FOREST GROWTH AND YIELD

INFORMATION AND

KNOWLEDGE

PEARSON TIMBERLINE FORESTRY CONSULTANTS

#315, 10357 - 109 Street

Edmonton, AB

Canada T5J 1N3

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THE PRINCE ALBERT MODEL FOREST ASSOCIATION

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Prince Albert Model Forest Association Inc.

P.O. Box 2406

Prince Albert, SK

S6V 7G3

Telephone: (306) 922-1944

Fax: (306) 763-6456

EXECUTIVE SUMMARY

Understanding forest stand growth (changes in stand characteristics overtime) and yield (amounts of stand attributes or values that can be obtained at a point in time) is crucial for developing long-term plans for sustainable forest management. This report summarizes forest growth and yield knowledge for natural and managed stands of black spruce (*Picea mariana*), white spruce (*Picea glauca*), Jack pine (*Pinus banksiana*), and trembling aspen (*Populus tremuloides*), following a brief review of the basic concepts site (an area's potential for tree growth) and stocking (the extent to which an area's site potential is currently being realized). Emphasis is placed on knowledge derived from or applicable to sites in or near the Prince Albert Model Forest (PAMF).

Black spruce growth and yield information is based on analysis of data from a set of permanent sample plots (PSPs) established in 1951 and remeasured in 1961, 1970, and 1971. Yields vary from 0.9 m^3/ha yr on poor sites to 2.4 m^3/ha yr on good sites. Analyses of this data were published in 1953 and 1973.

White spruce growth and yield information is based on analysis of data from a set of PSPs established in 1949 and remeasured in 1954, 1955, 1959, and 1966. Yields vary from 0.9 m^3/ha yr on poor sites to 4.3 m^3/ha yr on good sites. Analyses of this data were published in 1951, 1955, 1957, 1962, and 1971.

Jack pine growth and yield information is based on analysis of data from a set of temporary sample plots established in 1950. Yields vary from 1.3 m^3/ha yr on poor sites to 2.8 m^3/ha yr on good sites. An analysis of this data was published in 1956.

Aspen growth and yield information is based on analysis of data from a set of PSPs established in 1949 and remeasured in 1951 and 1955. Yields vary from 2.0 m^3/ha yr on poor sites to 3.5 m^3/ha yr on good sites. Analyses of this data were published in 1956 and 1957.

A summary of available knowledge, along with a questionnaire, was forwarded to fourteen experts and practitioners familiar with forest growth and yield in the boreal forest in general, and in Saskatchewan in particular. Twelve responses were received and analyzed.

Active growth and yield programs are in place within SERM, forest industry, and CFS. Locational data were obtained for the 71 active PSPs within the PAMF boundaries. A digital map coverage of these PSP locations was prepared.

Few of the published growth and yield reports are being used by industry or SERM. A Biometrics Working Group has been formed, which is having the following new products prepared:

- natural stand yield tables;
- growth and yield estimation tools; and
- a locally calibrated stand dynamics model.

In addition, industry and SERM are continuing to remeasure and install PSPs. Increasing attention is being paid to collecting ecological data, to improve abilities for forecasting ecosystem dynamics under various forestry practices and changing environmental conditions.

The report concludes with four recommendations for the PAMF:

- participate directly in the Biometrics Working Group;
- assess existing PSPs in and near the PAMF area;
- pursue cooperative opportunities with the CFS Climate Change Group; and
- consolidate available data into a mixedwood stand dynamics model.

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INTRODUCTION

An understanding of stand growth and yield is crucial for developing long-term strategies for forest management. A knowledge of growth allows managers to link harvest rates to volume increment, ensuring the resource sustainability. A knowledge of yield allows managers to link harvest rates to mill requirements, allowing volumes, species mixes, and piece sizes to be forecasted.

This report summarizes forest growth and yield knowledge for natural and managed stands of black spruce (*Picea mariana*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*), and trembling aspen (*Populus tremuloides*). Emphasis is placed on knowledge derived from or applicable to sites in or near the Prince Albert Model Forest (PAMF). Recent literature reviews are the bases for much of this report. Published information and expert opinion for each species are presented, following a brief review of the basic concepts site and stocking. Expert opinions were obtained using a questionnaire distributed to growth and yield researchers and practitioners familiar with the PAMF area (Appendix 1 and Appendix 2). Current growth and yield plots within the PAMF are described and mapped. The report concludes with recommendations for further work, which should be designed to integrate all PAMF growth, yield, and quantitative silviculture programs.

Basic Growth and Yield Concepts

Growth is the change or rate of change in a selected stand attribute over time. Yield is the amount of some selected stand attribute that can be harvested at any point in time. Thus, growth is a biological production concept, and yield is an operational concept. Both are usually measured in physical units such as volume, basal area, or weight.

The ideal data for growth and yield analysis are complete chronological records for entire stands from establishment to harvest. However, the available data are always either temporary sample plots (TSPs) covering a wide range of sites and ages, or permanent sample plots (PSPs) which have been established and re-measured at fixed intervals.

Growth and yield information may be presented and analyzed in tabular, graphic, or equation form. The first two approaches were widely applied before the advent of computers and advanced mathematical techniques. However, since estimates of growth and yield were typically derived independently using these techniques, there was often an inconsistency between growth summation and terminal yield. Summation of a succession of periodic growth estimates added to an initial volume would not necessarily lead to the final stand volume indicated by the yield table. The application of calculus led to a resolution in which the algebraic form of the yield model could be derived by mathematical integration of the growth model.

Basic growth processes are common across most boreal forest stands. The available productive capacity of a given area is generally referred to mensurationally as "site". Competition for available light, water, and nutrients limits actual stand development to levels less than site. The extent to which site potential is being realized is commonly referred to as "stocking". Site and stocking together determine growth and yield (Davis 1966). These two concepts underlie much growth and yield research, although the terms site and stocking are not always applied consistently. To avoid confusion in this report, they are discussed in some detail below.

Site

Site is an area's potential for tree growth, considering biotic, climatic, and soil conditions (Ford-Robertson 1971). Site may be measured in many ways. It is possible to individually measure the many factors that affect forest land productivity, and integrate these into an index. However, some of these factors are not easily measured, and the process may be time consuming. Carmean (1975) and Hagglund (1981) provide overviews of site evaluation techniques. Schmidt and Carmean (1988) discuss some of the difficulties associated with relating site to soil and topography characteristics.

Various measures of stand volume, soil characteristics, and lesser vegetation have been used as indicators of site quality in Saskatchewan. Harris (1980) advocated using understorey vegetation for identifying and mapping forest sites in Saskatchewan. Kabzems (1971) suggested a site productivity rating system for Saskatchewan based on an edaphic grid (soil drainage and soil texture) with mean annual increment (MAI) as the dependent variable. The Provincial Forestry Branch incorporated soil drainage and texture measurements into its inventory procedures in 1978, and officially adopted the Ecological Site Capability Classification (ECSS) system in 1982-83. Kabzems *et al*. (1986) emphasized forest cover, minor vegetation, soils, and regional climate in their study of site relationships. Loseth *et al*. (1990) used the ECSS approach to develop SI prediction models for the tree species discussed in this report. Their study resulted in a site productivity prediction method that was compatible with the existing Saskatchewan forest inventory and the ECSS approach. Regression equations were developed which used the ECSS approach to predict SI at a base breast-height age of 50 years, for all four species and for all combinations of the independent variables of texture and drainage class, stratified by UTM zone.

Stand height growth has been the most popular measure of site. Height growth is highly sensitive to site, and it is also affected to a lesser degree by stocking. The standard practice is to describe site quantitatively using Site Index (SI). SI is the average height of dominant and codominant trees in a stand, at a specified reference age. For example, SI 15 on a 50 year base means the average height of dominant and codominant trees will be 15 metres at 50 years of breast-height age. The SI relationship is often described by curves of height over age (e.g., Cieszewski and Bella 1991). However, SI may not be applicable in stands which are too old, too young, uneven-aged, or suppressed. Gale *et al*. (1991) discussed the many problems inherent in assessing and measuring site. They reviewed the complex interactions among soil components and stand growth processes, thought to have led to a reliance by foresters on SI as a measure of site. Gale *et al.* suggested Productivity Index (PI) as a means of describing relationships between plant productivity and multiple soil properties, as these affect vertical root distribution. PI reflects a soil's relative potential to support tree growth. Gale and Grigal (1987) provide a further discussion of the importance of vertical root distribution to site quality.

Forest growth and yield practice has historically assumed site to be constant over time. Much research has occurred within the last two decades which indicates site qualities change over time, in response to many factors. Fire and harvesting practices can affect site productivity, altering nutrient cycling and nutrient availability by interrupting nutrient pathways and/or removing nutrient reserves (e.g., van Cleve and Dyrness 1983; Timmer *et al*. 1983; Kimmins 1993). Climate change through accelerated atmospheric $C0_2$ buildup is expected to be dramatic in interior continental areas such as Saskatchewan, with significant impacts on forest growth and yield (e.g., Wall and Sanderson 1990; Singh and Wheaton 1991; Kurz *et al*. 1992; Shugart *et al* 1992). Much remains to develop reliable and consistent tools for predicting site quality changes over time.

Stocking

Stand density is usually measured in quantitative terms, such as stems per hectare. Stocking is a related yet distinct concept, usually expressed as a ratio comparison of a stand's density compared to the density of an ideal stand (Davis and Johnson 1986). Stocking is often expressed as either a percentage in relation to what is judged to be the maximum density possible to fully utilize the site for the age, site, species, and end product involved, or in qualitative terms such as overstocked, fully stocked, or average stocking. Normal stocking is usually a synonym for full stocking, where the site is fully occupied. However, normal stocking is sometimes used to mean average stocking (actual site occupancy), which is generally less than full stocking. Empirical yields are typically based on stands of average stocking.

