,x[i]) notation. Also an index is used to identify the dimensions of the array and the order in which these dimensions are arranged.

Most operations involve extraction and manipulation of the elements in multi-dimensional arrays. For example, the first line of code reads: the 1953 year of **nonStkLnd** is set to the estimated value **nonstock53est** for all cover types s and districts d. This is a parallel operation where we assign one matrix by another element by element. The two matrices must be conformable in row and column size.

That is: nonStkLnd["1953",s,d] = nonstock53est[s,d]

Looping is generally avoided in S since it slows computational speed. However, we occasionally need to perform looping oprations. For example, the entire code of **STCmacroForest** occurs within a big time loop of the years of the simulation time horizon.

10.1 Input Variables

In Table 6 we list the names of the input variables, their structure and a brief description together with units of measure. Input variables are data. Time series or flow data include : historical roundwood production, fire rates and removals of productive forest land for parks. Stock data are the 1991 Canada Forest Inventory of stocked productive forest land area aggregated by cover type, age and district and nonstocked forest land area by cover type and district. Finally, regeneration rates for stocked and nonstocked forest land together with regeneration transtion probabilities complete the requirements for data.

Table 6:
Definition of Inputs

Input Variables	Description	Units of Measure
plnWdProd[k,w,d]	planned roundwood production	m^3/yr
fireRt[k,d]	annual forest fire rate	%/yr
nvph180[w,i,s,d]	volume per hectare	m^3/ha
natCCShr	natural regeneration share	%
RTMplnt[s,s]	regeneration transition matrix planting	%
RTMnat[s,s]	regeneration transition matrix natural	%
inv91age180[i,s,d]	1991 Canada Forest Inventory	ha
ccregen	regeneration rate of clearcut	%
parkadd24[k,d]	additions to park land	ha/yr
nsregen	regeneration rate of nonstocked	%
nonstock91[s,d]	1991 nonstocked forest land	ha

10.2 Output Variables

In contrast, output variables,as defined in Table 7, are calculated from the procedures defined in section 7.3. These provide the indicators of forest development in terms of the opening and closing stock of forest land and the flows of disturbances due to fire, harvesting and mortality. Also transfers of productive forest land to parks and logging roads are accounted for

.

Table 7:
Definition of Outputs

Output Variables	Description	Units of Measure
newCCLnd[k,s,d]	new clearcut forest land	ha/yr
harvRatio[s,w,d]	harvest ratio	%
potVol[w,d]	potential roundwood volume	m^3
growStk[k,i,s,d]	growing stock	m^3
actWdProd[k,w,d]	actual roundwood produced	m^3/yr
forLnd[k,i,s,d]	stocked productive forest land	ha
fLndBrn[k,i,s,d]	forest land burned	ha/yr
nonStkLnd[k,s,d]	nonstocked productive forest land	ha
areaCut[k,i,s,w,d]	forest land area cut	ha/yr
volBurnt[k,i,s,d]	volume lost to fire	m^3/yr
volDied[k,i,s,d]	volume lost to mortality	m^3/yr
RegenAplnt[k,s,d]	artificially regenerated area	ha/yr
RegenAnat[k,s,d]	naturally regenerated area	ha/yr

10.3 Procedures

assign time independent data and initialise non stocked forest land

nonStkLnd["1953",s,d] = nonstock53est[s,d]

initialise 1953 inventory with estimated area

forLnd["1953",i,s,d] = inv53est180[i,s,d]

