OLD-GROWTH FORESTS AND TIMBER SUPPLY: A CASE STUDY FROM THE BOREAL FOREST

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ABSTRACT

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Key Words: old-growth forests, silviculture, new forestry, forest simulation modelling, Harvest Schedule Generator (HSG), boreal forests.

Historically in Canada, old-growth forest preservation concerns, research, and analyses have centred on the stately coniferous forests of British Columbia (e.g., Clayoquot Sound). Within the past decade, however, the forests of Ontario have also come under scrutiny for their old-growth values. The Timmins Forest, a Sustainable Forest License, provides the background for this case study of Ontario's old-growth forests. Old-growth is defined conceptually as an integral landscape element, differentiated at the stand level by age The principal objectives of this study were to develop and examine the temporal impact of various timber harvest scenarios on the old-growth component of the forest. To support this analysis, silvicultural options for the creation of old-growth structures at the stand level were outlined for the boreal species under examination. One hundred-year simulation scenarios were run on a forest model called HSG. HSG operates by tracking the spatial identity of individual forest stands through time. As age and time increments are simulated, HSG updates stand successional changes and inventories, applies harvests, and allocates and schedules silvicultural treatments. Indicators for analysis included long-run sustained yield versus growing stock, and the percentage of the landscape in the old-growth condition per species. The scenarios ranged in design from no harvests, no silviculture, to the use of "old-growth windows" (where stands were protected from harvest) to the use of intensive silviculture. Results show that old-growth supply is maximized across the boreal species when a program of no harvests is undertaken. Protecting stands from harvest for a specified number of years provided the least amount of long-run sustained yield over time. Intensive silviculture increased harvest levels at the expense of old growth. The Benchmark Scenario provided the best option for the provision of both inventories of old-growth and long-run sustained yield.

Forest resource managers have the basic simulation tools necessary to measure and manage for old growth, but need to perform additional analyses such as cost-benefit-analysis to evaluate the role of old growth in the landscape context. Clarification and refinement of such methodologies and simulation tools will lead to the improvement of forest policies designed to create and manage sustainable forest management programs.

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CHAPTER ONE: INTRODUCTION

Historically within Canada, old-growth forest preservation concerns have centred on the stately coniferous forests of British Columbia, such as Clayoquot Sound, located on the west coast of Vancouver Island. These ancient forests attract attention because of the presence of very large, statuesque trees. Such trees supply large knot-free high-grade timber, whilst also providing habitat for fauna dependent on old growth (e.g., Spotted Owl [*Strix occidentalis caurina*] (Xantus)) (Meslow et al. 1981; Mannan et al. 1984; Lennartz 1988; Roemer et al. 1988; Schoen et al. 1988; Carey 1989; Doak 1989; Hopwood 1991; Thompson 1991).

The functional values and structural features associated with old-growth forests include: water reservoirs (contained within down logs), contributions to water quality and soil stability, and steady-state nutrient and volume conditions (Yuskavitch 1985; Whitney 1987; Rice 1990). Additionally, old-growth forests are important for other values including heritage, existence, aesthetic and spiritual values (Anderson 1988; Barnes 1989). Such old-growth values have recently gained credibility in addition to the traditional thoughts of old-growth forests as providers of raw timber (Doak 1989; Heinrichs 1984; Schoen et al. 1988; Spies and Franklin 1988; Rice 1990; Marchak 1995). Ever-increasing demands upon old-growth forest stands by various forest interests such as the forest-products industry, preservationists and First Nations is resulting in increasing conflict (Spies and Franklin 1988; Doak 1989).

Within the past decade, the forests of Ontario have also come under scrutiny for their old-growth values (e.g., Temagami). This recent attention has focused upon Great Lakes - St. Lawrence species such as eastern white pine [*Pinus strobus* (L.)] and red pine [*Pinus resinosa* (Ait.)]. Such a vision of old growth within Ontario ignores the major coniferous species of the boreal forest: black spruce [*Picea mariana* (Mill.) B.S.P.], white spruce [*Picea glauca* (Moench) Voss], balsam fir [*Abies balsamea* (L.) Mill.] and jack pine [*Pinus banksiana* (Lamb.)]. In addition, short-lived deciduous species such as trembling aspen [*Populus tremuloides* (Michx.)] and white birch [*Betula papyrifera* (Marsh.)] have not traditionally been considered species capable of fulfilling old-growth forest objectives.

SCIENTIFIC JUSTIFICATION

The focus on Ontario's old-growth forests has centred on the eastern white and red pine forests of the Great Lakes-St. Lawrence forest region, and more recently, on the ancient eastern white cedars of the Niagara Escarpment portion of the Deciduous forest region. Management planning approaches for the preservation of old growth in the boreal forest are still in the early stages of development, hence, the need to develop a broad, but comprehensive look at boreal old-growth definition, identification, development and maintenance alternatives.

RESEARCH OBJECTIVE

The objective of this research is to explore tradeoffs between production of timber (long-run sustained yields) and old-growth supply for a boreal forest area. A forest-level simulation will be used to examine the relationships between timber, old-growth supply and growing stock levels. In addition, a review of the silvicultural options for the production of old growth on a species-by-species basis will be presented. This thesis concludes by identifying and discussing additional research needs and policy/planning implications for the production of old growth in a landscape-level approach to forest sustainability.

CHAPTER TWO: DEFINING OLD-GROWTH FORESTS

Defining old growth has been problematic. As a result of the complexity of ecological factors, differing opinions, varying forest types, degrees of public environmental awareness, and state of progress of research on the topic, multiple definitions have evolved. Some definitions are similar and may overlap in scope when describing the structural, functional and developmental characteristics of old growth. However, author bias (whether individual, group or governmental department) plays a strong role in the perspective given to the concept of old growth (Sirmon 1982; Hunter 1990; White 1990; Pojar 1991).

Prior to discussing the range of definitions which exist, it is important that the old-growth stage and its associated structural functions be understood in relation to the previous stages of forest development. The following section briefly describes the structural attributes of old growth, the way in which a forest develops over time, as well as the fate of the old-growth condition in any given forest.

This chapter will also cover the classification of definitions and definitions currently in use for Ontario's old-growth forests. Tied in with definitions are the values attributed to the old-growth condition and the use of old-growth indices.

The approach I have taken to define old growth in the boreal forest is outlined, with supporting background material from a workshop held for the explicit purpose of this thesis topic. A classification system defining three types of old-growth forest landscapes will also be presented. This classification system of old growth was derived from the results of the old-growth workshop. Economic variables relating to the old-growth debate will not be discussed in this thesis.

STRUCTURAL CHARACTERISTICS

Definitions of old-growth forests may be structural (physiognomic), developmental/successional or functional (process-based) (Pojar 1991; Hambly 1992). Structural definitions are used most often to describe ecosystem components and community relationships in connection with non-timber concerns (e.g., recreation and wildlife) (Oliver and Larson 1990). The physiognomic characteristics of old growth include:

- reverse J-shaped diameter and age distributions (Meyer and Stevenson 1943; Minckler 1971; Leak 1973);
- coarse woody debris (CWD) - standing (e.g., snags) (Franklin et al. 1981; 1986);
- CWD - down (Franklin et al. 1981; 1986);
- old, large trees (Nichols 1913; Franklin et al. 1981, 1986; Alaback 1984);
- a variety of tree and non-tree species (Leak 1973; Franklin et al. 1981, 1986; Alaback 1984); and

- a continuous vertical distribution of foliage (Lutz 1930; Hough 1936; Morey 1936; Franklin et al. 1986).

The physiognomic characteristics typically associated with old-growth stands may not be a direct result of the stage of stand development. Canopy gaps, a continuous vertical foliage distribution and CWD, both standing and down, may occur in stands of any age, depending upon the history of disturbance and plant population dynamics (Oliver and Larson 1990). The most common structural features associated with the old-growth condition, namely old, large trees, can occur at relatively young ages in both single and mixed-species stands. Species exhibiting relatively short life cycles and small dimensions, such as black spruce and trembling aspen, would never qualify as old growth under the structural definition (Franklin et al. 1981). Hence, reliance upon the structural definition of old growth is limited in application (Oliver and Larson 1990). Hambly (1992) suggested that this restriction may be effectively eliminated by the inclusion of 'relative' structural descriptions. Hence, a 20-inch black spruce of sufficient age may be considered to be old growth, if it is relatively large in comparison to the remainder of black spruce stems within the stand.

STAND DEVELOPMENT PROCESSES

To avoid the restriction implied within the structural definition of old growth, Oliver (1981) and Oliver and Larson (1990) defined the old-growth condition as one of four stages of stand development following disturbance. Although stand development is not restricted to the following stages, and may indeed not reach all of the stages, patterns of stand development over time typically may be projected, based upon the following:

- Stand Initiation Stage: following a major disturbance, new individuals and species appear on the site.
- Stem Exclusion Stage: no new species appear on the site, some existing stems die. The remaining stems begin to undergo height and diameter differentiation; species dominance may be expressed.
- Understory Reinitiation Stage: advance regeneration and new species in the form of herbs and shrubs appear in the shady understory, although growth is generally slow.
- Old Growth Stage: mortality begins within the overstory in an irregular fashion. With the advent of gaps, replacement understory trees begin to grow into the overstory (Oliver and Larson 1990).

Oliver and Larson (1990) have further refined the old-growth stage into two distinct types: 1) true old growth and 2) transition old growth (Figure 2.1(a), (b)). The true old-growth stage is found within single cohort stands (even-aged or broadly even-aged) which have developed in the absence of major disturbances or allogenic processes (e.g., changes caused by events external to the site). With respect to succession, the overstories of these old-growth stands do not contain any individuals (relics) which invaded the site after the initial disturbance. The autogenic condition (e.g., changes in available growing space caused only by plant interactions) in the stand is responsible for the death of the relics and for limiting the severity of disturbances. True old-growth stands are rare, as the risk of disturbance increases with increasing stand age. However, this stage may be reached if the species are short-lived and the frequency of disturbance is low (Oliver and Larson 1990) (Figure 2.1(a)).

Transition old growth refers to those stands which still contain relic trees within the canopy as well as stems of allogenic origin (Figure 2.1(b)). As the relic trees die, gap phase regeneration occurs. Once the relic trees have been replaced by the cohort of younger individuals and these age accordingly, then the true old-growth condition has been reached (Oliver and Larson 1990; Runkle 1981).

The processes of stand development which lead to either the transition or true old-growth condition stress the dynamics of growth, competition and mortality. Both definitions avoid the prediction of species composition and dominance patterns. Oliver and Larson (1990) emphasize that despite the absence of allogenic conditions during the development of a true old-growth stand, there is no evidence to support the claim that the species which constitutes the canopy will continue to dominate the site into perpetuity. Hence, avoidance of the term 'climax' when referring to the old-growth condition is wise (Hunter 1990; White 1990). I have adopted this stance as well, stressing the importance of the processes leading to the old-growth condition rather than the successional patterns (e.g., early, mid, and late seres) which are assumed to lead to the climax condition (Oliver and Larson 1990).

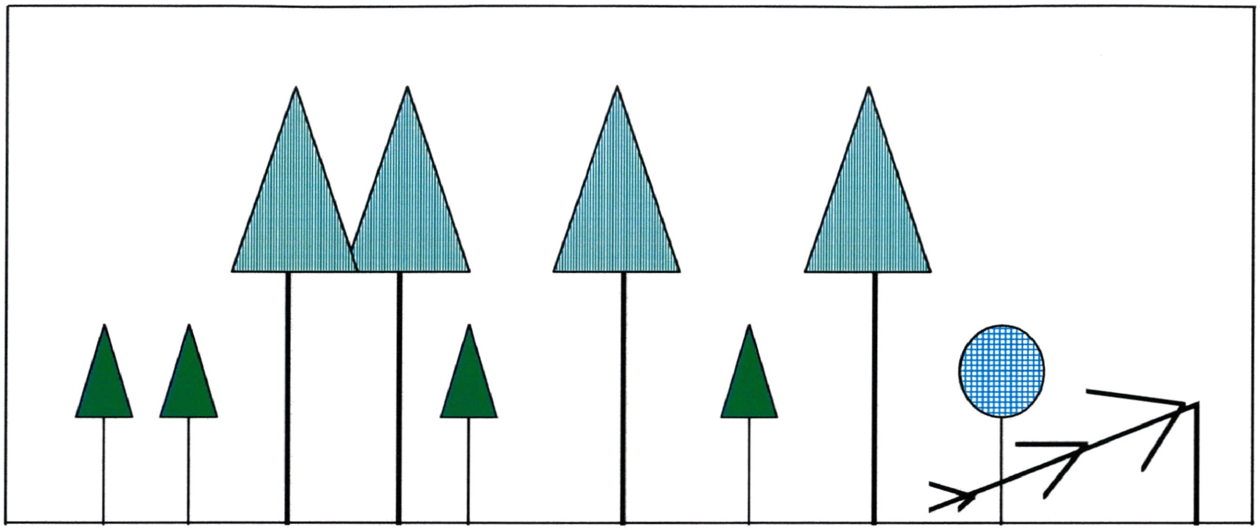


Figure 2.1(a). The true old-growth stage occurs in single cohort stands that have developed without major disturbances or external influences. The overstories of true old-growth stands contain only individuals that invaded the site initially. These old-growth stands are rare due to the increasing risk of major disturbance with increasing age. This stage may be reached with species that suffer minor disturbances and are short lived (Oliver and Larson 1990).