Density is the major factor a forester can manipulate in managing a stand. Maximum growth can occur over a fairly wide range of stand densities. End product requirements and utilization standards play an important role in defining optimum density since, if growth is held constant, only tree size and stems per hectare are variable. By changing stem numbers and spacing, managers can influence stem quality and diameter growth, as well as stand volume growth.

The need to control both tree number and tree size components of stand density has led to the development of indices for quantifying density. For example, relative density combines a basal area measure with a tree size measure. It is calculated by dividing basal area per hectare by the quadratic mean stand diameter at breast height (DBH). The crown competetion factor (CCF) estimates the area available to the average tree in relation to the maximum area it could use if it were open-grown. Reineke's stand density index (SDI) is the number of trees that a stand would have at a standard average DBH. Since Reineke's SDI is the dominant density measure used operationally and in the literature, further discussion is warranted.

Reineke's SDI was developed using three observed characteristics of fully stocked stands:

i) Different fully stocked even-aged stands of a species having the same quadratic mean DBH have approximately the same maximum number of stems per hectare.

ii) A curve of the maximum number of stems per hectare at different quadratic mean DBHs fitted with a log linear regression using data from fully stocked stands has the same slope (-1.605) for most species.

iii) In fully stocked even-aged natural stands, the number of trees in different diameter classes approximates a normal distribution, and therefore can be described by the average diameter alone.

Knowing these relationships, it is possible to directly compare the densities of stands with different quadratic mean DBHs. This is achieved by transforming the number of trees/ha at any given quadratic mean DBH to the number of trees/ha at a standard quadratic mean DBH. A graphical method is often used where the number of trees per hectare and the quadratic mean DBH of a stand are plotted on logarithmic paper. A line with a slope of -1.605 is then drawn through this point. This line represents the stocking of the stand. The number of trees indicated by this line at the chosen standard DBH is the SDI. The SDI can also be calculated using the following formula:

$$\log SDI = \log N - a(\log D - \log 10)$$

where
N = number of trees per hectare
a = slope (usually -1.605)
D = average stand diameter

In the imperial system, 10 inches is commonly used as the standard mean DBH. A standard mean DBH of 10 cm or 25 cm is commonly used in the metric system. Stocking can also be described qualitatively using SDI. For example, all stands within 2 standard deviations of the average SDI may be considered to have average stocking, while those above and below the 2 SD threshold may be considered to be overstocked and under-stocked respectively.

BLACK SPRUCE

Much of the growth and yield information for black spruce in Saskatchewan is based on analysis of data from permanent sample plots initiated in 1951. The most recent analysis of this data was completed by Benson (1973), who built on work by Kabzems (1953). Growth and yield functions were not given in these reports; instead, results are presented in curvesets and tables, as summarized in Table 1.

Table 1.
Black spruce growth and yield characteristics (Benson 1973).

Site Class	Site Index (m)	Number of PSPs	Economic Rotation (years)	MAI (m^3/ha yr)	Yield at Rotation (m^3/ha)	Maximum Yield (m^3/ha)
I (Good)	> 13.7	34	75	2.4	184	220
II (Average)	11.5-13.7	60	95	1.6	151	170
III (Poor)	9.2-11.4	49	129	0.9	115	130+
IV (Unproductive)	< 9.2	27	n.a.	n.a.	n.a.	n.a.

History

1951 150 1/5 acre (809 m^2) PSPs were established in black spruce stands within Saskatchewan's Provincial forest inventory area, between 52° and 55° North Latitude
1953 "Growth and Yield of Black Spruce" was published (Kabzems 1953)
1961 87 of the original plots were re-measured (the others could not be found, were considered understocked, or had been destroyed)
1962 Kirby wrote an unpublished analysis of the 1961 measurements
1970 99 of the original plots were measured again, and an additional 71 plots were established that fall and in the spring of 1971
1973 "Black Spruce in Saskatchewan" was published (Benson 1973)

Stocking

Kabzems (1953) reported that the emphasis on original plot selection was put on stands of average stocking, since the purpose of the black spruce PSP program was to develop empirical yield and stand tables. The plots selected approximated a normal distribution by stand density index (SDI), with the majority of stands in the range of 495 to 1110 SDI at a standard DBH of 25 cm. Since variety in age and site quality was desired, no attempts were made to systematically or randomly sample these stands. Instead, plots were selected from aerial photographs and were ground-truthed to verify that they met the selection criteria:

- productive (capable of yielding 45 m^3/ha of merchantable volume at a reasonable rotation age);
- over 75% of stand volume in black spruce stems; and
- sufficiently stocked (ie. crown closure of 30% or greater).

Benson (1973) did not quantify the stocking of these stands.

Site

Conventional SIs were determined from the 1951 measurements and the 1971 re-measurements, as well as from the additional plots established in 1970-1971. SIs were found to remain relatively constant over time (Benson, 1973). Benson classified the SIs from 173 measured plots into 4 classes as shown in Table 1, where SI is expressed in metres at the reference age of 100 years.

Kabzems (1953) qualitatively related timber productivity to site. The poorest sites were found on lowlands; typically muskeg with associated tamarack. These stands were usually considered unmerchantable. However, Kabzems believed that slightly improved utilization standards and favourable economic conditions could change the commercial value of stands on these sites. He also believed these stands and sites were undergoing gradual change due to slowly improving moisture regimes and soil (peat) build-up, and might approach commercial status on their own. The uplands were highly productive (average to better-than-average sites). However, the most productive sites were found in the transition zone between the lowlands and the uplands.

Benson (1973) examined a number of variables and their relationship to site, using linear regression. The purpose was to identify the effects of these variables on site, and therefore, on the growth and yield of black spruce. Variables examined included elevation, drainage and soil permeability. He concluded:

- average SIs on mineral soils are significantly higher than on organic soils;
- average SI on imperfectly to well drained soils is significantly higher than on poorly to very poorly drained soil;
- permeability of mineral soils has little to no effect on SI;
- higher elevation, well-drained sites are better able to develop into a productive black spruce forest;

and

- black spruce is longer lived on poorer sites than on better sites (see mortality table in Benson, 1973:49).

Growth and Yield

Height growth was studied by Kabzems (1953) to determine the time required to grow from stump to breast height (1.3 m). The variation was significant (from 3 to 27 years) but approximated a normal distribution, with an arithmetic mean of 10.7 years and a standard deviation of 5.4 years. Lindenas (1985) stated that black spruce will grow approximately 0.3 m/year in height until maturity (on a good site). The SI curves by Benson (1973:20) can be used to predict height growth over time for a variety of sites. Kabzems *et al*. (1986) applied a refined site classification with seven site quality groups and reported black spruce productivity in the range of 0.5 - to 2.4 + m^3/ha, depending on site class. Volume growth of black spruce is summarized in MAI curves by Benson (1973: 36-39).

In an attempt to measure the effects of a number of measured stand variables on MAI, Benson (1973) performed regression analysis with independent variables including SI, age, age squared, drainage class, permeability class, elevation, and rotation age (determined from SI). He found SI was the most significant variable in explaining variance in both MAI at rotation age and present MAI.

Terminal age (ie. the age at which volume growth is zero) is reported to be 160 years for black spruce by Lindenas (1985). Benson (1973) also reported a terminal age of 160 years for average sites, but showed it to be at approximately 135 years on good sites and 200+ years on poor sites.

Yield of black spruce In Saskatchewan is summarized in yield tables by site in Benson (1973:35).

WHITE SPRUCE

Much of the growth and yield information for white spruce in Saskatchewan is based on analysis of data from a set of PSPs initiated in 1949 (Table 2). Supplementary information was drawn from reports published in Ontario (MacLean and Bedall 1955) and Macleod and Blyth (1955). Growth and yield processes in the various reports are described by graphs, fables, and functions.

Table 2.
White spruce growth and yield characteristics (Kabzems 1971).

Site Class	Site Index (m)	Number of PSPs	Economic Rotation (years)	MAI (m^3/ha yr)	Yield at Rotation (m^3/ha)	Maximum Yield (m^3/ha)
I (Good)	> 18	28	70	4.3	305	385
II (Average)	14-18	86	75	3.1	235	290
III (Poor)	< 14	16	80	1.9	155	200

History

1949 329 1/5 acre (809 m^2) PSPs were established in mixedwood (white spruce-aspen) stands
1951 "Prediction of Growth in the Mixed-Wood Site-Type Saskatchewan" was published (Kabzems 1951)
1954 about 300 of the original plots were re-measured and 27 additional plots were established
1955 "The Growth and Yield of White Spruce Stands In the Mixed-Wood Belt of Saskatchewan" was published (Kirby 1955)
1956 34 additional plots were established
1957 "Influence of the Aspen Overstory on White Spruce Growth in Saskatchewan" was published (Cayford 1957)
1959 about 300 of the PSPs were re-measured
1962 "Growth and Yields of White-Spruce Aspen Stands in Saskatchewan" was published (Kirby 1962)
1966 about 300 of the PSPs were re-measured
1971 "Growth and Yield of Well Stocked White Spruce In the Mixed-Wood Section in Saskatchewan" was published (Kabzems 1971)

Stocking

Kirby (1962:5) stated that plots used in his analysis were, "for the most part", fully stocked. In constructing yield tables, he used only those PSPs having at least 76 percent softwood (primarily white spruce), by basal area. His yield tables were developed to show normal (full) stocking for white spruce stands. He described stocking in terms of stand density indices. Most plots fell between 495 and 740 SDI at a standard DBH of 25 cm.