assign time dependent data

```
# historical production of roundwood by wood type and district

plnWdProd[1953:1990,w,d] = indconsh[1953:1990,w,d]

fireRt = pfire

# assign parameters

nsregen = 0.015

ccregen = 0.8# annual time loop

for(k in 1:38) {

########### 1) Forest Fires

# calculate burned area

fLndBrn[k,i,s,d] = fireRt[k,d]*forLnd[k,i,s,d]

# for all i,s, and d.

# update stock for fire

forLnd[k+1,i,s,d] = forLnd[k,i,s,d] - fLndBrn[k,i,s,d]

########### 2) Mortality

# mortality is forest that reaches 180 years

fLndDie[k,s,d] = forLnd[k+1,180,s,d]

# adjust stock for mortality

forLnd[k+1,180,s,d] =0

########### 3) Adjustment for parks

# distribute park additions by age and cover type

parks[k,i,s,d] = parkadd24[k,d] * forLnd[k+1,i,s,d]/sum(i,s,forLnd[k+1,i,s,d])

# adjust stocked forest land for parks

forLnd[k+1,i,s,d] = forLnd[k+1,i,s,d] - parks[k,i,s,d]

############ 4) Harvesting

############### SOFTWOOD ###################

# cut the forest according to the volume requirement

# take 75% of softwood from coniferous and 25% from mixedwood cover type
```

```
# first calculate potential volume of softwood

potVol[s=1:2,"soft",d] = sum(i=80:180,forLnd[k+1,i,1:2,d]*nvph180["soft",i,1:2,d])

# then calculate harvest ratio for coniferous cover type

harvRatio[s=1,"soft",d] = plnWdProd[k,"soft",d]*.75/potVol[s=1,"soft",d]

# and for mixedwood cover type

harvRatio[s=2,"soft",d] = plnWdProd[k,"soft",d]*.25/potVol[s=2,"soft",d]

# determine area to be harvested from coniferous and mixed wood cover types

areaCut[k,80:180,s=1:2,"soft",d] = harvRatio[s=1:2,"soft",]*forLnd[k+1,80:180,s=1:2,d]

# adjust stocked forest land for harvest and remove 3% of harvest area for logging roads.

forLnd[k+1,i=80:180,s=1:2,d] = forLnd[k+1,80:180,1:2,d] - 1.03*areaCut[k,80:180,1:2,"soft",d]

# calculate actual softwood wood produced

actWdProd[k,"soft",d] = sum(i=80:180,s=1:2,nvph180["soft",i,sd]*areaCut[k,i,s,d])

################### HARDWOOD ################

# calculate potential volume of hardwood

potVol[s=3,"hard",d] = sum(i=80:180,forLnd[k+1,i,s=3,d]*nvph180["hard",i,s=3,d])

# then calculate harvest ratio for hardwood cover type

harvRatio[s=3,"hard",d] = plnWdProd[k,"hard",d]*.75/potVol[s=3,"hard",d]

# determine area to be harvested from hardwood cover type

areaCut[k,80:180,s=3,"soft",d] = harvRatio[s=3,"soft",d]*forLnd[k+1,80:180,s=3,d]

# adjust stocked forest land for harvest and remove 3% of harvest area for logging roads.

forLnd[k+1,i=80:180,s=3,d] = forLnd[k+1,80:180,3,d] - 1.03*areaCut[k,80:180,3,"hard",d]

# calculate actual softwood wood produced

actWdProd[k,"soft",d] =sum(i=80:180,s=1:2, nvph180["soft",i,sd]*areaCut[k,i,s,d])

# calculate new clearcut by year, cover type and district

newCCLnd[k,s,d] = sum(i,w, areaCut[k,i,s,w,d])

########### 5a) Age and regenerate burn and mortality

# spread the oldest age-class among age-classes 1:179

for (s in 1:3) {
```

for(d in 1:24) {

forLnd[k+1,1:179,s,d] =

forLnd[k+1,1:179,s,d]+(forLnd[k+1,1:179,s,d]/sum(i,forLnd[k+1,i,s,d])*forLnd[k+1,180,s,d]

} # end loop on d

} # end loop on s

age remaining age classes

forLnd[k+1,i=2:180,s,d] = forLnd[k+1,i=1:179,s,d]

clean out the first year age class for regeneration

forLnd[k+1,1,s,d]=0

regenerate burned forest land

forLnd[k+1,i =1,s,d] = forLnd[k,i=1,s,d] + sum(i ,s, fLndBrn[k,i,s,d])

############ 6) Natural Regeneration and Planting

calculate natural and planting regeneration in stocked from nonstocked and recently harvested area using the regeneration transtion matrices.

for (s* in 1:3) {

natural regeneration

RegenAnat[k,s,d] =

RegenAnat[k,s,d]+(ccregen*newCCLnd[k,s*,d]+nsregen*nonStkLnd[k,s*,d])*RTMnat[s*,s]

and planting

RegenPlnt[k,s,d] =

RegenPlnt[k,s,d]+(ccregen*newCCLnd[k,s*,d]+nsregen*nonStkLnd[k,s*,d])*RTMplnt[s*,s]