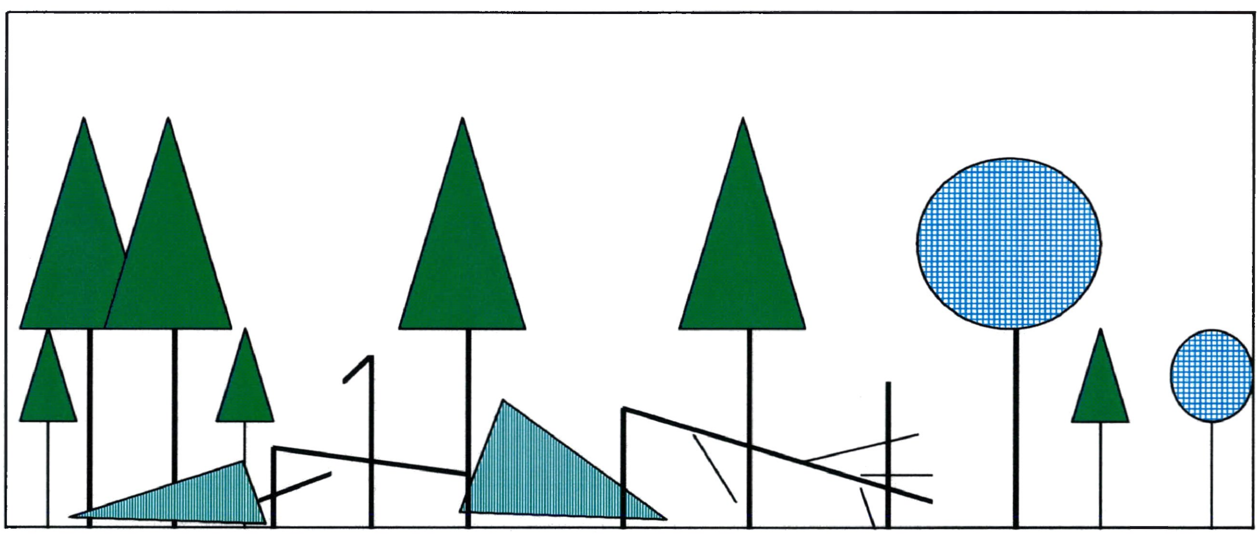


Figure 2.1(b). Transition old-growth stands are those which contain the original invading trees, in addition to those that were introduced as a result of external influences and major disturbances. Once the original invading stems have died, and are replaced through gap regeneration, and these stems in turn age accordingly, then the true old-growth stage has been reached (Oliver and Larson 1990).

OLD-GROWTH FOREST LIFESPANS

The fate of all trees, even in true old-growth forests, is eventual mortality. The time that must pass before all overstory trees in a stand die, varies, however, depending upon the species, rates of stem reinitiation and decomposition, climatic variables, and the type and severity of disturbance. Gradual mortality results in the regeneration of single and/or multiple cohort stands, while major disturbances usually result in single cohort (even-aged or broadly even-aged) replacement stands. Transition old-growth forests are subject to both minor and major disturbances prior to reaching the true old-growth stage (Oliver and Larson 1990) (Figure 2.2).

DEFINITIONS

Research conducted on old-growth forests over the past two decades has produced a large compendium of definitions. Classification into one or any combination of the structural, developmental/successional and functional categories often occurs. The perspective of the author often determines which category a definition will fall into. For example, Hunter (1990) suggests that foresters habitually define old growth in structural terms as they relate to the condition of the timber that would be found in such a stand: senescent, decadent and overmature. Wild life biologists use definitions which describe relationships between habitat, structure, and successional condition. Due to the multiple number of habitats which may be located in old-growth stands, definitions

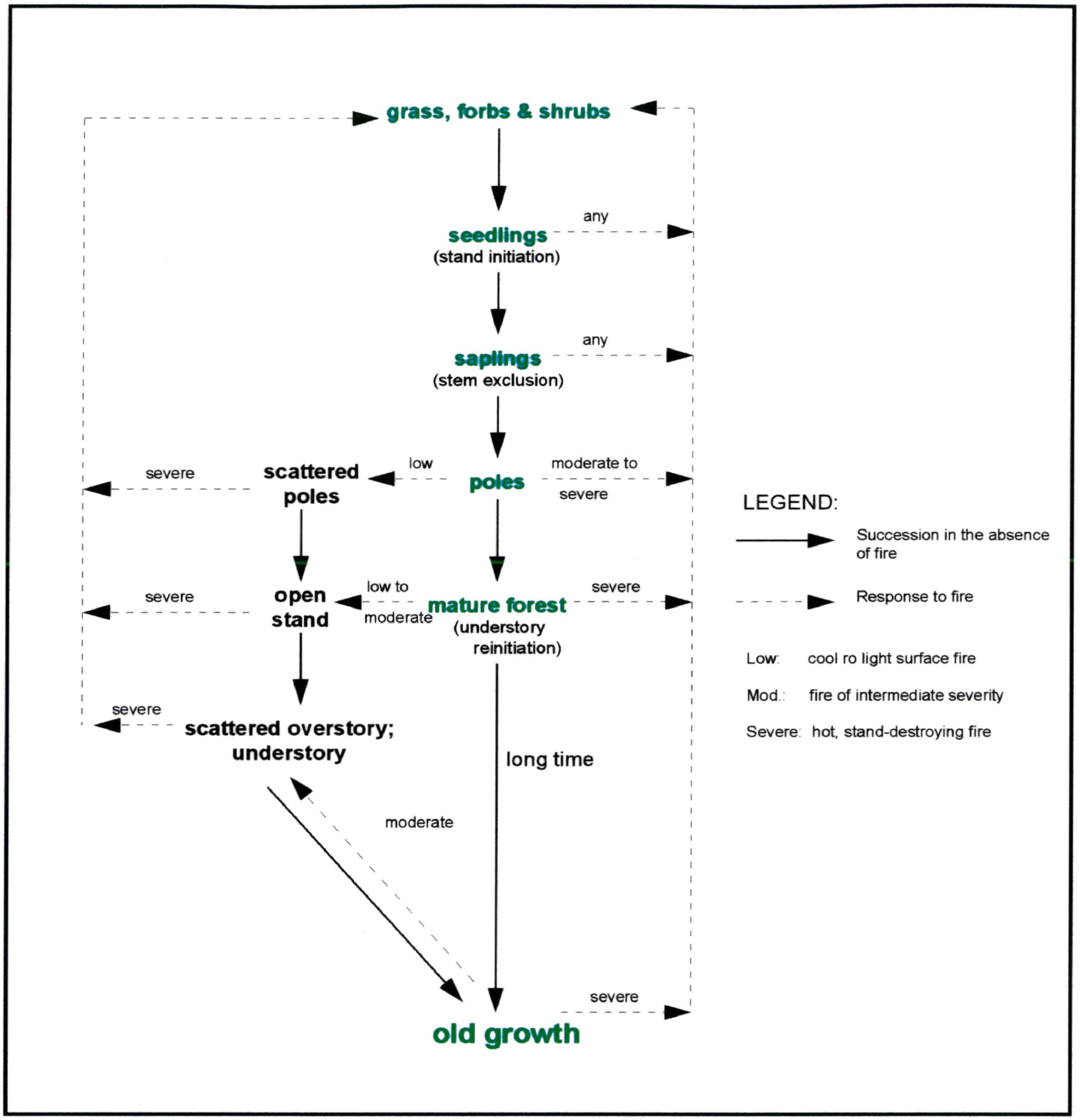


Figure 2.2. A typical fire-dominated successional pathway (Adapted from Oliver & Larson 1991; Moir 1992).

centred on wild life species usually reflect the species in question. Definitions have also been formulated to describe structural features in relation to visual landscape qualities (Sirmon 1982), as well as functional relationships between old-growth forest components (Rust 1990).

Interpretations for Ontario's Old Growth

As most old-growth research projects have been conducted in the coastal forest types of British Columbia and the U.S. Pacific Northwest, the transfer of such definitions to eastern (Ontario) forest types must be made with caution, and customized to local forest growth, yield, and cull conditions (Brennan 1991). Brennan (1991) refined work of Barnes (1989) in an attempt to define old growth in the Temagami area. Components of his definition included: age at rotation, age of advanced rot, and age at death. Brennan (1991) also proposes refinements such as live tree density, canopy characteristics, number of snags, number of fallen trunks, and the size of the old-growth stand area.

Concentrating on the ecology of red pine (*Pinus resinosa*) and white pine (*Pinus strobus*), Earthroots Coalition (1991) produced quantitative definitions of the old-growth state in an attempt to identify and isolate red and white pine old-growth ecosystems within the Great Lakes - St. Lawrence Forest Region. The definitions are composed of: minimum age and density of old trees, density of coarse woody debris (CWD), minimum diameter (DBH) and height of standing coarse woody debris, maximum diameter and length of CWD lying on the ground, and the degree of human disturbance.

The Old Growth Policy Advisory Committee (OG-PAC) of Ontario, employing a system of multi-party representation and extensive public consultation, has chosen to define old growth in the following manner:

> "Old growth forests are ecosystems characterized by the presence of old trees with their associated plants, animals and ecological processes. They are reflective of the pre-settlement forest." (OMNR 1993a)

Response to the definition of old growth as proposed by Ontario's Old Growth Policy Advisory Committee has been critical. Agencies representing both preservation and industrial concerns have concluded that the definition is ambiguous, subjective and difficult to implement in any forest condition. Earthroots (CIF 1993) reports that the definition does little to support the permanent preservation of existing old-growth trees, while the Ontario Forest Industries Association maintains that the definition, and report which contains it, fail to address socio-economic impacts of the implementation of the proposed policy (CIF 1993).

In response to additional comment from the private and public sectors in Ontario, the OG-PAC refined its definition of old growth to read as follows:

> "Old growth forest ecosystems are characterized by the presence of old trees and their associated plants, animals, and ecological processes. They show little or no evidence of human disturbance" (OMNR 1994a).

The revision to the definition changes the focus from pre-settlement forest conditions to forests exhibiting minimal human disturbance. This change was brought about by the fact that pre-settlement forest conditions may not be easily deciphered from historical or current forest data.

VALUES

In addition to structural, developmental and functional definitions, there is an associated body of work which assigns emotional values and opinions to the concept of old-growth forests. Old growth, when defined in this manner, is often of a descriptive, romantic nature and has little, if any, ecological grounding. Polarized opinions lend a fierceness to the old-growth debate to the extent that without some type of ecologically-acceptable definition, people will continue to misunderstand each other (Godbey 1988; Hunter 1990; White 1990).

Within the context of this thesis, it is recognized that values other than timber exist in old-growth forests. Blachford and Duinker (1992) suggest that aesthetics, biodiversity, education, existence/bequest, natural heritage, recreation, research, spiritualism and tourism contribute to the values that may be derived from boreal forest old growth.

FRAMEWORKS

Most definitions, whether structural, functional or successional, contribute to a conceptual framework for defining the old-growth condition. This framework can be generally applied across all forest types, and may be particularly useful in planning exercises that focus on the forest and landscape level. However, the limitation of the conceptual framework is that it is weak in addressing operational applications to specific forest types. Refinement, based on quantified ecological research, provides the ecological framework necessary to customize and calibrate definitions to fit specific forest types (Rust 1990; MOF 1992; ABCPF 1993; CPPA 1993; MacKinnon 1993).

OLD-GROWTH INDICES

In the old-growth conservation literature, there has been an increasing realization that in order to have a perpetual supply of old growth across the landscape, there must be a system which recognizes current and future old-growth stands.

Based on this principle, the Ontario Old Growth Policy Advisory Committee recommended the creation of an old-growth index which assesses the quality of old-growth stands and identifies specific silvicultural techniques to be employed in these stands (OMNR 1993a; OMNR 1993b). The index is to be developed at the provincial level and modified for application in the regions and districts, according to local forest conditions. The index, as it applies to old-growth red and white pine includes: age, minimum area, site conditions, tree species composition, tree density, level of human disturbance, species diversity, spatial configuration, the presence of rare, threatened, or endangered species and structural diversity (OMNR 1993a; OMNR 1994a) .

APPROACH TAKEN TO DEFINE BOREAL OLD GROWTH

For the purpose of this thesis, old growth is defined conceptually as an integral landscape element, differentiated at the stand level by age. Due to the lack of quantitative data pertaining to boreal species with respect to ages of rotation, ages of advanced rot, and age at death in old-growth management terms, the ages provided by Brennan (1991) will be used as benchmark estimates of the old-growth condition (Table 2.1).