In contrast, Kabzems (1971) used basal area as a measure of stocking, and observed that the majority of plots (95 percent - i.e. within 2 standard deviations of the mean) were in the range of 18 to 46 m^2/ha. His yields were empirical, representing average conditions in PSPs from well-stocked, even-aged, white spruce stands, having at least 75 percent softwood (primarily white spruce), by volume or basal area. Benson (1985) noted that results from these reports are suspect when applied against the white spruce covertype as a whole, since it includes all stands with a softwood component greater than 25 percent.

Site

The SIs prepared by Kirby (1962) were found to be inadequate after examination of plot measurements in 1966. Kabzems (1971) explained that this was due to the suppression of the dominant and codominant spruce by aspen in the early stages of their development in mixedwood stands. Kabzems (1971) constructed a new set of curves, based on a reference age of 50 years (Table 2).

Kabzems (1971) applied a biophysical approach to site description, using various vegetation, soil and physiographic characteristics. He described three major white spruce types - the Upland, Lowland and Dryland types. The Upland type was attributed with average to good productivity; the Dryland type was given a poor productivity rating; and the Lowland type was further split into a number of sub-types with one common characteristic - they grow on imperfectly to poorly drained sites with a high or seasonally fluctuating water table. Collectively, these sub-types range from the poor to the best in terms of productivity, depending on drainage. In 1986, Kabzems *et al*. described essentially the same types, but with a different nomenclature. The *Picea glauca - Agropyron/Arctostaphylos* ecosystem (low productivity) has much in common with the Dryland type. Similarly, the *Picea glauca - Pleurozium* (medium to high productivity) ecosystem is comparable to the Upland type and to the Lowland type on imperfectly drained soils. The *Picea glauca-Equisetum* type (lowest productivity) is comparable to the Lowland type on poorly drained soils. Kabzems (1971) also attempted to delineate the edaphic range of commercial white spruce by relating MAI to nutrient and moisture levels.

Lakusta (1994) argued that a need exists to explore interactions between white spruce and trembling aspen components of mixed stands, as these interactions may affect SI estimates. White spruce stems established along with trembling aspen stems, as primary succession following disturbance, develop differently from white spruce stems established as secondary succession (understorey).

Growth and Yield

Lindenas (1985) indicated that white spruce can be expected to grow 0.3 m in height per year until maturity on a good site. This is roughly equivalent to the site index curves developed by Kabzems (1971:35), which can be used to predict height growth over time for a variety of sites.

Diameter growth of white spruce is described by Kirby (1962:27) in a table showing the distribution of future 10-year diameter increment against present age and present diameter at breast height. This table can be used with the stand table projection method to directly estimate future volume growth, given that a stand table and local volume table are also available.

Volume growth of spruce is summarized in MAI tables and curves by Kabzems (1971:40-41). If maximum wood production for merchantable cubic metre volume is desired, then these tables and curves indicate technical rotation ages.

Kirby (1962) performed multiple regression analysis on plots between 40 and 130 years of age and having at least 26 percent or more softwood (mainly white spruce) basal area. A growth function was derived from this analysis that takes mortality and ingrowth into account. Kirby cautioned that this function should not be applied to data that go beyond the original data used to develop the function. The expected 10 year growth of softwood (mainly white spruce) in merchantable cubic meters per hectare (utilization of all trees 9.1 cm dbhob and larger) is

44.121 + 4.514 (percent softwood by Basal Area) - 0.49 (age).

The standard error of this estimate is 14.8 m^3 or 38.9 percent. The original function (1962) was expressed in imperial units, and has been transformed to metric units for this report.

Empirical yields of white spruce were summarized in curves and tables by site by Kabzems (1971:38-39). These yield tables are supported by additional information in the form of stand and stock tables for both pure white spruce and mixed spruce-aspen stands on average site.

Kirby (1962) derived a growth and yield function to predict merchantable softwood m^3/ha (mainly white spruce) for all trees 9.1 cm dbhob, as

$$-76.790 + 7.074 \text{ (Softwood BA in } m^2\text{/ha)} + 4.350 \text{ (Softwood average diameter in centimetres).}$$

The standard error of this estimate is 7.7 m^3 or 6.0 percent. The original function (1962) was expressed in imperial units, and has been converted to metric units for this report.

Kabzems (1971) noted that timber losses to mortality were greater than previously thought, especially on poorer sites. He summarized periodic annual mortality by age and site class in a table (Kabzems, 1971:63).

JACK PINE

Growth and yield information for jack pine in Saskatchewan is based on analysis of data from a set of temporary sample plots (TSPs) installed in 1950 (Table 3). Growth and yield functions were not published from this data; instead growth and yield processes were described In curvesets and tables.

Table 3.
Jack pine growth and yield characteristics (Kabzems and Kirby 1956).

Site Class	Site Index (m)	Number of PSPs	Economic Rotation (years)	MAI (m^3/ha yr)	Yield at Rotation (m^3/ha)	Maximum Yield (m^3/ha)
I (Good)	> 15.8	112	67	2.8	185	255
II (Average)	12.2-15.8	327	73	1.9	142	175
III (Poor)	< 12.2	93	77	1.3	102	115

History

1954 709 1/10 acre (404 m^2) TSPs were measured to randomly sample all major jack pine areas in the province of Saskatchewan.
1956 "Growth and Yield of Jack Pine" was published (Kabzems and Kirby 1956)

Stocking

The 1950 sampling was done primarily for forest inventory use, and therefore not all plots were reasonably representative for yield table construction. Plots were eliminated if they were:

- ‘A’ density (less than 30 percent crown cover),
- classified as mixedwood (less than 75 percent jack pine by volume),
- below 16 years of age or over 105 years of age, or
- more than 2 standard deviations from the average SDI (415 at average DBH of 25 cm).

This left 532 TSPs for analysis.

Average basal area was calculated as another measure of stand density, and the basal areas sampled were found to approximate a normal distribution with an average of 20.0 m^2/ha. Kabzems and Kirby (1956:13) stated that "Possibly the average stocking indicated here could be considered normal stocking for unmanaged pine stands of Saskatchewan". Later, they stated "normal" yield tables would be for pure even-aged and fully stocked stands. Although these would be ideal, a lack of information about what constitutes a normal stand necessitated empirical yield tables based on average stand conditions be developed instead.

Kabzems and Kirby (1956) argued that well-stacked jack pine stands produced long clear boles, while under-stacking resulted in trees that were short, bushy, and of poor economic form. Over-stacked stands (30 percent of jack pine stands in 1956) never reached merchantable size for products other than pulp. Thinning trials between 1945 and 1956 in these stands demonstrated that volume and basal area increments could nearly be doubled by reducing stand density. Kabzems (1959) indicated that jack pine stands were subject to the most serious under- and over-stocking of any covertype, as a direct consequence of forest fires. This may reflect the inflexibility of jack pine autecology (Lakusta 1994).

Site

The plots sampled in Kabzems and Kirby's (1955) work were classified into three site quality groups (Table 3), where site index is expressed in meters at a reference age of 50 years.

Another approach to site description was to recognize that, as a result of different environmental conditions, there are different jack pine vegetation associations with distinctive growth and yield patterns. In order of increasing productivity, they have been identified as the jack pine - *Cladonia* type, the jack pine - *Vaccinium* type, and the jack pine - *Hylocomium* (*Pleurozium/Lycopodium*) type. These associations are discussed in more detail in Kabzems and Kirby (1956) and Kabzems *et al*. (1986).

Growth and Yield

Lindenas (1985) reported that jack pine would grow between 0.3 and 0.5 metres per year in height on a goad site. The site index curves prepared by Kabzems and Kirby (1956:16) can be used to predict height growth over time for a variety of sites.

Diameter growth of jack pine was described by Kabzems and Kirby (1956:26) in a table showing the distribution of future 10-year diameter increment against present age and percent diameter at breast height.

Merchantable volume growth of jack pine was summarized in MAI tables and curves by Kabzems and Kirby

(1956:20). If maximum volume production is the goal of management, then these rotation ages are appropriate. However, if lumber production is the goal, then rotation age should be shifted by approximately 18 years, and would be in the range of 85 to 95 years depending on site (Benson 1973:18).

Kabzems *et al*. (1986) applied a refined site classification with seven site quality groups and reported jack pine productivity in the range of 0.8- to 3.2+ cubic meters per hectare depending on site class.

Terminal age (ie. the age at which volume growth is zero) is reported to be 115 years for jack pine on an average site. Kabzems and Kirby (1956) determined sightly different terminal ages of 95 years, 105 years and 115 years for poor, average, and good sites respectively.

Yield of jack pine was summarized in empirical yield tables by site in Kabzems and Kirby (1956).

ASPEN

Much of the growth and yield information for aspen in Saskatchewan is based on analysis of data from a set of PSPs initiated in 1949 (Table 4). Growth and yield functions were not given in the various published reports; instead, results are described in curvesets and tables. The Aspen Management Information System recently available from the Northern Forestry Centre provides easy access to a comprehensive database of published information on aspen, much of it applicable to Saskatchewan.

Table 4.
Aspen growth and yield characteristics (Kirby *et al* 1957).