) # end loop on s*

update nonstocked forest land

nonStkLnd[k+1,s,d] = (1-ccregen)*newCCLnd[k,s,d] +(1-nsregen)*nonStkLnd[k,s,d]

update regeneration in stocked forest land

forLnd[k+1,i =1,s,d] = forLnd[k+1,i =1,s,d]+RegenAplnt[k,s,d] + RegenAnat[k,s,d]

############ 7) Growing stock/volume lost

growing stock

growStk[k+1,i,s,d] = forLnd[k+1,i,s,d] *(nvph180["soft",i,s,d] + nvph180["hard",i,s,d])

```
# volume burned
volBurnt[k,i,s,d] = fLndBrn[k,i,s,d]*(nvph180["soft",i,s,d] + nvph180["hard",i,s,d])
# volume lost to mortality
volDied[k,s,d] = fLndDie[k,s,d]*
(nvph180["soft",i,s,d] + nvph180["hard",i,s,d])
# volume withdrawn to parks
volWithdraw[k,i,s,d] = parks[k,i,s,d] *(nvph180["soft",i,s,d] + nvph180["hard",i,s,d])
# add road volume lost due to hardwood harvest
volWithdraw[k,80:180,1:2,d] =
volWithdraw[k,80:180,1:2,d]+0.03*areaCut[k,80:180,1:2,d]*nvph180["soft",80:180,1:2,d]
# add road volume lost through hardwood harvesting
volWithdraw[k,70:180,3,d] =
volWithdraw[k,70:180,3,d]+0.03*areaCut[k,70:180,1:2,d]*nvph180["hard",80:180,3,d]
} # end loop on k
```