Note that although age is being used as the key indicator for the occurrence of old growth, multiple factors, such as stand density, tree size, site quality and stand size or functional integrity, contribute to a much fuller appreciation of the old-growth state. With this in mind, however, the unique structural diversity and function associated with old growth can not be identified from the information available in the Ontario Forest Resource Inventory (FRI) database, and hence the reliance on age (or year of stand origin). Similarly, 'relative' old-growth descriptors, such as stem diameter, can not be derived from the FRI database (Hambly 1992).

As used in the rest of this thesis, old growth is an ecological component which may be planned for at the landscape and forest level, but is operationally executed at the stand level by various management regimes. Certain silvicultural methods, such as single-tree selection, may reduce the scale of old growth to the tree level.

Table 2.1. Age estimates of old growth, death and advanced rot (adapted from Brennan 1991).

FOREST TYPE/WORKING GROUP	ECONOMIC ROTATION AGE (Years)	AGE OF ADVANCED ROT (Years)	AGE AT DEATH (Years)	**OLD GROWTH AGE (Years)**
Pw	120	151+	200	**141+**
Pj	80	91+	120	**101+**
Sb/Sw	120	141+	180	**131+**
Bf	60	71+	80	**71+**
Po	70	81+	100	**81+**
Bw	70	91+	110	**91+**

LEGEND:

Pw: eastern white pine
Pj: jack pine
Sb: black spruce
Sw: white spruce
Bf: balsam fir
Po: trembling aspen
Bw: white birch

BACKGROUND: OLD-GROWTH WORKSHOP

In support of this thesis, the Chair in Forest Management and Policy held a workshop in June of 1991. The workshop was attended by fourteen participants who represented a wide cross-section of expertise, including forestry, biology, wild life ecology, landscape ecology, recreation science, and environmental science. The goal of the workshop was to examine the forest-management implications of old growth in Ontario's boreal forest. The relationship between old-growth management objectives, stand traits used for old-growth identification, and stakeholder involvement defined the break-out sessions. The plenary session summarized the results of each group's work and was used to formulate a planning approach to the old-growth issue (Blachford and Duinker 1992).

The old-growth management values were determined to include: aesthetics, biodiversity, education, existence value, heritage value, recreation, research, spiritual needs, commodity timber, tourism (high access/frequent visitation), and tourism (low access/infrequent visitation). The forest species against which objectives for these values were applied included: white and red pine, jack pine, black and white spruce, white birch, poplar, cedar, and other hardwoods.

The stand traits that would best indicate the presence and location in space and time of boreal species' old growth were identified as: stand age, development stage, tree size, species, flora/fauna diversity, structural diversity, stand size, stand location, degree of stand uniqueness, degree of human disturbance, wood quality, tree health, degree of mortality, site class, presence of CWD-standing and CWD-down. Stakeholders with an interest in the old-growth issue were identified as: the forest products industry and labour, tourism operators, ecological researchers and educators, First Nations, cottage owners, hunters and trappers, boaters and anglers, preservationist, naturalists, and the general public.

To arrive at a framework on which the old-growth management objectives could be measured effectively against stand traits, species, and stakeholders, the participants determined that the following considerations should be addressed:

- how much old growth is needed over the landscape to fulfil societal demands?
- where in space and time is the old growth to occur?
- what are the ecological risks to providing old growth in the boreal forest (e.g., wild fire)?
- what management interventions are required to create, maintain and/or enhance old growth?
- how much human disturbance will be tolerated in old growth? and
- what are the mechanisms/legal frameworks for providing old growth across the landscape?

Blachford and Duinker (1992) hypothesized that three classes of old growth could form the framework for addressing the above-mentioned questions: old growth in wildlands, old growth in special forest landscapes, and old growth in managed timberlands. Each class possesses unique characteristics with respect to the degree of management intervention, area requirements, degree and type of human disturbance, risk with respect to old-growth provision in the various forest types (e.g., risk of catastrophic disturbance by species), and institutional/management arrangements (Table 2.2).

Table 2.2. Matrix of old-growth classes, their characteristics and implications for management.

	CLASS OF OLD GROWTH		
CLASS CHARACTERISTICS	**WILDERNESS**	**SPECIAL FOREST LANDSCAPES**	**MANAGED TIMBERLANDS**
DISTURBANCE; DEGREE OF MANAGEMENT INTERVENTION	None to minimal	Slight & gentle	Strong but infrequent
AREA REQUIREMENTS	Large: location fixed	Modest: location is fixed & key	Modest: location independent & moveable
DEGREE AND TYPE OF HUMAN DISTURBANCE	Infrequent: personal visitation	Frequent: personal visitation	Infrequent: timber management disturbances
RISK WITH RESPECT TO THE PROVISION OF OLD GROWTH	Boreal: low	Boreal: low	Boreal: low
MECHANISMS/LEGAL FRAMEWORK	Provincial parks, ecological reserves	Provincial parks, ecological reserves	Forest Management Planning Process

Old Growth in Wildlands

Old growth in wildlands requires natural, undisturbed stands across the forest landscape in which management intervention is restricted and/or prohibited. Such stands provide pristine, natural areas where the visitor has the opportunity to experience maximum heritage and spiritual values. Old-growth stands found in wildlands are often associated with a variety of age classes amongst neighbouring stands. Hence, although old-growth stands may be found in wilderness areas, not all wilderness areas are composed solely of old growth.

The wildlands designation implies large, contiguous areas free of development. Therefore, once an area has been identified, its location becomes fixed for the long term. This permanence, coupled with the absence of management interventions, results in stands which are not protected from disturbance (whether catastrophic or of gap-phase scale). Natural events such as insect attack, disease, windthrow or wildfire combine to influence all stands, such that old growth may or may not exist in perpetuity across the wildlands landscape (Blachford and Duinker 1992).

Human interaction with old growth in wildlands is usually infrequent and often on a personal-recreation basis. Mechanisms which may be employed to attain the wildlands designation include the use of provincial parks (OMNR 1978), ecological reserves (OMNR 1992), and conservation reserves (Davidson 1996).

Old Growth in Special Forest Landscapes

Special forest landscapes exist in locations of high visibility and use by the public. Such areas often occur beside lakes and rivers, on cliff faces, and high-profile vistas. Old growth within these areas is often valued for its recreational and aesthetic properties. Management/silvicultural treatments are usually slight and tempered such that disturbance does not offend people. The management objective in special forest landscapes is to perpetuate the old-growth condition. Hence, with gentle management techniques and continual monitoring of stand conditions, old growth may be provided on a more or less continual basis (Wellbaum and Doyle 1991).

Old Growth in Managed Timberlands

In the production of timber, managers harvest stands as soon as required after they have become eligible by virtue of volume per unit area and piece size. The age at harvest is often much younger than the age at which old-growth structures or processes begin occurring. Hence, if old growth is to be provided in managed timberlands, managers must have an accurate inventory of stands which are approaching the age in which old-growth conditions appear. In addition, managers must be able to locate younger candidate old-growth stands which can replace the current old-growth stands prior to stand mortality and/or harvest.

Key management values to be obtained by the production of old growth in managed timberlands includes biodiversity, high-value timber and research. This class of old growth assumes that visitation by the public is infrequent. Management interventions (e.g., harvest and renewal) within timberlands are often much more intensive, although they may not be as frequent as silvicultural practices associated with old growth in special forest landscapes. The accommodation of old-growth values into the managed forest landscape occurs during forest management planning processes (OMNR 1986; Blachford and Duinker 1992).

ECONOMICS

The economic factors that contribute to the debate of old-growth preservation and use are varied and complex. Costs, benefits and values have been described extensively in the literature, with benefits ranging from the measurable (e.g., harvest of old-growth timber) to the non-commensurable (e.g., existence and bequest values) (Chase 1995; van Kooten 1995). Frameworks and economic models that have been developed in conjunction with the evolution of quantified costs and benefits are beyond the scope of this thesis.

CHAPTER THREE: SILVICULTURE AND OLD-GROWTH MANAGEMENT

While policy decisions regarding the fate of old growth are dealt with at the forest and landscape level, the objectives of policy are implemented at the stand level by the use of various silvicultural techniques and practices (Klinka et al. 1990; Luken 1990; Chase 1995). This chapter will describe the relationship between silviculture and old growth and explain how the use of silviculture may create, maintain and/or restore the old-growth condition to a forest landscape. This chapter will also briefly outline the major silvicultural regeneration methods and vegetation management tools available to managers when considering old-growth objectives. In addition, a description of the characteristics of the boreal forest region, the arboreal species contained in it, and the role of disturbance will be examined. Next, I propose a framework that outlines the development of old growth in managed timberlands and special forest landscapes. To support this framework, a summary of the major regeneration methods that contribute to the creation, maintenance and restoration of boreal old growth across the landscape will be presented.

Chapter three also describes the relationship between silvicultural options for old-growth management and the principles of New Forestry. The combination of New Forestry and silviculture leads to the concept of landscape forestry, and its focus at the landscape level. The forecast of forest benefits such as old growth and timber supply are facilitated in landscape forestry through the use of computer simulation models. Chapter three concludes with a brief look at the advantages of simulation models, and how computer models enable managers to forecast multiple landscape-level scenarios over time and space.

THE SILVICULTURE - OLD-GROWTH RELATIONSHIP

Spurr (1979) defined silviculture as the art of producing and creating a forest by using the science of applied silvics. Technical competence based on both quantitative and qualitative knowledge of forest establishment, growth, and yield is to be used by silviculturalists in the attainment of the production of crop trees (Smith 1986). Traditional schools of thought assumed that crop trees were primarily for commercial timber purposes. With increased concern regarding old-growth forests and the structures contained within them, perceptions regarding the nature of crop trees has changed from a strictly utilitarian perspective (Guldin 1991) to one which is more holistic in nature (Orians 1990; Graham et al. 1994; Jimerson et al. 1994; McNeel et al. 1994; Turpin et al. 1994; Chase 1995).

Hence, crop trees not only include desirable species tended strictly for the production of commercial timber, but also trees which provide functional duties such as reservoirs of water and soil stability, and structural features such as old, large trees, snags, and downed logs ((Guldin 1991; Yuskavitch 1985; Whitney 1987; Rice 1990; Chase 1995).

Traditional concepts in silviculture with respect to old-growth forests have been defined by terms such as create, promote, develop, maintain, perpetuate, retain, restore and rehabilitate. To reduce ambiguity, this paper will use only create, maintain and restore in further discussions.

The Society of American Foresters (S.A.F. 1984) noted with caution that, due to the lack of quantification and documented successes in creating old-growth structures within forest stands, an 'adequate' supply of old growth should be maintained and left alone until enough experimentation had permitted managers to function in an ecologically responsible manner (Guldin 1991).

Creating Old Growth

An old-growth forest stand can be created by two processes: 1) natural dynamics operating in a mature or younger stand, such that, if left undisturbed and barring major natural disturbance, the stand will eventually progress to an old-growth condition; or 2) the imposition of selected silvicultural practices to create old-growth structures and conditions in mature forest stands. A third option which may be employed to attain the old-growth condition is that of natural dynamics operating in cutblocks from the time of harvest (in managed timberlands). This method is probably the least reliable of the three, as the old-growth condition may or may not be reached during the lifespan of species on the site due to risk of disturbance (Figure 2.2).

Although the probabilities of disturbance between the three options may not differ, I assume that the harvest action in the third option has a severe impact on the site. This impact may extirpate some site elements that contribute to the stand eventually reaching the old-growth state.

In addition, by depending upon natural regeneration, one may not get back the previous forest structure for many decades, if at all. For example, the harvest of a spruce-dominated stand may result in a new stand structure and composition dominated by trembling aspen. In this case, if spruce were the desired old-growth species, the management objective would not be met.

Silvicultural practices to create old growth include small-scale stem removals (to emulate gap dynamics) (Runkle 1984), girdling of mature stems to create snags, and/or the destruction of the top portion of the crown of a mature stem (usually by explosives) to create wild life habitat and encourage the introduction of decay-causing organisms (Nyberg et al. 1986; Kimmins 1992).

Maintaining Old Growth

The maintenance of old growth implies that the old-growth condition, whether reached by natural stand dynamics or through silvicultural intervention, is to be continued on a more or less permanent basis. On a temporal scale, the window of opportunity for old growth production is therefore extended, assuming no interference from large-scale natural disturbances.

Restoring Old Growth

The concept of restoring old growth originated in the United States where, in a situation of limited supply, managers assumed that the critical question was not which areas require preservation, but which areas need restoration (rapid redevelopment) and then future maintenance (Henderson and Hedrick 1991; Boyce 1995). This management paradigm thus assumed that the old-growth component was once a much higher landscape component than is currently shown to exist in inventories. Hence, restoration procedures require knowledge of past forest histories, current landscape dynamics, and future temporal-spatial landscape implications (Henderson and Hedrick 1991; Kaufmann et al. 1992; Jimerson et al. 1994).

Restoring the old-growth component of a forest landscape incorporates the principles of both creating and maintaining old growth. The key difference between creating and restoring old growth lies in the time factor. Although both options, in practical terms, may require the same amount of time to reach the old-growth state, restoration implies a hastening of successional processes.