Site Class	Site Index (m)	Number of PSPs	Economic Rotation (years)	MAI (m^3/ha yr)	Yield at Rotation (m^3/ha)	Maximum Yield (m^3/ha)
I (Good)	> 18	41	65	3.5	230	305
II (Average)	15 -18	96	71	2.8	196	240
III (Poor)	15	50	77	2.0	157	185

History

1949 80 1/5 acre (809m^2) PSP's were established in hardwood cover types
1954 PSPs were re-measured
1955 129 additional 1/5 acre (809m^2) PSP's were established in hardwood covertypes.
1956 "Growth and Yield of Aspen in the Mixedwood Belt in Saskatchewan" was published (Burton and Kirby 1956)
1957 "Growth and Yield of Aspen in Saskatchewan" was published (Kirby *et al*. 1957)

Stocking

The selection of plots in 1949 was not random, as a cumulative record of age-class distribution was kept, and plot selection was constantly adjusted to ensure that all age classes were adequately sampled. For the 1957 report, the 209 PSPs were examined to see if they met the following criteria:

- over 75 percent of stand volume in hardwood stems;
- even-aged; and
- not abnormally over- or under stocked (deviated by more than twice the standard error from the average of 270 SDI at 25 cm DBH).

A total of 22 plots were rejected for not meeting one or more of these criteria, leaving 187 plots for growth and yield analysis. The remaining sample was thought to approximate normal stocking for commercial aspen stands. There seems to be inconsistency in the terms used, since the sample represented average (empirical) rather than full (normal) stocking. Later in the report, Kirby *et al* (1957:19) indicated the yields were empirical. An approximately normal distribution of basal area was sampled, however the average basal area of 25 m^2/ha was considerably higher than the overall average basal area of hardwood stands sampled for forest inventory of 20 m^2/ha.

Site

Kirby *et al*. (1957) classified the site indices from the aspen growth plots into three classes as shown in Table 4, where site index is expressed in metres at a reference age of 50 years.

Kabzems *et al*. (1986) recognized, as a result of different environmental conditions, different aspen vegetation associations with distinctive growth and yield patterns. In order of increasing productivity, they have been identified as the Aspen-*Rosa/Elymus* type, the Aspen-*Corylus* type, and the Aspen*Aralia/Linnaea* type.

Growth and Yield

Lindenas (1985) reported that aspen would grow between 0.3 and 0.5 metres per year in height on a good site. The site index curves prepared by Kirby *et al*. (1957:15) predict height growth over time for a variety of sites.

Diameter growth of aspen is described by Kirby *et al*. (1957:23) in a table showing the distribution of future 10-year diameter increment against present age and present diameter at breast height.

Kirby *et al*. (1957:33) stated that decay was the most serious factor limiting the growth potential of aspen stands in Saskatchewan, and therefore, aspen should be harvested before the onset of decay. This pathological rotation, however, generally produces material that is too small for lumber and plywood production. Volume growth of aspen over rotations applicable to pulpwood production is summarized in MAI tables and curves by Kirby *et al*. (1957: 25-26). Kirby *et al*. reported that exceptional aspen stands over 100 years of age have been logged in Saskatchewan, but in general, aspen rotations should not exceed 80 years due to marked increase in mortality and cull after that age.

Kabzems et a1. (1986) applied a refined site classification with seven site quality groups, and reported aspen productivity in terms of MAI in the range of 1.1- to 3.5+ cubic meters per hectare depending on site. Terminal age was reported to be 110 years for aspen on a medium site.

Yield of Aspen in Saskatchewan is summarized in yield tables by site in Kirby *et al*. (1957:19). The same table has been reproduced and converted to metric by Peterson and Peterson (1992).

GROWTH AND YIELD PLOT LOCATIONS

Information on current PSPs within the PAMF was provided by SERM and by Weyerhaeuser. Weyerhaeuser plots include both managed stand PSPs and juvenile Growth Assessment Plots. Figure 1 shows the PSP locations within a PAMF boundary coverage provided by PAMF staff. Locational data were provided to 10 m, 50 m, or 100 m precision, depending on the agency and program. This causes apparent clustering of the plots when mapped at the scale of Figure 1. The locational data in Figure 1 have also been provided to PAMF as an Arc/info coverage (export format), for integration with other spatial data, and for plotting at other scales. Table 5 lists the owner, plot number, and locational precision for each plot shown to Figure 1.

Figure 1.
Permanent Sample Plot locations within Prince Albert Model Forest.
Scale: Approximately 1 : 900 000

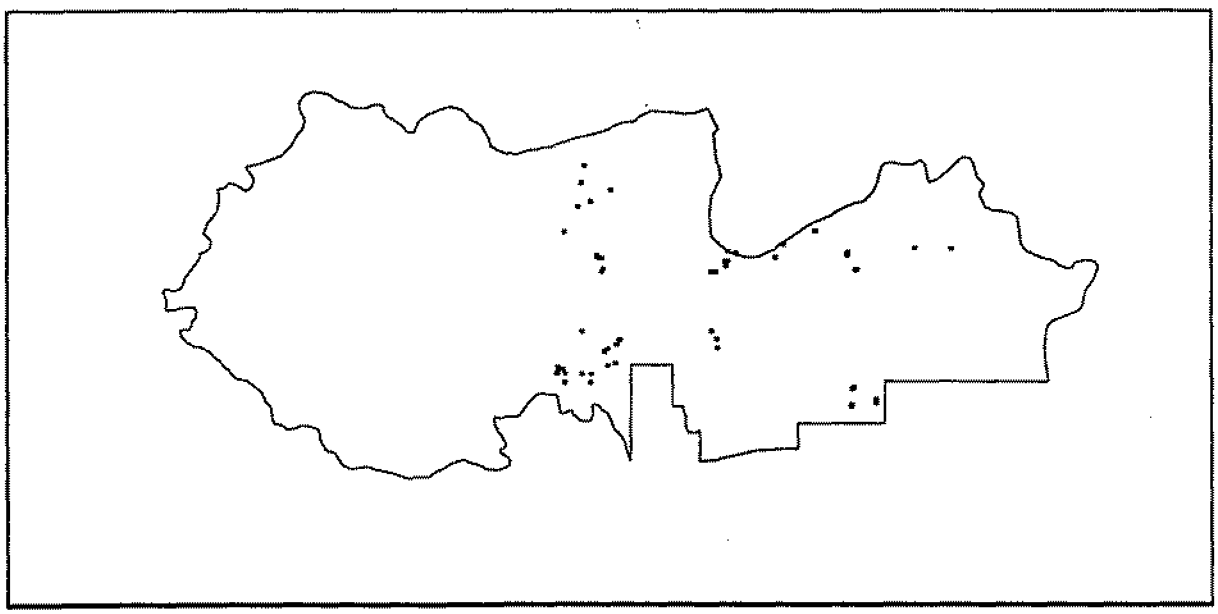

Table 5.
Permanent Sample Plots within the Prince Albert Model forest.

Agency	Plot Numbers	Locational Precision
SERM Forestry Branch PSPs	BS140, BS148, BS149, BA150, BS197, BS198, BS199, BS400, BS500, BS600, JP118, JP121, JP129, JP163, MW180, MW200, MW300, MW34, MW345, MW346, MW400, MW500, MW734, MW735, MW737, MW738, MW739, MW740, MW741, MW937, MW939, MW940, TA160, TA170, TA413, TA736, TA775, TA776, TA941, TA942, TA943, WS190, WS340, WS350, WS938	100 m
WeyCan PSPs	92-DT-04, 92-DT-05, 92-DT-06, 93-BR-02, 93-BR-03, 93-BR-05, 93-BR-06	10 m
WeyCan GAPs	GA-86-44, GA-86-45, GA-86-46, GA-86-47, GA-86-48, GA-86-49, GA-86-50, GA-86-51, GA-86-229, GA-86-230, GA-86-402, GA-86-403, GA-86-404, GA-86-601, GA-87-7, GA-87-8, GA-87-11, GA-87-207, GA-87-209	50 m

CURRENT ACTIVITIES

All questionnaire respondents reported current activities in growth and yield. SERM has had a mensurationist on staff since the 1990/91 fiscal year. A PSP inspection project was implemented recently by SERM, during which all PSPs were visited and maintained. Weyerhaeuser, Mistik, and MacMillan Bloedel have been maintaining and re-measuring PSPs within their Forest Management License Areas. Weyerhaeuser and Mistik have been installing additional PSPs, under PAIF support. Additional PSPs are also being installed by Geographic Dynamics Corp., as part of a site classification project for SERM.

The additional PSP data is being used for various purposes, including at least:

- development of natural stand yield tables (Weyerhaeuser);
- site classification (SERM); and
- Environmental Impact Assessment preparation (Mistik).

Weyerhaeuser has also initiated two installations under the WESBOGY (Western Boreal Growth and Yield) cooperative, one near Prince Albert and one near Big River. Neither installation is within the PAMF boundaries. These studies will provide useful information on stand dynamics of various mixes of trembling aspen and white spruce, established on cutovers. Weyerhaeuser has also initiated a set of permanent growth assessment plots, in young (5-25 years of age) stands of white spruce, jack pine, and aspen. Plots were installed under both natural and managed conditions. Weyerhaeuser has also established a set of PSPs in managed stands established using different silvicultural tactics.

Various forestry agencies in Saskatchewan have formed a Biometrics Working Group, with PAIF funding. This group has initiated cooperative studies on growth and yield, including the recent award of a contract to develop a set of natural stand yield estimation tools. This project will include calibration of a growth and yield model for Saskatchewan, and a set of yield tables for natural stands.

Staff of the CFS Edmonton lab are just completing a project which developed height/SI curves for various Saskatchewan species. The Edmonton CFS lab is also the focus of a major climate change program, designed to investigate, among other things, how forest ecosystems respond to climate changes. Several projects are underway within this program, such as the functioning of aspen forests across a climate moisture gradient. Unfortunately, only a partial response to the questionnaire was received from this group, so not all of their activities are reported here.