Figure 22:
Evolution of total stocked productive forest age-class structure

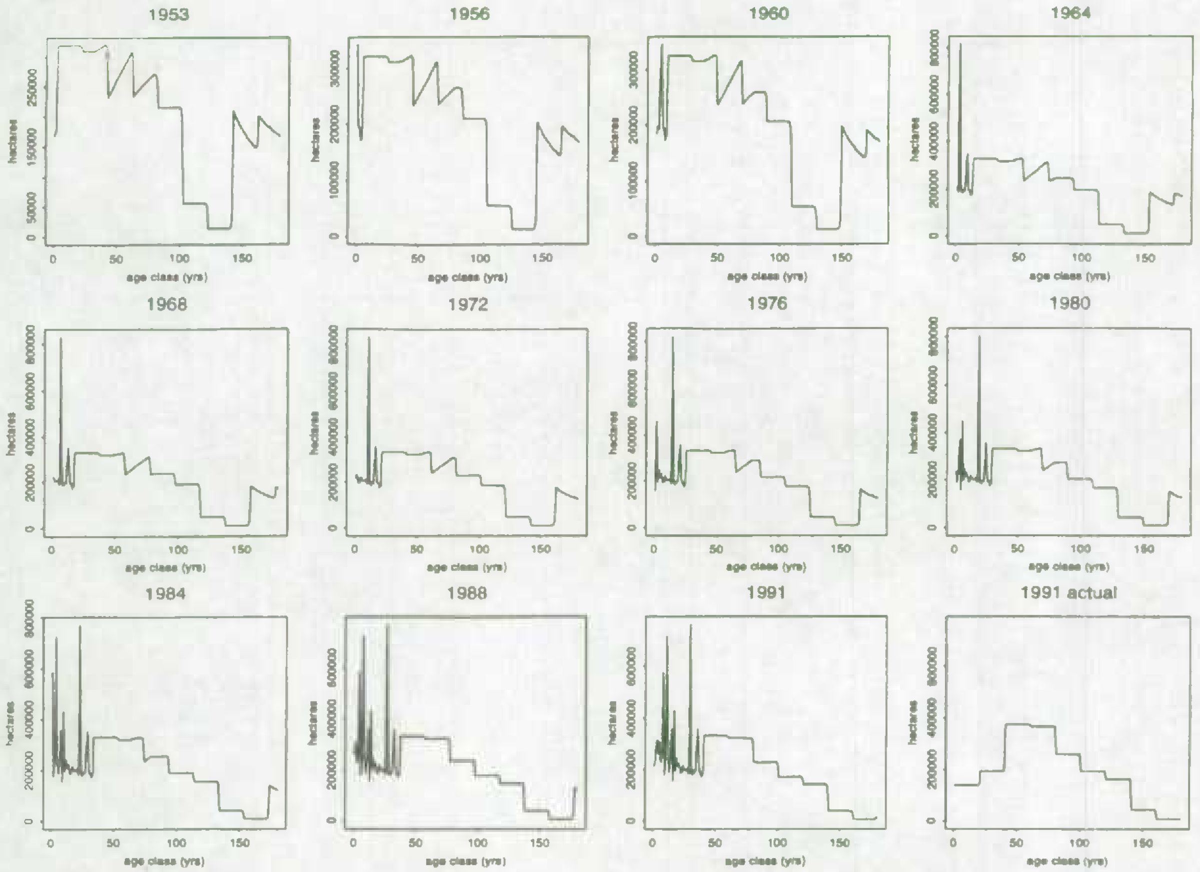


Figure 23:
Area of provincial stocked production forest by age

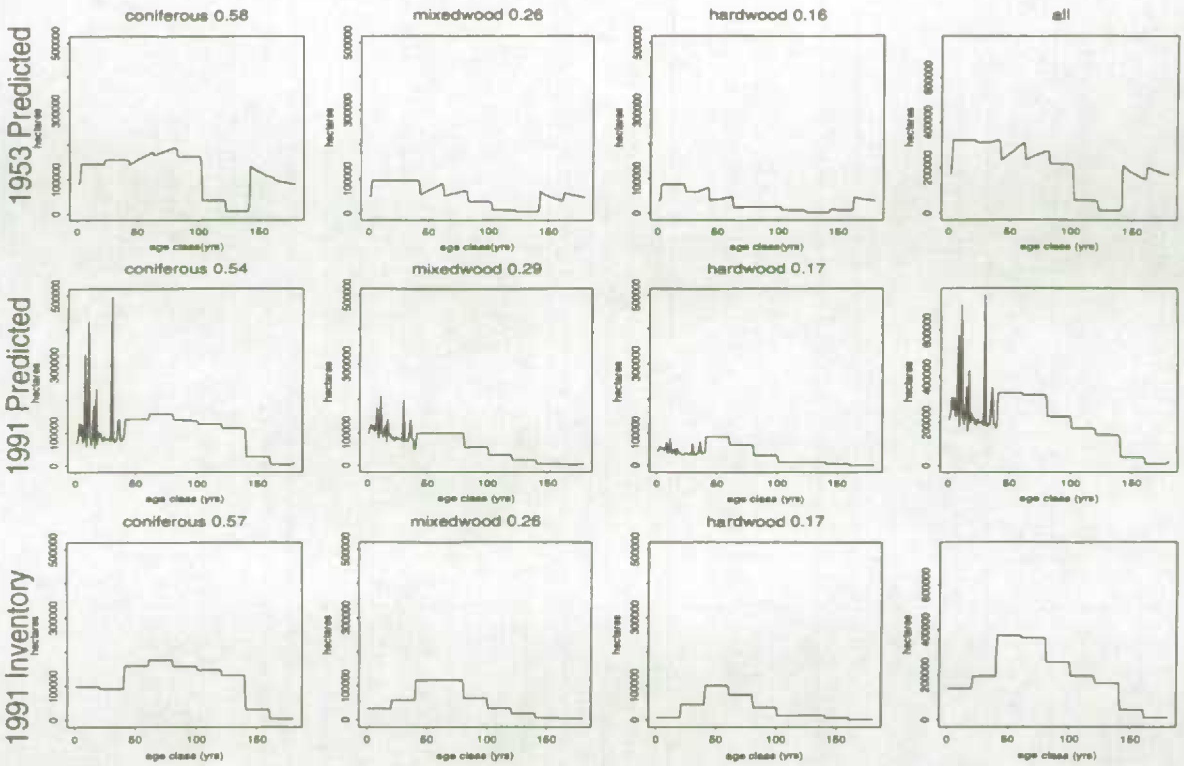


Figure 24:
Canada Forest Inventory Cell Map for Ontario