Silvicultural Systems

Multiple silvicultural systems may be employed in the creation, maintenance or restoration of forest old growth (Wellbaum and Doyle 1991) (Figure 3.1). By definition, a silvicultural system incorporates a comprehensive, designed

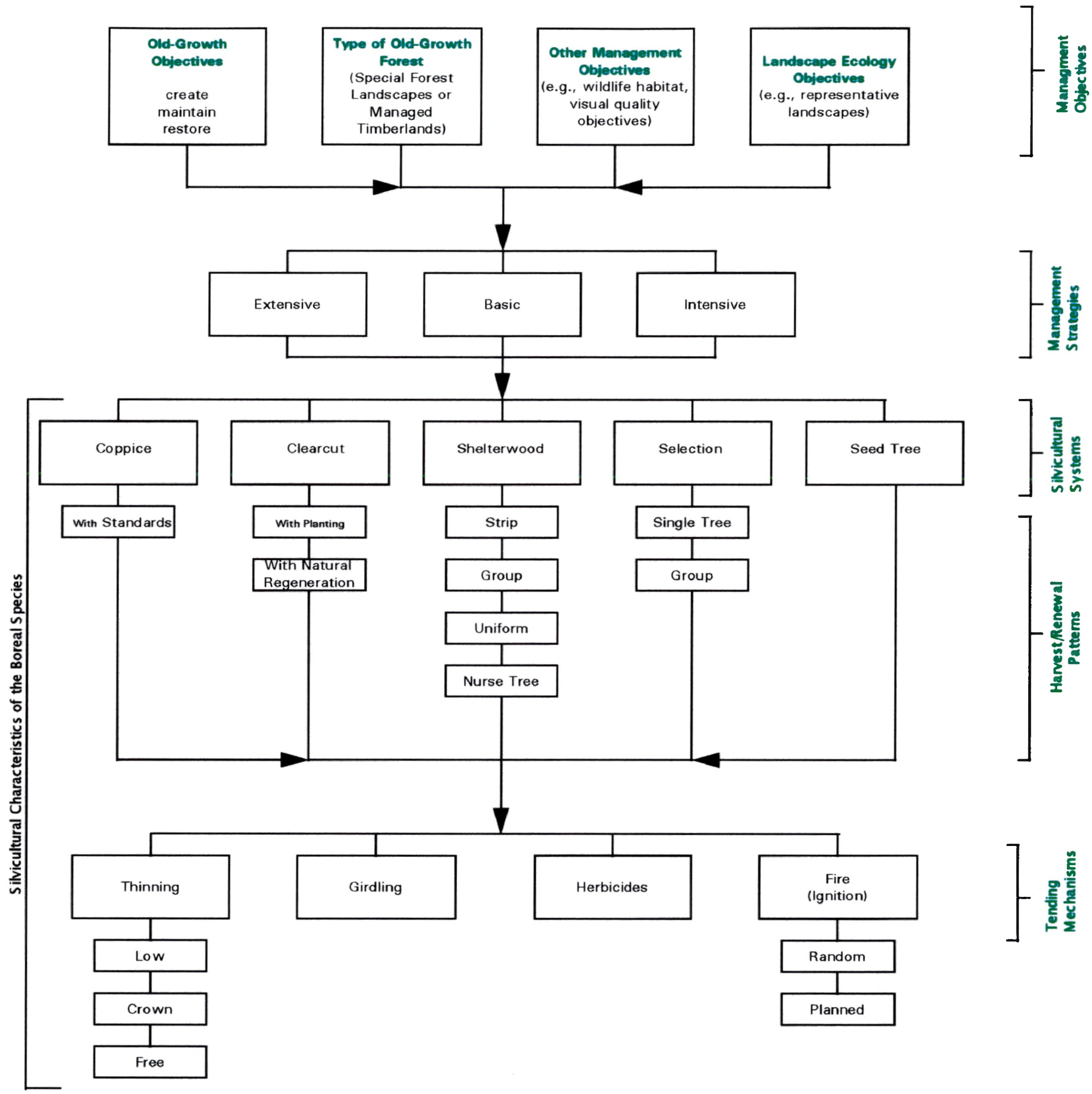


Figure 3.1 Inputs, decisions, and systems involved in silvicultural management for old growth in the boreal forest.

program of intervention during the life of a stand (Smith 1986). Not only are reproductive considerations included, but also tending and intermediate cuttings.

By assuming that intervention begins before the initial disturbance to a stand, managers are better able to predict and project silvicultural success. For this reason, clearcutting should be thought of as a harvest tool as well as a silvicultural tool. The reproduction method, whether it be shelterwood, selection or clearcutting, is the procedure utilized by managers in the re-establishment of the stand (Smith 1986). For example, clearcutting is the reproduction method used to achieve the objectives of the clearcutting silvicultural system.

Prior to determining which silvicultural system is to be employed on any site, there are two key questions which need to be addressed. The first question determines which species is capable of being created, maintained or restored as the old-growth indicating species for a particular site (Klinka et al. 1990). As the same site often is capable of producing old-growth stands of different species, it is assumed that managers will be able to decide which species outperform others on the same site (Klinka et al. 1990; Weetman and Vyse 1990). The second question tackles the problem of which silvicultural system will achieve the old-growth objective and provide opportunities for maintaining the condition once established (Klinka et al. 1990).

In addition to the points listed above, Smith (1986) and Alexander (1986) have identified additional considerations to be taken into account prior to the initiation of stand interventions:

· how will regeneration be accounted for?

· what effect will stem removals have on advanced regeneration, if present?

· how efficient is the system with respect to growing space and site productivity?

· what is the risk from damaging agents and will they be controlled?

· does the system contribute to sustainable forestry and/or old-growth objectives?

· what is the best way to optimize financial investment and growing stock?

· what will be the intensity of management intervention and how can efficiency be maintained or improved?

Regeneration Methods

There are six common methods used to regenerate forests which can be used in many forest types and conditions, depending upon local site factors. The six include: coppice growth, coppice-with-standards, clearcutting, seed tree systems, shelterwood systems and selection systems. Table 3.1 presents the six regeneration methods, combined with their typical size requirements. Each system has also been ranked according to the classification of old growth given earlier, namely old growth in special forest landscapes and old growth in managed timberlands. Although Table 3.1 is general in nature, its purpose is to

Table 3.1. Regeneration methods, their size and relationship to old growth, as found in special forest landscapes and managed timberlands (adapted from Klinka et al. 1990).

REGENERATION METHOD	AVERAGE SIZE OF OPERATING AREA	APPLICABLE IN SPECIAL FOREST LANDSCAPES? [1]	APPLICABLE IN MANAGED TIMBERLANDS? [1]
1) Coppice	> 1 Ha	Y	Y/N*
2) Coppice-with-standards	> 1 Ha	Y	Y/N*
3) Clearcutting	> 1 Ha	N	Y
4) Seed Tree	> 1 Ha	N	Y/N*
5) Shelterwood:			
Strip	width < 2 times stand height	N	Y/N*
Group	0.01 to 0.1 Ha	Y/N*	Y/N*
Uniform	> 1 Ha	Y/N*	Y/N*
Nurse-tree	> 1 Ha	N	Y/N*
6) Selection:			
Group	0.01 to 0.1 Ha	Y/N*	Y/N*
Single tree	< 0.01 Ha**	Y/N*	Y/N*

* Species dependent
** Maximum size of opening within an operating area

[1] see Table 2.2

illustrate what is available to resource managers when addressing the second key question as defined by Klinka et al. (1990).

Vegetative Reproduction: Coppice and Coppice-with-Standards

Coppicing involves the renewal of a stand after harvest solely by vegetative means (e.g., stump sprouts or root suckers). The usual harvest method of clearcutting predisposes the site to reinvasion by vegetative growths of the previous woody inhabitants. Coppicing is often found in pioneer to early-successional species which are subject to cyclical disturbances (Smith 1986; Burns 1983; Weetman and Vyse 1990). Coppicing is useful in the regeneration of poplar species (e.g., trembling aspen) and white birch, both of which are shade-intolerant.

Coppice-with-Standards is a modification of the coppicing silvicultural system. In this situation, standards or selected individuals bearing superior genetic qualities are maintained in extended rotations, while the remaining stems are harvested using the clearcutting method. Coppicing-with-standards differs from the selection silvicultural system in the fashion with which the stand regenerates itself. The purpose of standards is to upgrade the genetic quality of the stand over time (Smith 1986; Weetman and Vyse 1990).

Clearcutting

Clearcutting is the simplest way to harvest a stand, making available almost all of the growing space for new individuals and creating an even-aged stand condition. Clearcutting involves the complete removal of the stand in one operation, with regeneration obtained either naturally or with human assistance. Natural sources of regeneration include advanced regeneration, stump sprouts, root suckers, and seed from neighbouring stands. Cultural sources include artificial regeneration techniques such as planted seedlings and/or sown seed (Burns 1983; Smith 1986 and Weetman and Vyse 1990). Clearcutting is used most often with exposure-tolerant species during stand establishment (Klinka et al. 1990; Smith 1986).

The negative connotation often associated with clearcutting needs to be considered in light of silvicultural interventions in managed timberlands, and especially in special forest landscapes. Although clearcutting is often the best way to regenerate an overmature stand, both for the species in question and from a point of view of worker safety and operational efficiency, clearcutting does not meet any management objectives for aesthetics. As Smith (1986) points out, foresters often fail to recognize the ugliness associated with clearcutting. Hence, as shown in Table 3.1, the clearcutting system is not a viable option in the special forest landscapes old-growth class due to the deleterious effects upon landscape and viewscape aesthetics.

Seed Trees

The seed tree silvicultural system utilizes clearcutting as the harvesting option on a site, but differs from the clearcut system in that a small number of trees are left on the site, either singly or in groups, to regenerate the site naturally from seed. The number of seed trees varies by species, but usually ranges between 20 and 30 stems per hectare (Weetman and Vyse 1990). The seed trees either remain on the site indefinitely, or are removed in a second cutting (Smith 1986; Weetman and Vyse 1990; Burns 1983). In addition to considering the risk to dieback, insect and disease attack, lightning strike and windthrow, managers must also be cognizant of the viability of seed and the sporacity of the seed crop, to ensure adequate natural regeneration. The stand which emerges after harvest is even-aged (Smith 1986).

Shelterwood Systems

As with the clearcutting and seed tree silvicultural systems, shelterwoods produce essentially even-aged stands. However, the removal or harvest of portions of stands occurs over a protracted period of time, as opposed to the one-time entry of the clearcutting system. In principle, shelterwood methods provide some degree of shade and protection for advanced regeneration. According to species composition, frequency, distribution, and shade tolerance, managers are able to manipulate the growing space on a given site according to management objectives. Although in shelterwood systems harvests are completed in one-quarter to one-tenth of the rotation, they are flexible enough that modification based upon old-growth objectives may be used (Burns 1983; Smith 1986; McAninch et al. 1987; Wills 1987; Weetman and Vyse 1990; McNeel 1994).

For each of the four shelterwood methods (strip, group, uniform and nurse tree), multiple entries may be required to attain the desired stand structure and composition. As mentioned above, species composition, frequency, and distribution influence whether preparatory cuttings, seed cuttings and removal cuttings are required (Weetman and Vyse 1990). Preparatory cuttings create gaps in the canopy to increase the growing space available to the most productive seed producers. Seed cuttings, similar to the seed tree method, prepare the site for the introduction of advanced regeneration, and removal cuttings eliminate growing space occupied by seed trees for the advanced regeneration (Smith 1986; Weetman and Vyse 1990). Although seed trees may eventually be slated for harvest, modifications for old-growth objectives often permit their presence on the site indefinitely. Thus, seed trees often outlive their regenerative purpose to become snags and contribute to the coarse woody debris on the forest floor.

The silvics of the tree species involved in each of the cutting regimes (if applicable), determine which shelterwood method may be used. Group shelterwoods may be used with those species capable of producing advanced regeneration; strip and uniform shelterwood methods are advantageous for those species which are exposure-tolerant; and nurse tree shelterwood methods may be employed in stands which are both exposure-requiring and exposure-tolerant (Smith 1986).

A variation on the shelterwood system is the production of uneven-aged stands, whereby the removal cutting is delayed such that at least two distinct age classes are created in the stand. This modification contributes to not only vertical structural diversity, but also to higher variety of species and more variations in the amount of standing and down coarse woody debris. This shelterwood method is commonly called the irregular shelterwood method (Smith 1986; Klinka et al. 1990).

Selection Systems

Unlike the silvicultural systems mentioned above, selection systems, whether applied in groups and patches or to individual trees, seek to create or maintain uneven-aged stands. Three age classes define the uneven-aged condition (Burns 1983; Smith 1986; McAninch et al. 1987; Wills 1987; Weetman and Vyse 1990). Selection systems are most appropriate to fulfilling old-growth objectives (and wild life habitat objectives), because not only are diverse structural and functional features and processes encouraged, but aesthetic concerns are accommodated by the creation or maintenance of such diversity.