RECOMMENDATIONS

The questionnaire and associated interviews provided much useful information for guiding future growth and yield activities within the PAMF. Table 6 summarizes the key questionnaire results. Appendix 2 contains transcribed responses to the questionnaire.

Table 6. Summary of questionnaire results.

Topic	Summary of Responses
Existing Growth and Yield Programs	- SERM and industry have active programs, including recently maintained PSPs for natural and managed stands - both SERM (45 plots) and Weyerhaeuser (26 plots) have active PSPs within PAMF area, with digital data available - older (inactive) CFS study sites may be present within PAMF
Growth and Yield Estimators	- few of the published tables and graphs are being used - Biometrics Working Group is having Natural Stand Yield Tables prepared
Models	- no locally calibrated stand dynamics models are in use - Biometrics Working Group is having a model localized for Saskatchewan - better tools are needed for modelling stand dynamics under changing forestry practices and environmental changes
Mixedwood	- Weyerhaeuser has completed analyses of mixedwood stands - US Climate Change Group is collecting data in mixed stands
Integrated Resource Management	- various ecological data is being collected by industry, as PSPs are remeasured - SERM may begin collecting additional ecological data on PSPs
General	- Biometrics Working Group offers a useful communications and coordination forum - PSPs are critical to a growth and yield program
Recommendations	- participate directly in Biometrics Working Group - analyze existing PSPs in and near PAMF area - assess information needs for forest planning

Based on the questionnaire results and the findings from the information and knowledge review, the following detailed recommendations are offered.

1 Participate directly in the Biometrics Working Group.
The Biometrics Working Group has members from most government and industry sectors of the Saskatchewan forestry community, with a common interest in improving stand dynamics information and knowledge. Several questionnaire respondents felt there was overlap between this project and one or more similar projects underway or planned by the Biometrics Working Group. Strong common interests exist in areas such as stand dynamics forecasting under alternative silvicultural practices.

2 Assess existing Permanent Sample Plots in and near the PAMF area.
There are 71 PSPs within the PAMF boundaries, and these offer a wealth of information for predictive modelling. The data for these plots should be reviewed in detail for possible contribution to PAMF modelling needs. Locational and access data could be improved, and the plots might offer some interpretive potential as the basic data source for sustainable forestry planning.

The PAMF, with a broad perspective on forest resource management issues, could offer advice on extending the PSP concept to include non-timber ecological data, to help understand and forecast impacts of changing forestry practices on stand growth and yield.

There may be some older, inactive CFS research plots within the PAMF boundaries. This was mentioned by staff of the CFS Prince Albert office, and should be pursued further.

3 Pursue cooperative opportunities with the CFS Climate Change Group

The Climate Change Group at the Edmonton CFS lab has strong common interests with PAMF, with respect to stand dynamics forecasting under changing environmental conditions. Despite numerous contacts, no questionnaire response was received from Dr. Mike Apps, leader of this Group. The Group is rumoured to have several study sites in or near the PAMF. This possibility should be investigated.

4 Consolidate available data into a mixedwood stand dynamics model

Available data, knowledge, and expert opinion should be consolidated into a locally calibrated model of mixedwood forest stand dynamics. This has the benefits of

- capturing available data and information in a highly structured framework, for ease of retrieval and application;
- forcing data from various sources to be linked across site, stand composition, and treatment gradients;
- explicitly identifying research needs during the calibration process;
- providing a tool for forest planning and training, based on the current information base; and
- providing the basic stand dynamics forecasting engine for other Model Forest activities and projects.

The model should consolidate data and expert opinion on growth and yield of pure and mixed stands of white spruce, black spruce, jack pine, and trembling aspen, under natural and managed conditions. A modest amount of field data collection is anticipated, as data gaps become apparent.

The Biometrics Working Group is initiating a project to complete this calibration for all of Saskatchewan. Consideration should be given to refining this calibration for the PAMF area.

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APPENDICES

APPENDIX 1
QUESTIONNAIRE

The questionnaire was sent to fourteen experts and practitioners familiar with forest growth and yield in the boreal forest in general, and in Saskatchewan in particular. Responses to the questionnaire are presented in Appendix 2.

1) Growth and Yield Programs

Growth and yield reports found in the literature review were published between 1953 and 1973. Most make reference to a Permanent Sample Plot (PSP) program. In 1981, the Saskatchewan Forest Inventory Section published a revised "Saskatchewan Growth and Yield Survey Field Procedures Manual". It stated that permanent sample plots have been established in six species associations: White Spruce, Black Spruce, Jack Pine, Tamarack, Mixedwood (Spruce), and Trembling Aspen.

i) What is the current status of this survey (ie. number of plots by species, history, maintenance schedule)?

ii) Is the data available in paper or digital form? Please elaborate.

iii) Can you provide details of plot locations (maps, coordinates, aerial photos, etc.)? Please elaborate.

iv) Have you undertaken any other growth and yield studies in Saskatchewan (eg. density control/thinning trials, WESBOGY cooperative research)? Please elaborate.

v) Does forest industry in Saskatchewan maintain a PSP database? What is its status?

2) Growth and Yield Estimators

Most of the written work on growth and yield in Saskatchewan summarizes the processes in tables and graphs.

i) Are you using these yield tables? Please elaborate.

ii) Have you developed growth and yield functions? Please elaborate.

3) Models

i) A base-level calibration of the Stand Projection System (SPS) Model was recently completed for Saskatchewan. If you are familiar with this work, please provide comments. Are you satisfied with the model and the calibration? Can you identify any weaknesses?

ii) Have you used and/or calibrated any other growth and yield models for Saskatchewan? If so, are these available? Do you have comments on their usefulness for growth and yield modelling to Saskatchewan?

iii) Do the existing data and equations/models allow you to assess the growth and yield implications of changing forestry practices and of environmental changes (i.e., global warming, increasing atmospheric CO_2 concentrations, and disturbance of regional hydrologic patterns? Do you see a practical need for such assessments in your growth and yield projections?

4) Mixedwood

The white spruce growth and yield reports use data derived from mixedwood stands, with the emphasis on white spruce. Have any analyses of mixedwood stands been completed? Please elaborate.

5) Integrated Resource Management

Growth and yield information is not only used in harvest planning - it is also used by wildlife biologists, hydrologists, and other resource planners. Is information relating to other aspects of forests and stands (eg. snags, dead and down woody material, mineralization rates) being collected and/or projected? Please elaborate.

6) General

Please provide any additional comments on growth and yield research needs, or on this questionnaire.

7) Recommendations

i) What should be done now by the PAMF to improve the usefulness of local growth and yield data and information? Please be as specific as possible, and try to relate your comments to the information needs of the PAMF.

ii) What should be done by the PAMF to assess the impacts on the boreal forest of current forestry practices and of environmental charges?

APPENDIX 2
QUESTIONNAIRE RESPONSES

The questionnaire was completed by twelve practitioners in Saskatchewan, Alberta, and Manitoba. This appendix presents their responses, by question. A summary of the responses is provided in the body of the report.

1) Growth and Yield Programs

Growth and yield reports found in the literature review were published between 1953 and 1973. Most make reference to a Permanent Sample Plot (PSP) program. In 1981, the Saskatchewan Forest Inventory Section published a revised "Saskatchewan Growth and Yield Survey Field Procedures Manual". It stated that permanent sample plots have been established in six species associations: White Spruce, Black Spruce, Jack Pine, Tamarack, Mixedwood (Spruce), and Trembling Aspen.

i) What is the current status of this survey (ie. number of plots by species, history, maintenance schedule)?

(much material was received from SERM Forestry Branch - see body of report)

Talk to Marek Zieba, SERM Forestry Branch, Forest Inventory Unit. Data is being supplemented with additional PSPs installed as part of the Site Classification project (contract with Geographic Dynamics Corp.), and PSPs installed and remeasured by WeyCan and Mistik

Mistik has undertaken to maintain and build on the growth and yield PSPs established by the Prov. Forestry Branch within the NorSask FMLA. This program of maintenance has been established to ensure that the PSPs are not "lost" over time. A list of PSPs measured during 1992 and 1993 is attached.

Within the Weyerhaeuser FMLA, there are approximately 85 bS, 78 jP, 155 mW, 120 tA, and 110 wS. I'm not aware of any tamarack PSPs, prior to the Site Classification project establishing new PSPs in 1993. Attachment #1 shows the number of plots by species. It also subdivides the total number of plots within a species into three categories: .
1) Unsure - SERM's PSP reconnaissance program shows that this plot cannot be found, is destroyed, or if they found it, the trees have all lost their numbers.
2) Retain and Remeasured - the recon program has found these plots, and has deemed them to be remeasurable. The plots have been remeasured at least twice, and as many as seven times.
3) Retain and Unmeasured - recon program deems them remeasurable, but they have not been remeasured, just established.

The Province of Saskatchewan has installed natural stand PSPs as early as 1949. The first mensurational efforts consisted of circular plots in mostly white spruce sawlog stands, where trees were measured by dbh class for volume estimates. Establishment of further plots were rectangular plots that had individual trees marked/tagged. PSPs were established in species-specific (i.e., wS, bS, mW, jP, and tA) 'surveys'. For example, in 1951 all PSPs established (approximately 30) were dedicated to a single species, black spruce. Subsequent provincial PSP effort after 1958 has been dependent upon external (Federal government) funding. In 1980 and 1981 a major PSP plot establishment program was funded by the federal Department of Regional Economic Expansion (DREE) (see Attachment #2). Approximately 325 plots were established, of which, 70 were aspen. After 1981, there was the recession and government cutblocks which resulted in no PSP efforts (installation or remeasurement) for a period of ten years. In 1990-91 and 1991-92, the provincial government spent $50,000 each year to implement their "PSP Inspection Project". This was made possible by the hiring of a mensurationist (Mr. Marek Zieba). Plots were not remeasured, but the status of each PSP was evaluated as shown in Table 1. The trail leading from the road to each plot was re-painted, new plot posts were installed, and tree numbers re-painted.