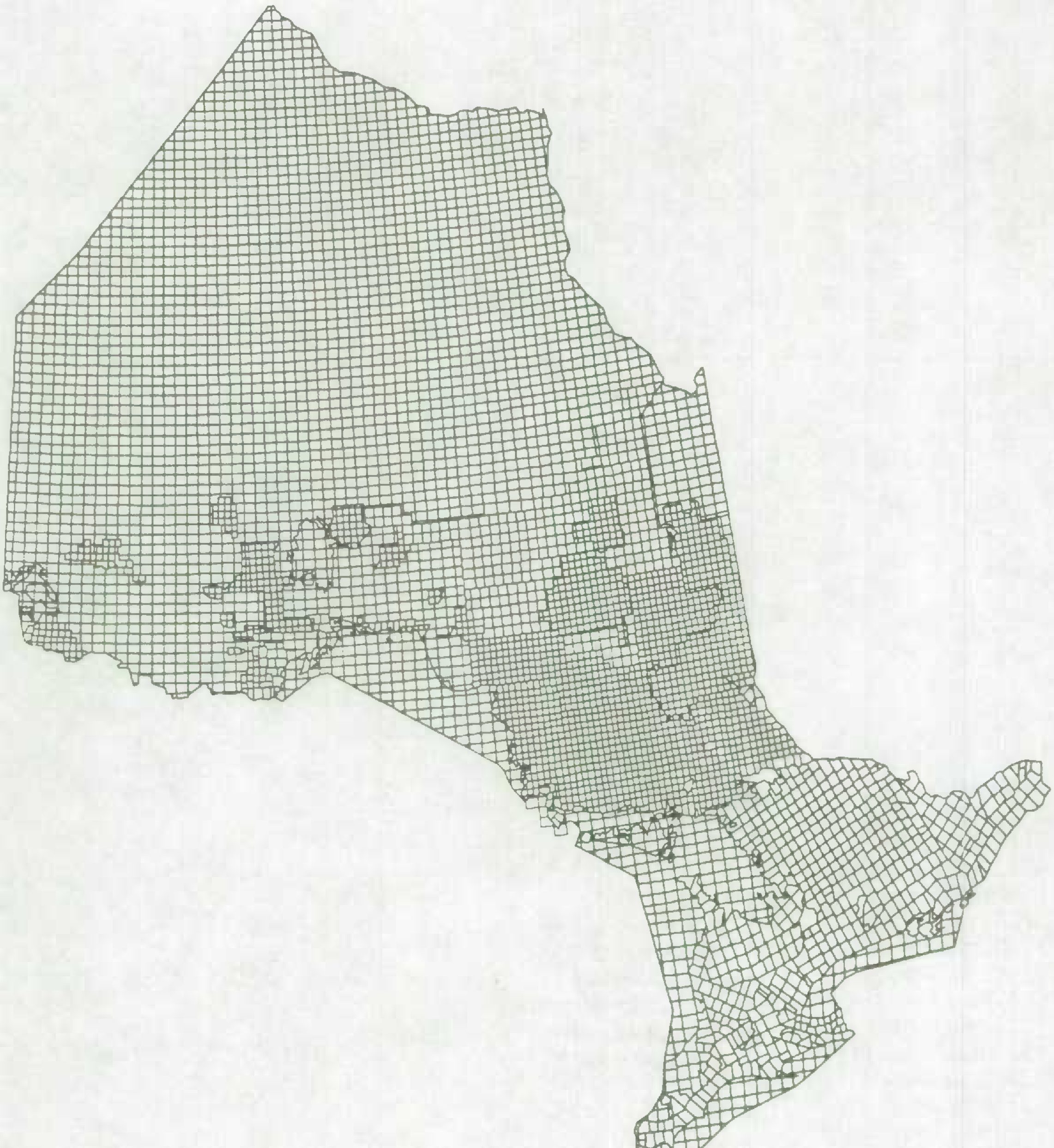
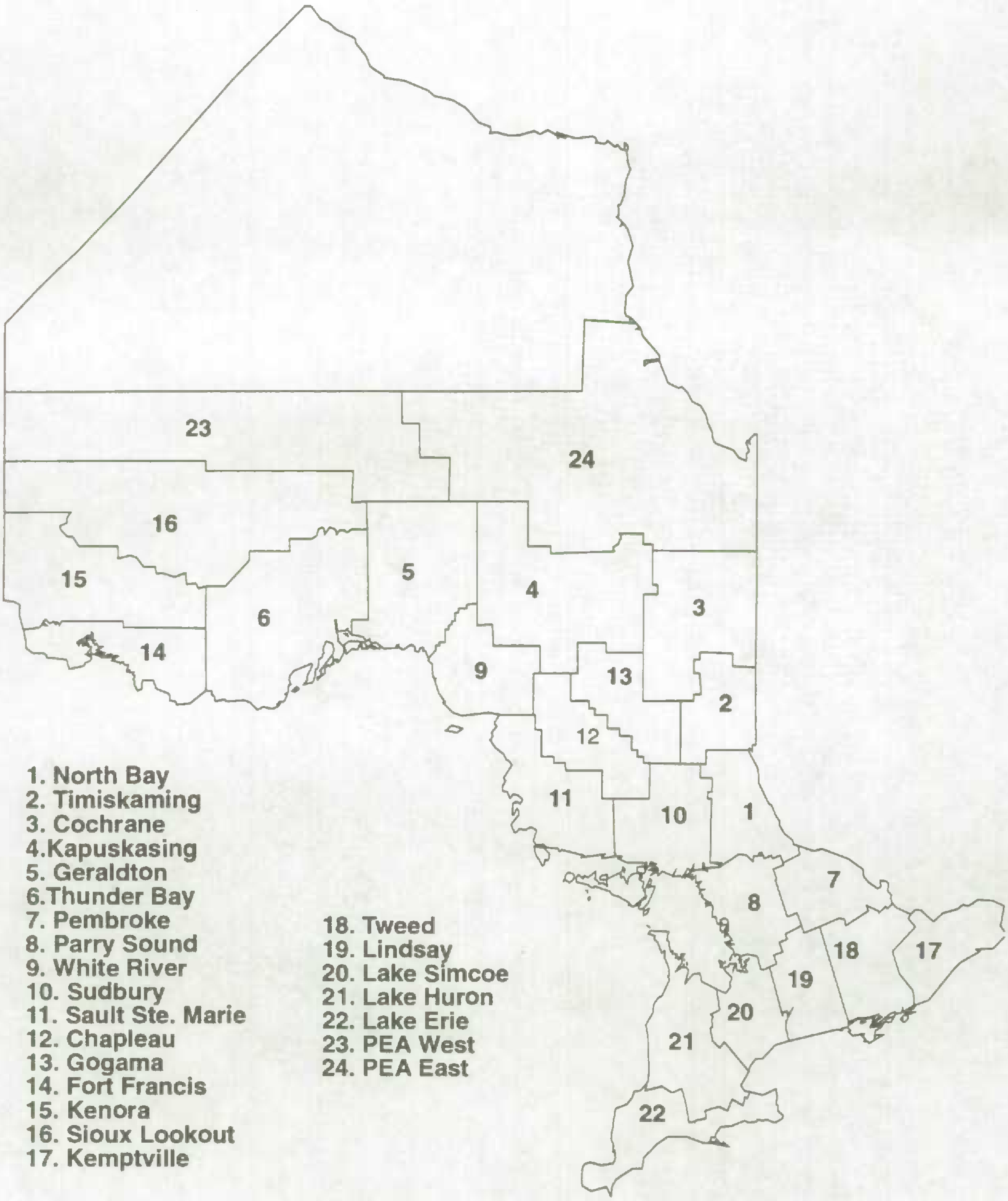
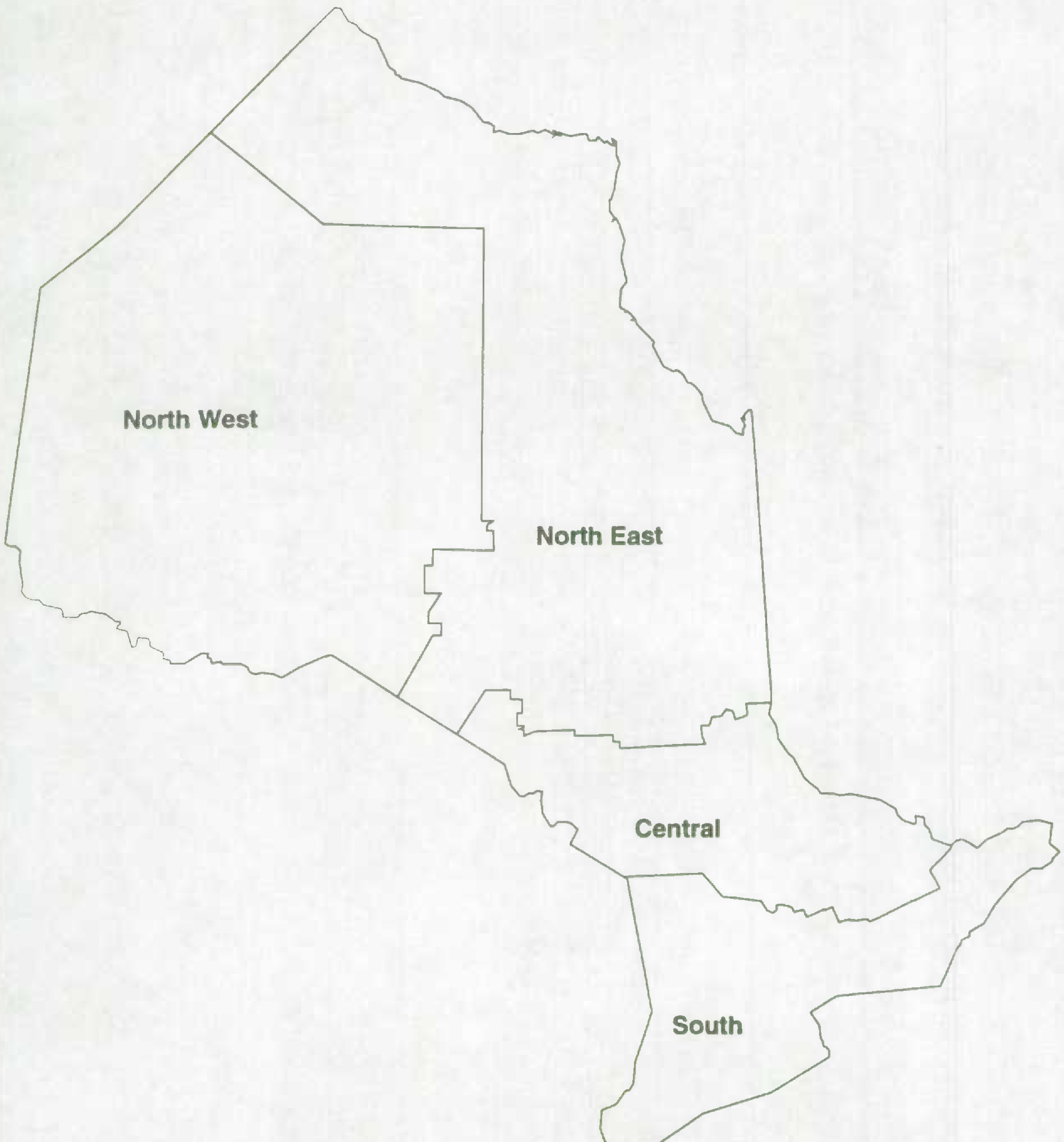