The group selection method, ranging in size from 0.01 to 0.1 ha (Klinka et al. 1990), permits managers to create small pockets of even-aged trees within a larger mosaic of an uneven-aged stand. The removal of groups of trees enables managers to create environmental conditions suitable to the regeneration of exposure-requiring species, while improving harvesting efficiency by concentrating operations and minimizing residual tree damage (Smith 1986). Reproduction within the gaps may be obtained from either natural or cultural sources (Weetman and Vyse 1990).

Single-tree selection involves the removal of individual stems within the stand. This variation is intensive in its application, and is suitable to maintaining the old-growth condition within stands of shade-tolerant species, and/or pioneer or early-successional species which are capable of outcompeting more shade-tolerant species for growing space (Smith 1986).

The creation of small gaps by the removal of individual stems mimics the patchy gap pattern often found within old-growth stands. Hence, by emulating canopy mortality and initiating gap-phase regeneration, managers may culturally modify a stand to maintain the natural dynamics associated with the old-growth condition (Lertzman 1990). Smith (1986), however, cautions managers of the risk associated with depending upon natural dynamics to control regeneration within the gaps. Even with the use of planted seedlings in the gaps, there is a chance that neighbouring canopy individuals will fill in the growing space made available by the removal of a stem or small clump of stems (Runkle 1984). This effectively eliminates or greatly reduces the growth rates of new stems within the gaps. Operational problems associated with single-tree selection include increased removal costs and possible increased logging damage to residual trees (Smith 1986).

Vegetation Management Tools

In addition to the silvicultural systems described previously, the manager's toolbox also includes vegetative management release techniques. Options such as thinning, girdling, herbicides and small-scale prescribed burning may be employed, in conjunction with silvicultural systems to bring about a desired stand structure and composition.

Before employing any release mechanism, managers have to consider the following factors and forecast the implications for their local forest site conditions: vegetative reproductive ability (e.g., sprouting, epicormic growth), degree and pattern of desired application within the stand, and the size and other associated characteristics of stems to be removed (Smith 1986; McNeel 1994).

The objective of thinning is to stimulate the growth of the remaining trees in a stand (Smith 1986). From an old-growth perspective, this serves to increase the growing space available to the trees identified as those which best fit the desired future stand structure and composition. For example, if large trees are identified as expressing the old-growth condition within a stand, then the most promising stems may be singled out, and surrounding stems removed (Kimmins 1992).

Issues to consider when applying a thinning regime include increases in rotation length, decreases in the value of the remaining stems due to the risk of cull/decay, and residual stem damage from repeated entries into the stand (Smith 1986). In addition, thinning operations also produce copious amounts of debris on the site, often offending visual quality in addition to endangering recreational use of such stands, such as those found within the special forest landscapes class of old growth. Human risks in thinning operations also include overhead hazards from dead and dying branches and trees (Smith 1986).

Girdling is the removal or killing of a ring of bark around a tree stem so that the flow of carbohydrates from the crown to the roots is interrupted permanently. This results in the death of the roots, which in turn results in the death of the tree. Herbicides often produce the same effect as girdling. Although snags are the end-product of both processes, many trees are capable of sprouting or producing epicormic shoots before they die. In this situation, although the parent tree is killed, many vegetative individuals may arise as a result of the girdling (Smith 1986). Forest managers must decide whether the introduction of multiple stems into the understory aids in achieving the desired old-growth structure.

In general, there are four types of fire management programs, which by their nature, dictate management response to fire as it occurs in forests: 1) natural fire; 2) random-ignition fire; 3) planned-ignition fire; and 4) complete fire exclusion. Natural fires are those started naturally, e.g., by lightning. Random-ignition fires, started either naturally or by humans, are permitted to burn to fulfill specific management objectives. Planned-ignition fires are prescribed fires, conducted in controlled situations, where burn limits are determined on the basis of topographic features, prevailing winds, and fuel loading. Complete fire exclusion is used to protect property and ensure public safety. However, complete exclusion carries two associated risks: 1) an ever-increasing fuel load; and 2) loss of diversity over time (Alexander and Dube 1983).

Alexander and Dube (1983; p. 273) stated that "boreal forests are fire-dependent systems that would lose their vigour and faunal and floral diversity in the absence of fire". What is the implication of this statement on old-growth management in the Ontario range of the boreal forest? Although excluded primarily from the silvicultural implications, old growth in wilderness implies that, in the absence of fire protection programs, natural fires and random-ignition fires burn uninhibited. In both managed timberlands and special forest landscapes, the risk of fire loss varies with the type of fire, fuel type and quantity, elevation, slope and aspect, size and shape of stands and adjacent parcels of land, weather indices, weather forecasts and the degree of management intervention (e.g., protection or let-burn policies) (Hawkes et al. 1990). Risk with natural and random-ignition fires is high, planned-ignition fires risks range from low to high depending upon the planned location of the burn, and complete fire exclusion implies low risk with complete protection.

From a silvicultural perspective, resource managers have to consider species' reactions to fire, the effect on the seedling bed and residual trees, the fire intensity required to stimulate release of seed in serotinous species, timing of the burn, fuel loading, and any potential conflicts regarding fire suppression with regional and/or provincial fire suppression programs.

In areas of high quality aesthetics or visitor use, Alexander and Dube (1983) suggest that fire techniques be limited to planned-ignition fires only. Translated into the old-growth framework described in Blachford and Duinker (1992), special forest landscapes fit well into this type of fire management program. In addition, the resource manager also has to take into consideration: the role of fire in the ecosystem involved, size of the old-growth stand, predicted size of the fire, and its potential beneficial/detrimental effects in the stand if the fire is undertaken.

In special forest landscapes, resource managers must realize that the public may not support the use of fire as a silvicultural tool. Decades of campaigns waged at total fire suppression (e.g., Smokey the Bear), may not easily be changed in the mindset of a public which desires the creation and maintenance of the old-growth resource. Active education, communication and information programs, aimed at providing the public with factual information regarding any unnatural ecosystem effects resulting from a program of total fire exclusion, need to be undertaken to ensure that fire indeed remains a viable tool (Alexander and Dube 1983; Thompson 1993).

THE BOREAL FOREST

The boreal forest region of Canada is a continuous forest belt that extends southward from the Yukon, to the Rocky Mountain trench of British Columbia and Alberta, and eastward to Labrador and Newfoundland. The arboreal species within the Ontario range of the boreal forest are primarily coniferous and include: black and white spruce, jack pine, balsam fir, tamarack [*Larix laricina* (Du Roi) K. Koch)], with eastern white cedar [*Thuja occidentalis* (L.)] in the southern portion. Deciduous species attaining tree form include: white birch, trembling aspen, and balsam poplar [*Populus balsamifera* (L.)], with American mountain-ash [*Sorbus americana* (Marsh.)] and black ash [*Fraxinus nigra* (Marsh.)] in the southern portion. In northwestern Ontario, Alaska birch [*Betula neoalaskana* (Sarg.)] is also included as a boreal species (Hosie 1979). Hardwoods present, but usually found in shrub form, include: showy mountain-ash [*Sorbus decora* (Sarg.)Schneid.], pin cherry [*Prunus pensylvanica* (L.f.)], choke cherry [*Prunus virginiana* (L.)], speckled alder [*Alnus rugosa* (Du Roi)

Spreng.(*Alnus incana* (L.) Moench)], and *Salix* (L.) species (Fowells 1965; Hosie 1979; Farrar 1995).

Extending southward from the boreal forest in Ontario is the Great Lakes - St. Lawrence Forest region. An intermixture of conifers and hardwoods predominates, such that species such as eastern white pine, red pine, eastern hemlock [*Tsuga canadensis* (L.)Carr.], largetooth aspen [*Populus grandidentata* Michx.] and yellow birch [*Betula alleghaniensis* (Britton (*Betula lutea* Michx. f.)] often are found extending northward into the southern range of the boreal forest. Additional species found in both forest regions include: serviceberry [*Amelanchier* Med.] spp., red maple [*Acer rubrum* L.], mountain maple [*Acer spicatum* Lam.], and white elm [*Ulmus americana* L.] (Fowells 1965; Hosie 1979). (Figure 3.2).

Employing Brennan's (1991) age criteria in defining the old-growth state, the remaining discussion on the role of silviculture in old-growth management is limited to those species presented in Table 2.1 (namely: white pine, red pine, jack pine, spruce (black and white), balsam fir, poplar and white birch). The Other Conifer and Tolerant Hardwood forest types will not be examined in this paper.

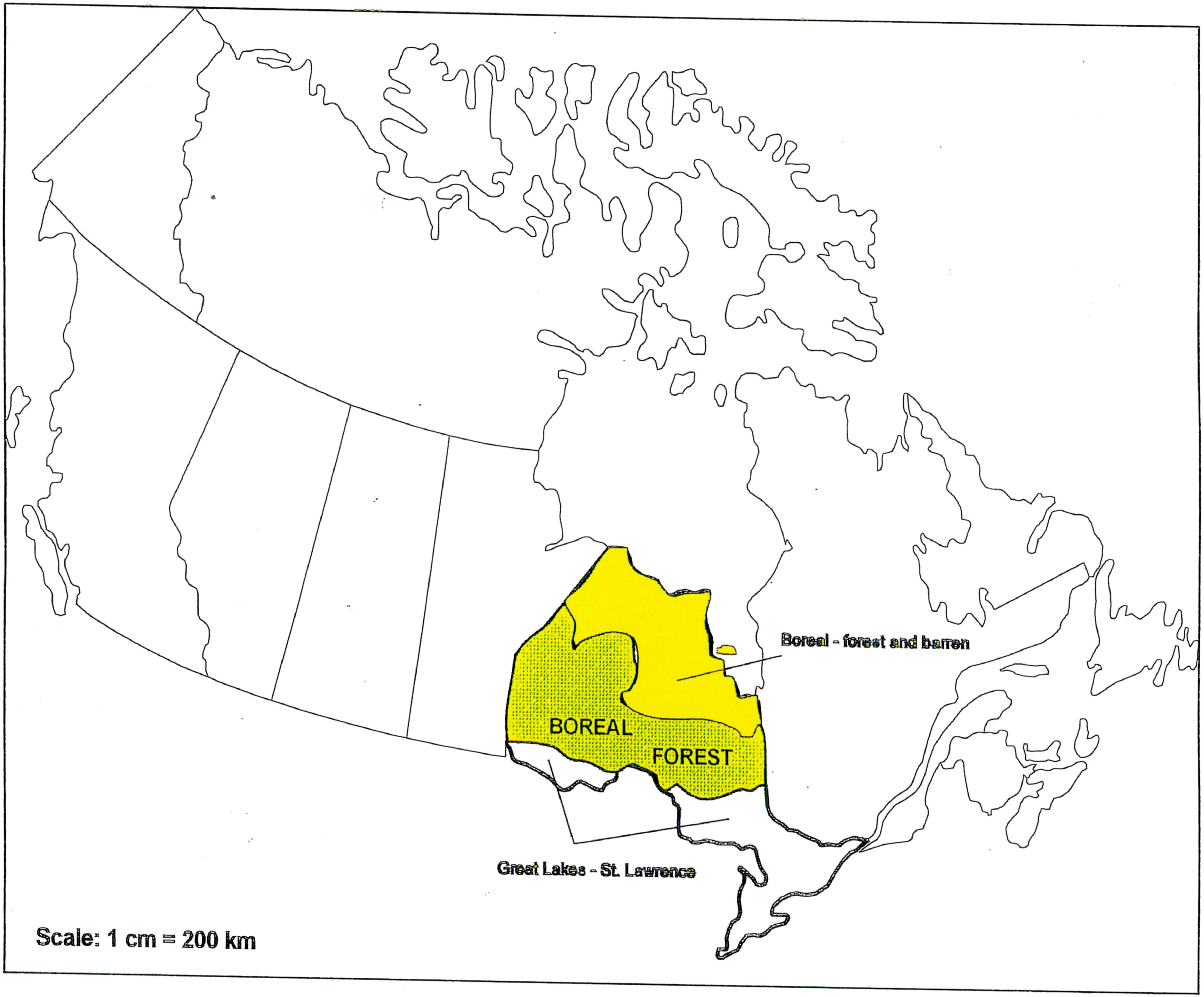


Figure 3.2 The boreal forest region of Ontario.

The Role Of Disturbance In The Boreal Forest

Prior to discussing the silvicultural opportunities available, it is imperative that the disturbance history of the boreal forest region be understood. Disturbance interrupts forest succession at various stages with varying intensities. Managers must understand disturbance to be able to gauge the ecological risks and financial implications associated with each silvicultural alternative.

In the boreal forest, the primary disturbance mechanism is wildfire, which has an average frequency of 60 to 150 years (Cwynar 1978; Terasmae and Weeks 1979; Heinselman 1981; Viereck 1983). Suffling (1988) found that in the absence of fire control in northwestern Ontario, approximately 1-3% of the land area per year is disturbed. In general, fire often precedes the onset of an old-growth state.

However, in northern portions of the boreal forest, where there is little to no fire disturbance, climatic conditions result in cold seasonal temperatures and retarded decomposition rates. In this situation, stand vigour can decline to a point where the resultant old-growth condition is sphagnum [*Sphagnaceae* (L.) spp.] bog (Miller and Davis 1989; Kuusela 1990; Oliver and Larson 1990).