Table 1.
Example of information within the permanent sample plot inspection project evaluation.

Survey	Plot #	Date	Access	Plot Type	Trail Re-Painted	Paint Status	Plot Re-Painted	Plot Status	Corner Posts	Comments
MW	569	Jul90	car	circle	Y	good	Y	retain	Y	good
WS	759	Jul91	car	square	Y	unreadable	Y	retain	Y	healthy trees
JP	179	Jul91	car	unsure	Y	fair	Y	retain	N	unsure

source: Forest Evaluation Branch, Forest Inventory Section, Forestry Branch, Saskatchewan Environment and Resource Management.

In 1992, Mistik Management Contracted TAEM (Meadow Lake) to remeasure the 74 provincial PSPs on their FMLA, as part of their EIA (Environmental Impact Assessment). Soils and vegetation information were collected, in addition to remeasuring the trees. The provincial government remeasured 47 PSPs in Hudson Bay, which had never been remeasured before. MacMillan Bloedel remeasured aspen PSPs established in the 1960s with PAIF funding. In 1993, Weyerhaeuser sponsored a PAIF project (Project #3019) to remeasure 40 PSPs on the Weyerhaeuser FMLA. The data was sorely needed for another PAIF project (project #8090), NSYTs (Natural Stand Yield Tables). The provincial government had a PSP remeasurement program in 1993, but the majority of the effort went to eastern Saskatchewan (Hudson Bay area). However, 11 PSPs were remeasured on the Weyerhaeuser FMLA. Mistik remeasured another 75 plots on their FMLA. Site classification contract with PAIF established soils pits and vegetation plots on xx PSPs. In addition to this work, xx new PSPs were established as site classification plots. In 1994, Weyerhaeuser plans to contract remeasurement on 50 PSPs (Budget of $25,000) to natives. SERM is uncertain if any PSP work will be done in 1994, as it depends on the provincial budget, funding availability, etc. They will not know until the 1994/95 fiscal year (May 94).

SERM has no maintenance schedule. Their remeasurements are on an ad hoc basic, and largely dependent upon federal funding initiatives. Weyerhaeuser Canada has begun to remeasure the FMLA PSPs, and plan on a ten-year remeasurement cycle, with the exception of over-mature black spruce on wet sites, where the remeasurement cycle will be 20 years (Table 2).

Table 2.
Remeasurement status of Weyerhaeuser FMLA PSPs as of April 1993.

# measurements	# plots	percent (%)
1	380	69.1
2	43	7.8
3	31	5.6
4	79	14.4
5	73	13.3
6	36	6.6
7	5	0.6
Total	550*	100.0

* # plots column adds to 645, but this number is exaggerated. due to double-counting plots with repeated measures. Actual total number of plots is 550.
source: Forest Evaluation Branch, Forest Inventory Section, Forestry Branch, Saskatchewan Environment and Resource Management.

Alberta has a permanent sample plot manual that could be used as a reference when reviewing Saskatchewan's manual. Some of the Alberta PSPs could be used to supplement those in Saskatchewan if same valid method for selecting the appropriate plots were developed. Some combination of site index and ecosite factors could be used. We have the following PSPs that could be considered for that purpose.

regular PSPs	650
stand dynamics plots	249
monitor plots	104

The Manitoba governement began a PSP program around 1985. They established approximately 200 PSPs, some of which have been remeasured. However, due to budget constraints the program has been frozen.

Manitoba has a long-term forest management plan under development, with a growth and yield component. Manitoba has abut 280-300 plots in jack pine, black spruce, trembling aspen, white spruce, larch, and mixedwood stands. Emphasis on plot selection was on young stands. The first plots were established in 1987. These are well-distributed over the province, with up to two remeasurements. The program is currently inactive, due to budget cuts. CFS has many PSPS in Manitoba.

ii) Is the data available in paper or digital form? Please elaborate.

The vast majority of SERM PSP data is available in ASCII format. Depending on age of PSP there may be tree data available in addition to plot data.

Data is available in both paper and digital form. Paper tally sheets used in the field and later keypunched. The paper data is organized by year of survey, and by species (<u>not</u> by plot). SERM is the keeper of the digital data. Marek Zieba tells me that the data has been transferred from the Westbridge mainframe to his PC (dBase?).

Talk to Marek Zieba. We (CFS) have obtained the digital files (1993 measurements not included).

The Mistik data is available in paper and digital (dbase) format for PSP measurements initiated by Mistik in 1992 and 1993.

The Alberta PSP data is available in paper or digital form.

The Manitoba PSP information should be available to the digital form. All data was collected using Husky Hunter field recorders.

iii) Can you provide details of plot locations (maps, coordinates, aerial photos, etc.)? Please elaborate.

Plot locations of active plots are on paper copies of SERM standard 1:12,500 maps. Also have a digital listing of plots with UTM locations to 100 metre coordinates.

Best obtained from Marek Zieba.

All Mistik plot data has been provided via the PAIF growth and yield study. Maps are available.

There are no aerial photos with plot locations marked on them. Plot coverage (1984 vintage) does exist, but the plots would have to be visited and locations marked. There are no locator's maps for these PSPs. Tiepoints, distances, and azimuths to the plots are non-existent. Instead, the PSP locations are marked on the Forest Inventory Maps (FIM) 1:12,500 scale, with 100 m accuracy using UTM coordinates. This low level of accuracy often places the PSP in another stand.

A listing of Alberta plots could be provided. Only those that are appropriate for application to Saskatchewan should be considered.

The location of Manitoba plots has been recorded on maps (1:15,840).

iv) Have you undertaken any other growth and yield studies in Saskatchewan (eg. density control/thinning trials, WESBOGY cooperative research)? Please elaborate.

Fertilization trials were undertaken some time ago. They have been remeasured and some analysis conducted but no formal report prepared.

Yes. PSPs have been established in conjunction with renewal activities (Mistik).

WESBOGY - Weyerhaeuser have two complete installations, one in Prince Albert, one in Big River (None fall within PAMF). GAP - Growth Assessment Plots. Young (aged 5-25 years) jack pine, white spruce, and aspen PSPs, in plantation, fire-origin, scarified, and naturally regenerated sites. Some of these plots have thinning as a treatment response trial. All plots are in pairs to allow measures of variability, and to allow treatment on the second plot in the future, if treatment response trials are desired. (19 paired plots are within the PAMF). No spacing trials. Managed stand PSPs (PAIF partial funded). 20 m X 20 m PSPs located in disc-trench, Bracke, and V-plow sites for jack pine and white spruce (7 in PAMF). Lack good information on response of stands to silvicultural treatments.

Several old CPS studies were done: e.g., MS-18 (thinning jP); MS-19 (thinning/pruning jP); MS-153 (wS release); MS-155 (tA thinning). Weyerhaeuser has installed 2 WESBOGY installations, received PAIF funding for one of them. WeyCan and Mistik are receiving PAIF funding to establish PSPs in managed stands.

Refer to NoFC PSP catalogue.

Alberta has two WESBOGY plots located in the Salve Lake Forest near Fawcett Lake. Some FMA holders have also established such plots. They have not been in place long enough to yield useful data.

LFS lacks good data on the effects of density control/thinning as do other forestry agencies. The Stand Dynamics Plots may provide some useful data. Some of the long established FMA holders like Weyerhaeuser (Grande Prairie) may have data (for example, on spruce growth under an aspen overstorey) that would be useful if the Company is willing to provide the data.

You would have to contact the Manitoba government for this answer. Repap Manitoba has done some studies in growth and yield. Students have done their theses on density control, site index, and growth and yield.

v) Does forest industry In Saskatchewan maintain a PSP database? What is its status?

Some of the industry does. Current status varies according to company. Big players are Mistik Management, Weyerhaeuser and MacMillan Bloedel.

WeyCan and Mistik did remeasurement of SERM PSPs in 1993. MMB maintains approximately 200 to PSPs established 1976-1980 (contact John Daisly 865-1700). WeyCan and Mistik are receiving PAIF funding to establish PSPs in managed stands. WeyCan maintains Growth Assessment Plots (contact Paul LeBlanc)

For natural stand PSPs, Weyerhaeuser obtained SERM data. For managed stand PSPs, have GAP data and managed stand PSP data. Second measurement data exists for GAP. Still need to error-check data and analyze.

I understand that Weyerhaeuser and MacMillan Bloedel have assumed responsibility for measuring those Saskatchewan government PSPs located within company agreement areas. In Alberta PSP data from CANFOR and Weyerhaeuser (Grande Prairie) may be applicable to Saskatchewan.

2) Growth and Yield Estimators

Most of the written work on growth and yield in Saskatchewan summarizes the processes in tables and graphs.

i) Are you using these yield tables? Please elaborate.

No (CFS-PA). I have the G&Y reports, but have had no occasion to use the tables and graphs.

No (SERM). Timber supply planning uses total standing volume at or near rotation age divided by area to give estimated yield at and beyond maturity, by growth type. PSP data alone overestimates yields and reduces rotation age because they were established in the better forest types.

No (Mistik).