Figure 25:
Ontario districts map



1. North Bay
2. Timiskaming
3. Cochrane
4. Kapuskasing
5. Geraldton
6. Thunder Bay
7. Pembroke
8. Parry Sound
9. White River
10. Sudbury
11. Sault Ste. Marie
12. Chapleau
13. Gogama
14. Fort Francis
15. Kenora
16. Sioux Lookout
17. Kemptville
18. Tweed
19. Lindsay
20. Lake Simcoe
21. Lake Huron
22. Lake Erie
23. PEA West
24. PEA East

Figure 26:
Regions of Ontario



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2. Hamilton, Kirk and Doug Trant (December 1989): ***Statistical Aspects of the Application of Geographic Information Systems in Canadian Environment Statistics***, Journal of Official Statistics 1989, vol. 5, no. 4, pp. 337-348.

3. Smith, Robert (September 1990): ***An Annotated Bibliography of the Resource and Environmental Accounting and Valuation Literature.***

4. Gervais, Yvan (October 1990): ***Some Issues in the Development of Natural Resources Satellite Accounts: Valuation of Non-renewable Resources.***

5. Mitchell, Bruce and Kirk Hamilton (December 1990): ***Environmental Statistics at Statistics Canada,*** also available in French: ***La statistique environnementale à Statistique Canada.***

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c. 2