The effect of fire disturbance on the landscape is varied and depends on several factors, including the stage and age of forest succession, climate, time of year and fire severity. The ability of a site to revegetate itself following fire disturbance is influenced by site parent material, length of frost-free growing season and weather patterns (Viereck 1983; Noste et al. 1987; Bell 1991).

Silvical Characteristics of the Boreal Species

To match the regeneration methods with the boreal species capable of fulfilling old-growth management objectives, an understanding of the basic silvics of the species is required. Most woody arboreal species are classified according to their tolerance for growth in shade. Hence, plants may range from very intolerant, to intermediate, to very tolerant of shade. The boreal species under examination fall under one of two categories: exposure-tolerant or exposure-requiring (Klinka et al. 1990; Powell 1987).

I have chosen shade tolerance as the classifier to keep the discussion to a manageable level, although in addition, woody plants may also be classified according to growth habit (e.g., size, rate of growth), climatic range, frost, flood and fire tolerance, successional status, vegetative and sexual reproductive strategies (Sims et al. 1990; Bell 1991).

Exposure-tolerant species include those species which are very shade tolerant to intermediate in tolerance, but are capable of tolerating exposure (Klinka et al. 1990). In the boreal situation, exposure-tolerant species include: eastern white pine, black spruce, white spruce, and balsam fir (Powell 1987). Exposure-requiring species are those which are shade tolerant to very shade intolerant (Klinka et al. 1990), and include: trembling aspen, jack pine, white birch, and red pine (Powell 1987).

Table 3.2 illustrates the basic silvical characteristics of the boreal old-growth species under consideration. Risk of loss, the main cause of loss (mortality), and successional status are also presented for the purpose of comprehending species' reactions to silvicultural interventions in the management of old growth.

APPLICATIONS AND IMPLICATIONS

Old-growth stands, whether in special forest landscapes or managed timberlands, can be created, maintained and/or restored. Summarizing the information based upon inventory data, silvical characteristics of the species, the role and reaction of species to disturbance, silvicultural systems, tools of management, and species reactions to natural dynamics and intervention, the following framework is suggested as a conceptual tool for managers when seeking to fulfill socially-determined old-growth objectives. In addition to the framework, the implications of each of the major silvicultural systems upon the boreal species will be presented.

Table 3.2. The silvical characteristics of boreal old-growth species (adapted from Weetman 1991; Source: Burns 1983; Powell 1987; Sims et al. 1990).

SPECIES	MAIN NATURAL AGENCY OF LOSS/ DISTURBANCE	RISK OF LOSS TO AGENCY	SUCCESSIONAL STATUS	TOLERANCE RATING
Pw	blister rust, weevil	moderate	sub-climax to climax	intermediate
Pr	budworm, windthrow	moderate	early to late	intolerant
Pj	fire, budworm	high	early to mid	very intolerant
Sb	windthrow, fire	low	early to late	tolerant
Sw	budworm, windthrow	mod. low	climax	tolerant
Bf	budworm, root rot, windthrow	mod. high	sub-climax to climax	very tolerant
Po	various pathogens fire	low	early	very intolerant
Bw	various pathogens fire	low	pioneer to early	intolerant

Managed Timberlands: Options and Alternatives

Working within a framework of current forest structure and socially-determined old-growth objectives, managers, when creating old growth are presented with three options: 1) letting natural dynamics operate in recently harvested cutblocks, 2) natural dynamics in mature stands (previously unmanaged), and 3) active management in stands of any age (Table 3.3) (Figure 3.3).

The first option includes potential for natural disturbance dynamics where the old-growth condition may or may not be reached. If the old-growth state is reached, without active management intervention to maintain it, the stand will eventually lose the old-growth condition and succeed into a new stand. Using natural dynamics in mature stands (option 2) also assumes that the old-growth condition may not be reached if catastrophic disturbance interrupts the successional status of the site. As well, the condition will be lost if the stand progresses beyond the old-growth stage. I make the assumption that the third option (active management intervention in the stand) provides the best chance of reaching the old-growth condition, once quantitative and qualitative measures of function and structure can be evaluated.

Table 3.3. Old-growth objectives, options for implementation and implications for management in managed timberlands.

OLD GROWTH IN MANAGED TIMBERLANDS		
OBJECTIVE	**OPTIONS**	**IMPLICATIONS**
CREATE	• natural dynamics in recently harvested cutblocks (stands)	• stands may or may not reach the old-growth stage • if old-growth stage is reached, natural dynamics dictate that the old growth will eventually convert to an earlier successional status
	• natural dynamics in previously unmanaged, mature stands	• same as above
	• active management	• the old-growth stage will most likely be reached
MAINTAIN	• obtain stands under natural dynamics	• both options assume that managers have an accurate inventory of current and replacement old-growth stands
	• obtain actively managed stands	• old-growth stage most likely perpetuated
RESTORE	• active management in mature stands (species dependent)	• planning for old-growth restoration usually occurs at the landscape level
	• active management on recently harvested cutblocks	• intensive management required from time zero to old-growth stage

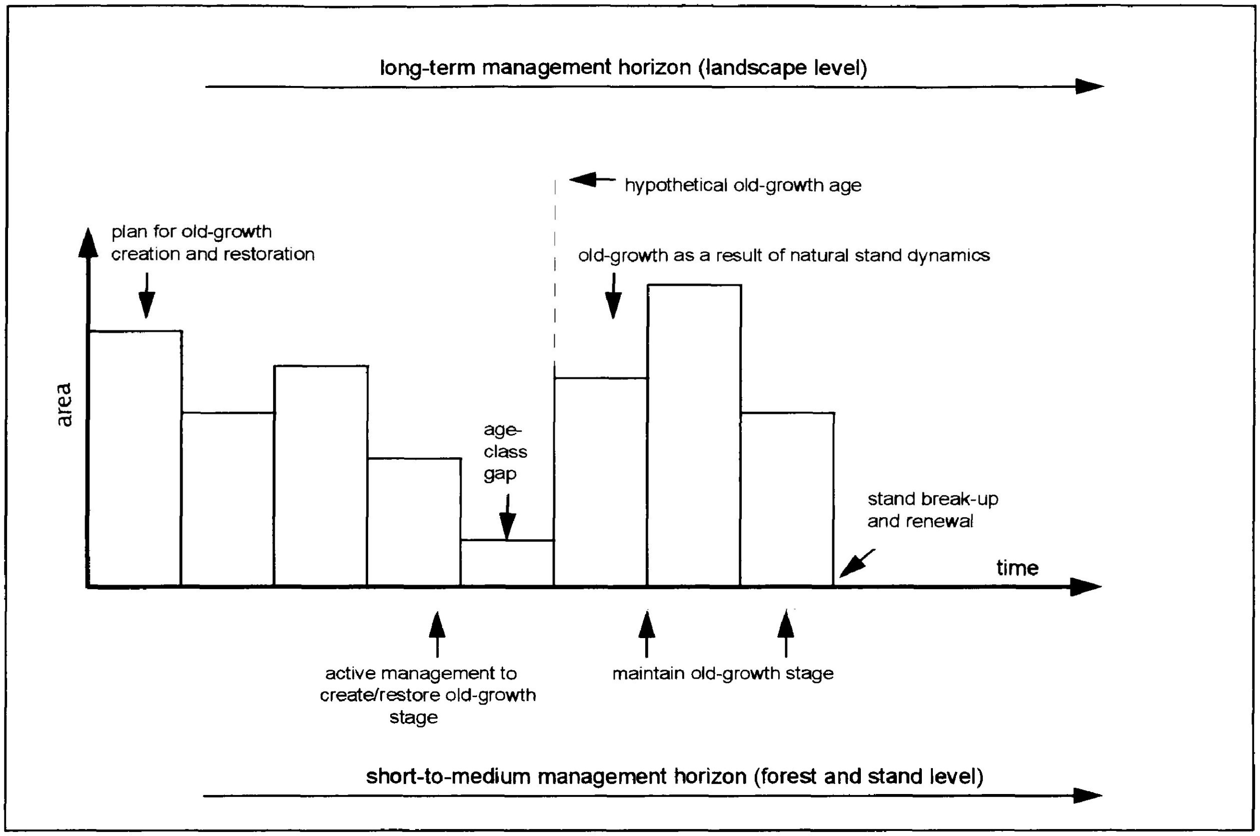


Figure 3.3 Options for old-growth creation, maintenance and/or restoration across a forest landscape over time.

Active management for maintenance of old growth in managed timberlands requires that an accurate inventory of current and candidate old-growth stands exists and is available to managers for planning purposes. Once the old-growth stage has been reached within stands, maintenance may be provided by one of two methods. The first method presumes that replacement old-growth stands may be obtained on a perpetual basis from those stands where natural dynamics operate. Stands that have reached the old-growth condition through active management intervention provide the second way with which to update the forest old-growth inventory.

Due to the urgency implied in the restoration of old growth on a landscape basis, there are two ways to operate within the implied time constraints. The first method dictates that active management intervention be applied to mature stands, whether they were previously managed or not. The second method seeks to convert sites from time of harvest to the old-growth stage with active management. The implied investment in silvicultural activities over the long term may not warrant using the second method in managed timberlands, unless no other options are available.

Special Forest Landscapes: The Mechanics of Old Growth

Unlike old growth in timberlands, managers facing old-growth creation within special forest landscapes do not have the option of creating stands from scratch, that is, stands originating after major disturbance, such as a clearcut harvest. This assumption is based upon the location of the stands (e.g., around lakeshores containing a high population of cottagers), such that a commercial clearcut has never occurred. Thus, only two options are available for creation within this class: 1) natural dynamics in mature stands, and 2) active intervention in young to mature stands (e.g., selection system). The implications for these two options are similar to those found in managed timberlands (Table 3.4).

If the old-growth condition is to be perpetuated indefinitely within this class, only one option is available to managers. Active management intervention (perhaps

Table 3.4. Old-growth objectives, options for implementation and implications for management in special forest landscapes.*

OLD GROWTH IN SPECIAL FOREST LANDSCAPES		
OBJECTIVE	**OPTIONS**	**IMPLICATIONS**
CREATE	• natural dynamics in previously unmanaged, mature stands	• stands may or may not reach the old-growth stage • if old-growth stage is reached, natural dynamics dictate that the old growth will eventually convert to an earlier successional status
	• active management	• the old-growth stage will most likely be reached
MAINTAIN	• active management	• old-growth stage most likely perpetuated (species-dependent)
RESTORE	• active management in mature stands	• planning for old-growth restoration usually occurs at the landscape level • warrants significant investment in silvicultural activities over the long-term

* Table 3.4 differs significantly from Table 3.3 in that the option of using recently-harvested cutblocks for the creation, maintenance, and/or restoration of old growth is prohibited due to aesthetic reasons.

using one or any combination of vegetation management tools, as well regenerative silvicultural methods) has to be used if the old-growth window for a given species is deemed worth the intensive investment. Note, however, that for some species, trembling aspen for example, old-growth maintenance may not be feasible due to a relatively short lifespan and an intolerance of shade.

The conversion of mature stands, with the aid of active management intervention, is the limit to options available to managers trying to restore old growth, on a landscape basis, within the special forest landscapes class. Although the timing of entry into the stand may vary with rates of use and stand condition, restoration in this class implies a conversion from one land use to old-growth protection (Table 3.4).

Silvicultural Options in Special Forest Landscapes

Let us now turn to the silvicultural implications of old-growth management within special forest landscapes. If we can assume that each of the boreal species is equally capable of fulfilling old-growth objectives, then we can explore which silvicultural-regeneration systems can be utilized in the creation, maintenance or restoration of the old-growth state (Table 3.5).

Table 3.5 presents the six regeneration systems and their relationship to each of the species. The coding in each cell is based upon whether a given species can support a regeneration system. If the species is biologically capable, the cell will contain a 'feasible' response. If a method is highly recommended by authorities, then the cell will contain a 'recommended' response. If a system is feasible or recommended based on the capabilities of the species, but is impractical or

Table 3.5. Silvicultural options for the creation, maintenance and/or restoration of old growth for the boreal species in special forest landscapes.

OLD GROWTH IN SPECIAL FOREST LANDSCAPES

SPECIES	REGENERATION METHOD										
	CP	CPS	CCP	CCN	ST	SWS	SWG	SWU	SWN	SG	SS
Pw	○	○	⊜	⊜	○	⊜	◍	⊜	○	●	◍
Pr	○	○	⊜	⊜	⊜	⊜	●	⊜	⊜	◍	○
Pj	○	○	⊜	⊜	⊜	⊜	○	●	⊜	◍	○
Sw	○	○	⊜	⊜	⊜	⊜	⊜	⊜	○	◍	◍
Sb	○	○	⊜	⊜	⊜	⊜	◍	⊜	⊜	◍	◍
Bf	○	○	○	⊜	⊜	⊜	◍	⊜	⊜	◍	◍
Po	⊜	⊜	○	⊜	○	○	○	○	○	○	○
Bw	⊜	⊜	○	⊜	○	○	○	○	○	○	○

LEGEND:

CP: Coppice
CPS: Coppice with standards
CCP: Clearcut with planting
CCN: Clearcut with natural regeneration
ST: Seed tree
SWS: Strip shelterwood
SWG: Group shelterwood
SWU: Uniform shelterwood
SWN: Nurse tree
SG: Group selection
SS: Single-tree selection

● RECOMMENDED
◍ FEASIBLE
○ NOT FEASIBLE; SILVICS
⊜ NOT FEASIBLE; AESTHETICS

unsightly based on old-growth aesthetic concerns, it will receive a 'not feasible; aesthetics' response. Likewise, systems which are not biologically feasible receive a 'not feasible: silvics' response.