We (Weyerhaeuser) do not use any of the yield tables summarized by Pearson Timberline. Instead we use Saskatchewan Average Stock Tables (1974 vintage). In addition, we are localizing these stock tables, and supplanting them (replacing information for commercially important cover types) with operational cruising data, aggregated by cover type. Sample sizes and statistical measures of variability are also included.

I (CPS-NoFC) have used data on aspen height, dbh, density, and basal area from the sources quoted by Peterson and Peterson (1992) as a means of comparing the growth of aspen at our drought-stressed Batoche site in the aspen parkland, with that in the main boreal forest. The "site index" at Batoche would be about 10 metres (due to the dry climate).

We (LFS) aren't using Saskatchewan yield tables although we did consider using those for black spruce and jack pine, species for which we have little data. We have used empirical inventory-based yield curves in the past. Yield curves based on PSP data will likely be used in future. The stand model developed by Dempster and the individual tree-based model (MGM) still being improved by Titus are possible models we may use.

Manitoba has no yield tables.

ii) Have you developed growth and yield functions? Please elaborate.

Under current PAIF, the Biometrics Working Group developed specifications for development of Natural Stand Yield Estimation tools. We are currently in the process of negotiating a contract through Supply and Services Canada.

Yes, to a certain extent. Provincial stand/stock tables developed by SERM have been limited to forest succession models.

No we (Weyerhaeuser) have not developed growth and yield functions (yet), as we are planning to do so for managed stands (GAP data). Paul LeBlanc is also a PAIF Biometrics Working Group member, who are issuing a contract to develop natural stand yield tables for Saskatchewan, based on PSP, 3-P, and temporary sample plot data.

Not really. Current PAIF is initiating a NSYT project.

No, only height/SI curves that just finished (Cieszewski and Belle), to be published by CFS. An unpublished report has been provided to SERM, for the commercial tree species in Saskatchewan.

Growth and yield functions work poorly at our site. Tree-ring analysis at Batoche show that severe drought causes the growth increment of aspen to be chronically reduced (for 5 years or more) by 50-80% compared to normal years. In the late 1980s, drought and tent caterpillar caused massive mortality of aspen across large areas of the aspen parkland in Alberta and Saskatchewan. Thus we cannot assume that climate is constant or that insect damage is negligible. Under these circumstances, we need to use models that include these driving variables.

Growth and yield functions have been developed for Alberta using LFS PSP data. Those include Dempster's stand-based model plus individual tree-based models including MGM, SPS and TASS.

Repap is currently studying the use of cruise data (point in time data) for growth and yield equations.

No growth functions are currently available for Manitoba.

Some growth modelling was done in Manitoba by Frank Hegyi and Terry Honer, before they went to the Victoria CFS lab. The whereabouts of this work is unknown.

3) Models

i) A base-level calibration of the Stand Projection System (SPS) Model was recently completed for Saskatchewan. if you are familiar with this work, please provide comments. Are you satisfied with the model and the calibration? Can you identify any weaknesses?

I (CFS) am not familiar with it. The Saskatchewan members of WESBOGY had discussed having an SPS calibration done several years ago. SERM agreed to fund the calibration in-house. I helped draw up the contract specifications, but my understanding was that they never followed through with it.

A review has not occured at this time (Mistik).

I (Weyerhaeuser) am aware of, but not familiar with this work. It seems to have been a 'rough cut' that did not include all possible data sources. Mike Bokalo (U of A grad student) did MScF thesis on comparison of different growth models. Using AFS PSP data, he found that SPS poor for mixedwood and aspen sites in boreal Alberta.

If this is Arney's model - no such work has actually been completed that we (SERM Forestry Branch) are aware of. Some work was done, but never finished.

A version of SPS was calibrated for the LFS by Dr. J. Arney using LFS PSP data. He did not take advantage of the fact that our PSPs are mapped, even though SPS is designed to use such data. Our review of the model's performance suggested that predictions are optimistic.

ii) Have you used and/or calibrated any other growth and yield models for Saskatchewan? If so, are these available? Do you have comments on their usefulness for growth and yield modelling in Saskatchewan?

TRAS/TREES were acquired and attempts made to calibrate them were made but failed. This was done in the early 1980's.

Mistik has provided data for the PAIF growth and yield project obtained by the company over the past several years. Specific models developed by the company are preliminary and will be revised pending results of the PAIF project.

No. Talk to Weyerhaeuser about how they use the results of the Arney soil-site study (Arney 1988, summarized by Loseth *et al*. 1990) as input to their High Yield Forestry timber supply projections for their 20-year management plan.

No, we (Weyerhaeuser) have not. Through the PAIF, we have a contract to calibrate a growth and yield model for Saskatchewan.

The Mixedwood Growth Model (MGM) stilt under development by Titus was developed using LFS PSP data. That model should be considered for adoption in Saskatchewan.

iii) Do the existing data and equations/models allow you to assess the growth and yield implications of changing forestry practices and of environmental changes (i.e., global warming, increasing atmospheric CO_2 concentrations, and disturbance of regional hydrologic patterns? Do you see a practical need for such assessments in your growth and yield projections?

1. No.
2. Yes.

No. SERM's PSP network is exclusively in fire-origin stands. Some progress is being made with WESBOGY study, and installation of managed stand PSPs by Mistik and WeyCan. Same ARNEWS plots are in Saskatchewan. There is definitely a need for addressing more than growth and yield in undisturbed natural stands.

No, they don't, and probably no practical need for some time. Perhaps this depends on the interest of researchers. More specific studies are needed, such as large equipment implications on soil compaction.

No. Mistik is very interested assessing growth and yield implications to changing forestry practices/silivicultural systems.

No, the existing data and models do not allow this. I do see a practical need for modelling existing forest practices such as: tree improvement, -genetically improved planting stock; various intensive silvicultural practices: second-growth stands (scarified jack pine sites, naturally regenerated aspen sites); and plantations. I see a need for local environmental change (watershed effects, etc.), and a smaller need for global environmental change (needed for Environmental Impact Assessment etc.).

As I have alluded to earlier, I feel that traditional growth and yield models are inappropriate for making predictions under changing climatic conditions. The yield models of the future should at least include realistic responses of forests to climate, especially moisture, and should also take into account the possibility of increased losses due to insect and fungal pathogens, as well as the likelihood of more frequent fires. Increasing $C0_2$ levels may increase tree photosynthesis and water use efficiency, but I do not believe that we yet have a sufficient understanding of the feedbacks to say that there are any long-term benefits to the forest, arising from higher $C0_2$ levels in the atmosphere.

We (LFS) lack data on the effect of changing forestry practices and of environmental changes. Data on silvicultural practices is needed now to assist field staff to select by site which practice is best to apply. Estimates of the effects of different practices are also needed to assist in calculating AACs. We will have to develop our best estimates of the results that can be expected for immediate use and try to put in place a program to monitor the effects of different practices to enable our equations/models to be corrected in future.

No, they do not. There may be a need for this, but current climate change may or may not relate to growth and yield.

Environmental changes are very difficult to address. We appear to be experiencing such changes now. Differentiating between cyclical changes that are part of normal natural cycles and those caused by human activities is and will be difficult. Public concern over the effect of environmental change is likely to require attention being paid to this area of study even if the changes are the results of natural cycles that have occurred in the past.

Growth and yield information is essential to forest management which deals with attaining and maintaining the spatio-temporal order of the growing stock in a manner which is economically efficient, socially responsible, ecologically sound. Traditional growth and yield models were derived and used for temporal ordering and economic efficiency and were often not ecosystem-based. The emerging role addresses other performance criteria. Growth models will be expected to account for the effect of pollutants and changing climates on the forest and land area in question, as well as to provide reliable estimates of future forest state that support nontimber uses. The incorporation of ECSS system in Saskatchewan provides a good foundation for ecosystem integration.

Growth and yield research emphasized more on mathematical model development and used regressions techniques (curve fitting) and neglected biological mechanisms. Existing equations/models are inadequate for assessing growth and yield implications of changing forestry practices and of environmental changes. The need for developing deeper models to allow for these assessments is urgent. Biological mechanisms and processes should be explicitly included in growth and yield models to allow users to assess implications of environment change and management practices.

4) Mixedwood

The white spruce growth and yield reports use data derived from mixedwood stands, with the emphasis on white spruce. Have any analyses of mixedwood stands been completed? Please elaborate.

Not sure.

Kirby 1962 does present yields for softwood and hardwood.

No (Mistik).

Weyerhaeuser developed localized stock tables for mixedwood cover types, based on operational cruising data. Species site index comparison graphs (preliminary analyses), for the purpose of comparing site index values among species. We are including site index of the dominant tree species as stand attributes in the forest inventory stands that have operational cruising. At Bird Lake (within the PAMF) a 1/5 ha complete destructive stem-analysis plot was analyzed in 1992, as part of an operational cruising pilot study. The stand type was mixedwood (SH25C wStA). Weyerhaeuser started a study of stand ages in wS/tA mixedwood sites. Comparing wS ages to tA ages, for the purpose of determining which stands site index is valid for both species. Also have a project proposal started to compare basal area of wS to tA as a means of redefining inventory species associations (HS, SH). This would allow us to link PSPs to mixedwood cover types, by 'calculating' the cover type of each PSP.

The climate change group is making a variety of measurements on forest stands, including mixedwoods, within BOREAS and the Boreal Forest Transect Cash Study, at about 60-80 sites between Prince Albert and Thompson (Manitoba). Mike Apps at Canadian Forest Service, Edmonton, is heading a forest biometry and allometry study and should be contacted for further Information.