Eastern White Pine

Group shelterwood systems are feasible and aesthetically pleasing for regenerative attempts in white pine stands (Wendel et al. 1983). The removal of small groups of individuals satisfies the species' requirements for shade and soil disturbance in seedling regeneration.

Both group and single-tree selection regeneration methods are recommended for use in maintaining the old-growth condition within eastern white pine stands (Wendel et al. 1983). The success of group selection, like that of group shelterwoods, is based primarily upon the prime microhabitats created by the removal of clumps of large overstory individuals.

Red Pine

Because red pine is an exposure-requiring species, group shelterwoods are recommended (Benzie and McCumber 1983; Powell 1987). The size of gaps created often provides optimal full-sun exposure, while the mechanical removal of the groups prepares the seed bed for new seedlings and deters the growth of advanced tolerant understory species. The selection of groups of trees for removal, in order to ensure the perpetuation of the stand, is feasible in red pine.

However, the groups must be large enough to provide the high degree of full sunlight red pine seedlings require (Benzie and McCumber 1983).

With both eastern white and red pine, the creation of multistoried stands must be undertaken with consideration for the risks involved. Sanitation problems may arise where insects and diseases prefer multiple canopy layers. For example, *Sirococcus* tip blight in eastern white pine spreads easily from the upper crowns of mature trees to the planted, natural or advanced regeneration of the understory. While a disease or insect problem may not be noticeable in full-grown adults, it may be fatal to understory individuals of the same species (Benzie and McCumber 1983).

Jack Pine

Jack pine is an exposure-requiring species (Powell 1987), where the uniform shelterwood system is feasible and recommended as suitable for old-growth management objectives. However, the intensity of application must be tempered such that visual appeal is not diminished. Associated considerations for uniform shelterwoods include whether more-tolerant understory species may be capable of invading the openings and commencing site domination, in addition to how strongly tree density is related to visual appeal (Rudolph 1983).

Jack pine stands with initial high densities are subject to site stagnation. In this situation, especially within the context of special forest landscapes, density must be controlled early enough within the life of the stand, such that the resultant stand density actually permits the remaining stems to reach their optimum height and diameter growth rates (Wills 1987). In this way, in the absence of fire or other catastrophic disturbances, the remaining stems may be able to reach old-growth ages (e.g., 101+ years) (Brennan 1991) and thus enable the stand to be classified as old growth.

Group selections may also be used. The removal of groups must be sufficient to provide full sunlight conditions to seedlings while simultaneously deterring the invasion of more competitive plants (Rudolph 1983). In the creation of multistoried jack pine stands, vertical structural diversity is increased while the risk of damage by windthrow is reduced (Wills 1987). Multistoried canopies also produce more windfirm stands of white and black spruce, as well as balsam fir.

White Spruce

Management alternatives for white spruce old growth are restricted to the selection systems (Blum et al. 1983; Sims et al. 1990). Both the group and single-tree selections methods require intensive monitoring and management intervention to create or maintain an old-growth condition. Thus, although both are feasible, both require management attention to feasibility, risk (e.g., windthrow) and regeneration concerns.

Black Spruce

The only options available to managers in black spruce stands include the group shelterwood, group selection and single-tree selection systems. On poor sites, where layering is the dominant expression of self-perpetuation, all three methods encourage the growth of younger black spruce in the understory, while also providing vertical structural diversity and an increased resistance to windthrow (Johnston and Smith 1983). The build-up of *Sphagnum* layers on a poor black spruce site precludes the growth of more competitive species often found on better black spruce sites. On the better sites, the use of these regenerative methods require that stand tending techniques such as herbicides and girdling, attempt to control the competing vegetation (Johnston and Smith 1983; Smith 1986).

Balsam Fir

Balsam fir, like black spruce, often lacks the perception among forestry professionals and the general public alike that it is a species capable of representing old-growth forests. However, in this era of attention to ecosystems, biological diversity and forest legacies, it is imperative that this species be examined with respect to old-growth management.

The management of balsam fir within special forest landscapes is limited to the group shelterwood, group selection and single-tree selection systems. Like black spruce, balsam fir is capable of existing in the understory for decades, until a gap is created. Thus, the group shelterwood, group and single-tree management systems provide opportunities for self-perpetuation by advanced regeneration release, seedling growth and seed germination (Benzie et al. 1983).

Trembling Aspen

The only way to manage for trembling aspen old growth is to set it aside and classify the stand as existing in the old-growth state, until such time as when stand mortality occurs (usually a twenty-year period). Because trembling aspen is such a shade-intolerant species (Powell 1987), it is incapable of supporting any silvicultural intervention, regardless of the intensity (e.g., gentle). Therefore, it is not possible, due to the silvics of the species and the aesthetic concerns over coppice and clearcut methods of stand regeneration, to maintain the old-growth condition for longer than a twenty- to thirty-year period.

White Birch

White birch is another hardwood of the boreal forest which is both a prolific vegetative producer and early successional, intolerant species (Powell 1987). Like trembling aspen, it is incapable of supporting any silvicultural system which introduces gaps, shade or more tolerant understory species into its stand composition. As a result, white birch, like trembling aspen, may only be maintained in the old-growth condition for approximately twenty years. Creation and restoration of old-growth white birch is facilitated solely by the passage of the stand through its associated natural stand dynamics patterns (OMNR 1983).

Silvicultural Options in Managed Timberlands

In managed timberlands, the focus of application changes from restrictions based solely on aesthetics, to the biological capabilities of the species (e.g., seed viability, presence of advanced regeneration, density control) (Table 3.6). Operational considerations such as road location and maintenance will not be discussed here.

Eastern White Pine

Unlike the restrictions found within eastern white pine old-growth stands in special forest landscapes, managers may utilize the clearcutting (with natural regeneration) system for regeneration. It is not common practice to clearcut and plant eastern white pine due to the risk of damage from agents such as white pine blister rust (*Cronartium ribicola*) and the white pine weevil *(Pissodes strobi)* (Wendel et al. 1983; Stiell 1984).

However, keeping in mind the state of the old-growth inventory, clearcutting does fulfill the first option for creating old growth in managed timberlands (refer to Table 3.3; Options). Silvicultural considerations to incorporate into the clearcutting method include: periodicity and viability of seed crops, size of the cut, acceptability of advanced regeneration, and the risk of insect or disease

Table 3.6. Silvicultural options for creation, maintenance and/or restoration of old growth for the boreal species in managed timberlands.

OLD GROWTH IN MANAGED TIMBERLANDS											
SPECIES	REGENERATION METHOD										
	CP	CPS	CCP	CCN	ST	SWS	SWG	SWU	SWN	SG	SS
Pw	○	○	○	◍	○	●	●	●	○	●	◍
Pr	○	○	◍	○	◍	◍	◍	○	◍	◍	○
Pj	○	○	◍	◍	◍	◍	○	◍	○	○	○
Sw	○	○	◍	◍	○	○	◍	◍	○	◍	◍
Sb	○	○	●	◍	◍	◍	◍	◍	◍	◍	◍
Bf	○	○	○	●	○	◍	◍	◍	○	◍	◍
Po	◍	◍	○	●	○	○	○	○	○	○	○
Bw	◍	◍	○	◍	○	○	○	○	○	○	○

LEGEND:

CP: Coppice
CPS: Coppice with standards
CCP: Clearcut with planting
CCN: Clearcut with natural regeneration
ST: Seed tree
SWS: Strip shelterwood
SWG: Group shelterwood
SWU: Uniform shelterwood
SWN: Nurse tree
SG: Group selection
SS: Single-tree selection

● RECOMMENDED

◍ FEASIBLE

○ NOT FEASIBLE; SILVICS

infestations (Wendel et al. 1983; Weetman and Vyse 1990). Strip, group and uniform shelterwoods are recommended for use in eastern white pine management (Wendel et al. 1983).

It is important to modify and customize the application of the feasible systems to suit specific site conditions if the production of old growth is the goal of management. Each system must be evaluated with respect to fulfilling the structural and functional properties that characterize eastern white pine old-growth stands. Although research into the ecological characteristics of eastern white and red pine is immature and ongoing, alternatives for old-growth management should be explored and tested in the field. Such experimentation would permit managers to practice, monitor and evaluate which systems best fit which site conditions (Mann 1990).

Like the application of group shelterwoods, group and single-tree selections aim to create multistoried canopies, future snags, and increased vertical structural diversity within eastern white pine old growth.

Red Pine

Many of the silvicultural systems prohibited from use in special forest landscapes are permitted in managed timberlands. Assuming that aesthetics are not of primary concern, clearcutting with planting, strip shelterwood, seed tree and nurse-tree shelterwoods are all viable management alternatives (Benzie and

McCumber 1983). Once again, however, these systems require customization to local site conditions to fulfill old-growth objectives. The application of group shelterwoods demands an increase in management attention to operational details, as the creation of multiple age classes within the stand requires intensive monitoring and frequent entries into the stand (Benzie and McCumber 1983).

Jack Pine

Silvicultural systems banned from use in the special forest landscapes class of jack pine, based on aesthetic considerations, are all available for use in managed timberlands; namely clearcutting with planting, clearcutting with natural regeneration, seed trees, strip and uniform shelterwoods (Rudolph 1983).

Depending upon the state (e.g., condition, age, structure) of the jack pine stand, application of any of the recommended silvicultural systems must be tempered with a review of the objectives of management with respect to old growth. If creation and/or restoration is the management objective, then time windows must be analyzed in order to facilitate successful attainment of desired management goals. If old growth is to be maintained, then systems and management tools must be applied to the stand to extend the estimated twenty-five-year old-growth time window.

White Spruce

The risk of damage from windthrow is critical to the application of silvicultural systems within white spruce stands managed for timber production, even though these same systems were restricted in special forest landscapes because of the aesthetic implications. Eligible systems, such as seed tree and nurse-tree shelterwoods, must be modified to fit average stand height, size and shape considerations and prevailing wind direction, so that the risk of catastrophic disturbance is minimized (Blum et al. 1983; Sims et al. 1990).

The relative shade tolerance of white spruce opens up additional silvicultural systems for old-growth management when aesthetic constraints are relaxed (Blum et al. 1983). Clearcutting with planting and natural regeneration, group and uniform shelterwoods, in addition to both selection methods, provides managers with various options for creating/restoring and/or maintaining the old-growth condition.

Black Spruce

Similar to white spruce, managers must evaluate the risk to windthrow when designing management strategies to fulfill old-growth objectives within the context of managed timberlands. In addition to risk factors, managers should be aware that growth rates may be slower in those systems which promote vertical structural diversity (e.g., the shelterwood systems) (Johnston and Smith 1983).

In contrast to the systems available as viable management techniques in special forest landscapes, managers may be able to employ all of the systems, with the exception of the coppicing methods, in the creation or maintenance of old growth within black spruce stands (Johnston and Smith 1983). Objectives must be evaluated with respect to stand conditions as they exist in the old-growth inventory, and the applicability of the old-growth condition to black spruce as a species must be taken into account.

Like balsam fir, black spruce has not traditionally been thought of as a true old-growth species (Blachford and Duinker 1991). Hence, with the changing perspectives of forestry professionals and the public alike, serious consideration must be given as to the role that black spruce old growth can play across forested landscapes.

Balsam Fir

With the exclusion of aesthetic constraints, the clearcut with natural regeneration (e.g., advanced regeneration), strip and uniform shelterwood systems become available to managers as tools for creating and/or maintaining the old-growth condition within balsam fir stands (Benzie et al. 1983; Sims et al. 1990).

Trembling Aspen

With the elimination of aesthetic concerns, three methods of silvicultural renewal become available to managers in the management of trembling aspen old growth. The coppice, coppice-with-standards, and clearcutting with natural regeneration systems, all promote the regrowth of a trembling aspen stand (Perala et al. 1983). In terms of creating and/or restoring aspen old growth, these systems satisfy only the imposition of natural dynamics upon recently harvested stands. In addition, there is an approximate eighty-year waiting period from time of silvicultural intervention to the old-growth state in the absence of catastrophic disturbance (Brennan 1991).

The time window for old growth in this very shade-intolerant species is relatively short (approximately twenty to thirty years), thus maintenance of the condition is severely restricted.