A new initiative is underway in Victoria (PFC), headed by Bonnor, to develop G&Y model for Boreal Mixedwood, including tA - wStA - wS stands.

Using LFS PSP data some interesting trends in species composition have been noted. MGM tries to model some of these relationships. Further work will be necessary on this topic.

5) Integrated Resource Management

Growth and yield information is not only used in harvest planning - it is also used by wildlife biologists, hydrologists, and other resource planners. Is information relating to other aspects of forests and stands (eg, snags, dead and down woody material, mineralization rates) being collected and/or projected? Please elaborate.

Not in PSPs.

The SERM PSPs do carry information on standing dead and dead and down trees, but only of the first remeasurement following mortality (i.e, progress of decomposition not followed). Various Branches of SERM have held discussions on collecting a common set of data at all sampling locations (contact Terry Rock, Wildlife Branch 953-2893).

Yes (Mistik). All PSPs remeasured over past two years have included data collection for development of an ecosystem classification. These data pertain to forest soils, floristics, and small mammals.

Weyerhaeuser is collecting a lot of IRM data by 'piggy-backing' on other data collection programs.

Operational Cruising Program

- collecting pre-harvest silvicultural prescription (PHSP) data such as LFH depth, surface stoniness, understorey regeneration, etc.
- special forest products (commercial plants)
- wildlife observations (signs, scat, sightings)
- soils information (textures, horizonation, moisture regime, etc.)
- vegetation information (1 m X 1 m plot, % cover by all species)
- snags (dbh, height, condition) but do not measure down material, due to the plotless nature of prism sampling

Site Classification Project

- snags (dbh, height, condition)
- down and dead woody material
- 10 m X 10 m vegetation plot (% cover all species by six floristic layers) - full soil pit

The sampling program by Mike Apps (see above) aims to estimate total carbon content of forest, and thus includes the measurement of standing dead trees as well as downed woody debris.

The collection of data for non-timber resources is beginning. Unfortunately no one has been able to fully determine what variables should be measured. Some of the wildlife habitat modelling being done in conjunction with the Foothills Model Forest will help to decide what data is needed. Data needs related for assessing other resource values such as recreation have been given even less attention that wildlife.

I think not.

Yes, Repap Manitoba has collected information on snags, dead and down woody material, wildlife users, etc. This information was collected in both Timber Cruise and Regen Cruise programs.

Information relating to other aspects of forests and stands should be collected, modelled, and linked to other modes for an integrated resource management. Linking stand dynamics models within animal habitat suitability models may make it possible to reduce environmental uncertainty in animal habitat goals formed as parts of forest management plans.

6) General

Please provide any additional comments on growth and yield research needs, or on this questionnaire.

Plots were first established in 1949. Mature/overmature stands are flush with data. Immature stands are lacking same.

The Biometrics Working Group has been a useful vehicle for getting the various parties to agree to the funding of specific G &Y projects. Unfortunately, consensus-reaching has often been a slow, difficult process due to entrenched positions of certain individuals (inflexible, set ideas on "correct" methodologies, desired products, etc.)

I am disappointed that the "review of growth and yield information and knowledge" has (so far) been limited to the four G&Y reports (1950s and 60s into) from Sask. What we need is:

- a review of the current state of G&Y methodologies and products in North America
- a comparison of the 'average' and cutting edge methodologies and products to what (little) Saskatchewan has.

General note on questionnaire: It is strongly targeted to the growth and yield researchers, and thus its scope may be a little too narrow if you are looking for new ideas. It would have been good to ask each respondent to provide some background on the type of work they are doing (this should help in interpreting the responses). Since I use a PC, lack a typewriter, and have rather poor handwriting, I prefer to just receive the list of questions and submit a list of responses (as I have done).

Better discuss in person. Should build on the pending Saskatchewan modelling effort. Need MSYTs.

Maintain existing PSPs. There must be a component of PSPs in a G&Y program.

Growth and yield study involves many qualitative variables which are not satisfactorily quantified. New techniques and approaches such as object-oriented programming, neural networks should be explored. Object-oriented programming is ideal for problems where it is necessary to represent collections of objects (soil, climate, trees, shrubs) and relationships exist between them. The OOP offers a means by which the structure and development of a stand can to demonstrated in a very realistic way. Neural networks techniques probably can be used to identify growth and yield patterns of stands on eco-units.

Spatial order is gaining importance and noneconomic data are being valued more highly in decision-making. Valid criteria need to be developed and decision-making methods developed to integrate the new with the traditional criteria. Spatial concepts, prepositions, and theories applicable to growth and yield and forest management need to be explored.

All of the published information seems to have come out of analysis and re-analysis of the same set of PSPs and TSPs. It seems kind of limiting and also well gleaned already. Further activities would probably be most valuable in carefully establishing a greater database, with analysis in mind.

No mention of insects, disease, or decay is surprising and should be corrected in future work.

7) Recommendations

i) What should be done now by the PAMF to improve the usefulness of local growth and yield data and information? Please be as specific as possible, and try to relate your comments to the information needs of the PAMF.

PAMF should be a financial cooperator in the PAIF NSYT project. It appears that this project is duplicating somewhat with the PAIF project. The PAIF project will deal with the province as a whole.

It seems appropriate that this project should be tied to other growth and yield efforts currently underway via PAIF. Is this a duplication of effort?

Work to supplement and link with PAIF-funded projects, starting with Natural Stand Yield, and starting PSP networks in managed stands. PAMF should concentrate on managed-stand G&Y.

Measure and/or analyze existing SERM-PSP data for plots within/near PAMF. Analyze Weyerhaeuser GAP data for plantations within/near PAMF. Accurately locate position of all G&Y plots (regardless of Agency) using GPS technology, and put locations on digital map product. Attach site index values to stands within PAMF. Develop localized stock and stand tables. Determine site classification soil and vegetation type for all G&Y plots in PAMF, as a method of stratification.

PAMF staff should begin by determining what resources are of significant immediate and/or potential value or interest within the Model Forest. Information needs and shortfalls can then be determined. The literature and approaches being taken in other jurisdictions should then be reviewed. Data and techniques available from outside of the Model Forest should be assessed. Those of potential utility should be obtained/adopted if possible. Local growth and yield data and information could be used to assess the suitability of the imported material and/or adjust it to Saskatchewan conditions.

The short summary you have provided is a good start in identifying the traditional approaches. It will take time before the current "basic" research (e.g., our study and others within BOREAS) has developed to the point where we can apply our process models of forest-climate interaction to forest management. However, there is a huge effort underway in the Prince Albert area and I expect to see major advances in our understanding of boreal forest functioning within the next 2-3 years. I suggest that it would be useful to begin promoting communication between the different agencies, so that, for example, forest managers seriously consider the possible impacts of a major change in future climate, while basic researchers are made more aware of the recent advances in silviculture, especially the innovative approaches being taken within the PAMF. A workshop or conference (with short presentations) involving the various partners and interest might be the best way to start.

ii) What should be done by the PAMF to assess the impacts on the boreal forest of current forestry practices and of environmental changes?

Don't ignore the existing studies and data , e.g. old CFS studies of alternative harvest systems, etc. Make sure that efforts are tied in with existing efforts - need discussions of common data formats, need to avoid collecting redundant data, etc. Use the Biometrics Working Group (or whatever will exist after PAIF).

Again current and predicted needs should be assessed, data and information sought in Saskatchewan then in the literature and in other jurisdictions in the boreal forest. Data and information that appear to be appropriate and can be obtained should be "localized" to establish treads. Data and information on environmental change will be particularly difficult to find. Possibly the "Delphi Approach" will have to be taken to adjust available data to estimate environmental change effects.

If funds permit a data collection network should be established that will provide in future the data currently unavailable.

Stop spending money on flashy, high-public relations but low-substance projects, and do some actual, solid research on forestry practices and environmental change. The PAMF should also get involved with other researchers and projects, and cooperate/partnership/cost-share. This seems to have been very deficient to date.

Analyses should include understand of ecological site relationships, indicator species, LAI balance in a gross sense (tied to yield curves), and regeneration monitoring.

I am not conducting research in this area, and thus can provide only a few comments which represent my own personal opinions. The impacts seem to fall into at least two categories: 1) biological and 2) sociological (including cultural uses, aesthetics, forest economics, and recreation). The first category relies on scientific data (the literature, surveys, and experiments). Large-scale experiments are probably the most effective approach, whereby several large plots are selected and randomly assigned to treatments. The treatments could either be different harvesting methods, or a comparison of harvested and unharvested plots. The variables of interest (e.g., wildlife populations, seedling survival, transpiration) should ideally be monitored both before and after the treatments are applied. Several replicates of each treatment are needed to allow statistically valid comparisons of their results. Environmental changes are not under the control of the investigator so the experimental approach is more difficult to use. Simultaneous monitoring of both environmental variables (e.g., pollutants, climate) and biological responses, coupled with modelling, is one approach that can be taken. The measurement tools might include, for example, tree-ring analysis in relation to the past climate record at Prince Albert (1890 to present). Another type of monitoring is to use mapping and remote sensing techniques to examine, for example, the proportion of each forest type and age class that has been harvested. Are there certain forest types (e.g., aspen-spruce mixedwood, balsam fir, birch) that are disappearing under the current management plans? I do not feel qualified to recommend assessment techniques for the second category (sociological), but I believe that this category warrants a significant effort and attention. My only comment in this area is that the assessment should involve a wide range of people with their divergent viewpoints and value systems; i.e., the assessment should not be dominated by a single interest group. This comment might equally be applied to the first category of impacts.

Long-term monitoring of PSPs should be done for climate change, global warming, and growth and yield.