White Birch

In managed timberlands, white birch is seldom considered in an old-growth context because of its relative shade intolerance, its narrow old-growth time window (e.g., ten to fifteen years), and the prominence of eastern white and red pine old growth in the media and literature. The coppice and clearcutting with natural regeneration systems (OMNR 1983) are the only tools with which managers may control the creation and/or restoration of the old-growth condition.

Summary

In comparing the silvicultural options for managing old growth in special forest landscapes and managed timberlands, we can see that tools in special forest landscapes are restricted in scope. This restriction is based on aesthetic considerations. Conversely, where aesthetics are less important, as in managed timberlands, there are many more opportunities for managing for old growth. In managed timberlands, when having a choice, managers may want to use the most economical method. However, the demand for old growth will be focused primarily on special forest landscapes, so managers must bear in mind the economic costs of each option when designing overall management strategies. In both classes of old growth, some options may be prohibitive. For example, some options in special forest landscapes are recommended for use over others because the method takes aesthetics into account. In managed timberlands, however, several options may be feasible, and the one chosen by managers would normally optimize resources available (e.g., road systems) and minimize expenses.

Silvicultural Options for Old-Growth Management

Both even-aged and uneven-aged silvicultural systems may be employed, depending upon stand structure and species composition, in the creation, maintenance and/or restoration of an old-growth stand. The desired structural conditions often sought in old growth, and thought to define the condition across species, are produced best in uneven-aged silvicultural systems (Foss 1990).

Selection systems produce gaps, provide sources of seed, offer shade protection, and encourage the creation of multiple canopy layers and thus habitat niches. They are thus the silvicultural foundation of the New Forestry movement. New Forestry (Franklin 1990) offers an alternative approach to integrating traditional timber values with the production of other forest values, namely, old growth (Foss 1990).

NEW FORESTRY

The concept of New Forestry embraces the principles of holistic stand-level practices built into a landscape-level framework. Within this concept, commodity production is integrated with ecological and environmental values such that better forest use and increased public participation in objective-setting and decision-making processes takes place (Franklin 1990; Orians 1990; Kimmins 1992; M'Gonigle et al. 1994; Boyce 1995).

New Forestry is seen as increasing the number of management tools for use by resource managers, while changing management attitudes towards non-timber values. The paradigm of New Forestry changes the management focus from the tree level to the ecosystem level (Foss 1990; O'Keefe 1990; DeBell and Curtis 1993; McNeel et al. 1994).

While New Forestry promotes sustained forest development in light of natural disturbance and stress in combination with the extraction of commercial timber, the techniques of stand-level intervention focus upon influencing structural characteristics, which, theoretically, promote functional objectives (Kimmins 1992). Biological legacies, a phrase used to describe remnants of previous stands which have survived catastrophic disturbance, set the framework for cataloguing and classifying structural characteristics which may be maintained, and which are thought to enable a disturbed stand to pass into the next successional stage with an intact set of functional processes (e.g., refugia and inocula sources) (Franklin 1990; Mitchell 1992b; Franklin 1993; Chase 1995).

Snag, down-log and green-tree retention, canopy closure delays, and changing extraction and utilization standards have all been suggested as solutions and/or tools of New Forestry, in which biological legacies are maintained at the stand level. Landscape-level opportunities include retention of interconnected reserve systems, protection of riparian ecosystems, and minimization of forest fragmentation (DeBell 1990b; DeBell and Curtis 1991; Foss 1990; Franklin 1990; Kimmins 1992; Mitchell 1992b; Jimerson 1994; Chase 1995).

Stand-level treatments affect species composition, stand structure, age of harvest eligibility, and the amount and distribution of coarse woody debris. With respect to species composition, New Forestry promotes an increased interest in creating and maintaining non-traditional timber species, not only in pure stands, but also in mixtures. Silvicultural treatments such as thinning, planting, and green-tree retention (reserve trees) are suggested as tools to control stand structure, such that gaps are created, and vertical structural diversity and wildlife habitat increased (Newton and Cole 1987; DeBell 1990b; Kimmins 1992). The peak mean annual increment of a stand (usually an explicit numerical value) (Davis and Johnson 1987), often referred to as the end of rotation, is delayed, such that viable wood volumes still exist (DeBell 1990b; Brand 1992). Such rotation extensions mean a longer period during which thinnings can take place (DeBell 1990b).

LANDSCAPE FORESTRY

Taking the New Forestry concept one step further, Boyce (1995) concludes that silvicultural practices should be used to create desired stand conditions that result in desired landscape patterns. The application of silviculture to stands in this context changes management focus from that of solely producing stands with desired physical structures, to that of a pattern of stands with a range of desired structures, so that an interrelated web of stands across the landscape exists.

Organizing the landscape in this fashion provides managers with the ability to meet a variety of consumer demands, such as old growth, timber supply, aesthetics, wild life habitat, and biological diversity. These consumer demands, known as 'benefits', are drawn from forested landscapes or 'baskets', such that the goal of landscape forestry is: "to produce baskets of benefits that require two or more kinds of stands ordered over space and time" (Boyce 1995; pg. 3).

Implied in the provision of baskets of benefits is the use of a common model for comparing future scenarios of land use, the simulation of natural disturbances on such scenarios, the examination of relationships between desired benefits, and the ability to direct the arrangement of forest landscapes to satisfy consumer demands (Boyce 1995). Forest simulation models contribute the means by which varied options may be emulated and evaluated across space and over time.

MODELS

A model is a quantitative description of a physical system, consisting of one or more mathematical relationships. It is an abstraction of a real system; a simplified representation of reality (Barnthouse and Van Winkle 1980; Titus and Morton 1985; Morton 1990; Boyce 1995). A model represents a compromise between achieving accuracy at the cost of simplicity. The use of models allows resource managers to test management alternatives under simulated time increments to determine system response (Titus and Morton 1985; Boyce 1995).

Models can be classified as either simulation or optimization models. Simulation models require the user to specify treatment types and levels; no optimal solution is given. In contrast, optimization models attempt to maximize an objective function through an optimal combination of competing activities and activity levels (Titus and Morton 1985). Old-growth forest impacts on the landscape in this study were examined using a forest simulation model called HSG (Moore and Lockwood 1990).

Forest simulation models are relatively cost-effective when compared to field-level analysis. As well, they are non-intrusive and non-disruptive methods of hypothesis testing. Additional benefits of utilising quantitative simulation models include: 1) the use of explicitly stated assumptions, 2) the ability to create and test hypotheses, 3) the identification of knowledge gaps and the direction of data collection into those gaps, 4) concise system descriptions, 5) concise data storage and use, 6) organization of ideas and concepts, 7) the testing of impact scenarios, 8) identification of monitoring and mitigation programs and 9) effective teaching and communication tools (Beanlands and Duinker 1983).

CHAPTER FOUR: METHODS

To tie in the silvicultural characteristics and systems of the boreal species into a modelling framework, chapter four describes the HSG model and its key system drivers. The Timmins Forest is used as the forest estate on which the HSG simulations are based. In addition, the indicators used to evaluate, and the scenarios employed to describe forest relationships are defined. The purpose of each of the simulation scenarios is outlined, and leads into the methods used to compare and validate results from each scenario.

HSG: A FOREST MODELLING SYSTEM

The Harvest Schedule Generator (HSG) simulation model is a quantitative forest inventory projection tool that assists in the design and evaluation of long-range timber harvest schedules. This model was selected to provide the principal analytical framework for this study.

HSG is a sequential forest inventory projection system that operates by tracking the development of individual forest stands through time. HSG retains the spatial identity of all stands described in the forest inventory through all forecasts, and its outputs can be mapped and spatially analysed using the IDRISI GIS (Dendron Resource Surveys Inc. 1993; Cumming et al. 1994). The maintenance of stand spatial identity improves simulation results in two ways: 1) harvest allocation and silvicultural treatments are defined on a stand-by-stand basis, and 2) detailed stand-level data can be provided to the growth forecasting procedure (McCallum 1993).

How HSG Operates

HSG uses the forest stand as the basic unit of analysis. HSG is initialized with FRI data describing each stand's composition. Each stand's original species composition is separated into individual species (sub-components), each with a separate site class, stocking and age. Stocking for each sub-component is the product of the original stocking and species composition for each stand (Dendron Resource Surveys 1993; McCallum 1993). Figure 4.1 illustrates the steps involved in the operation of HSG as a wood supply model.

Age and time increments are simulated by advancing an internal clock. Each time step advances the age of each stand to the new date. After each time step has occurred, HSG evaluates each stand record and records the changes that occurred since the previous period.

Silvicultural and successional rules, located in a state table (Appendix I) are used at this stage in the simulation to describe changes caused by silviculture and succession (Moore and Lockwood 1990; McCallum 1993). Stand yields are then calculated for the updated stand inventories. Yields are calculated for each stand sub-component using age and site class as the index to the yield curves. The value obtained from the yield curve is multiplied by the stocking of the sub-component to provide current sub-component yield (Moore and Lockwood 1990; McCallum 1993).

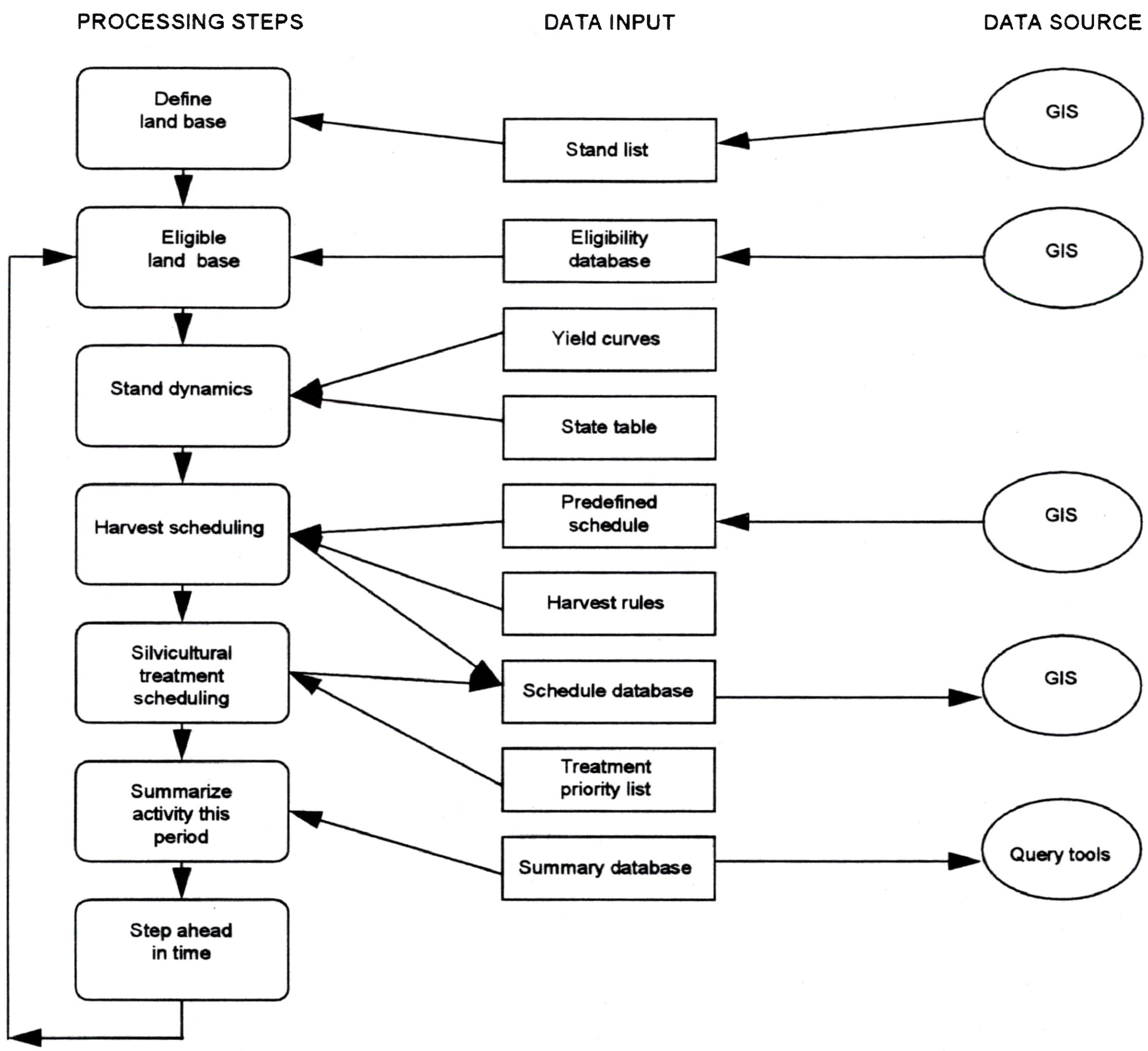


Figure 4.1. Diagram of the operational steps used in HSG (Source: Moore and Lockwood 1990)..

The last stage in the update process checks each stand against an eligibility database. This database provides the opportunity to specify when individual stands become eligible or ineligible for harvest (McCallum 1993).

Once the forest inventory has been updated to the current age, new yields calculated, and the state table checked for stand break-up, harvest simulation starts. HSG allows control over the harvest scheduling process by two means: 1) a user-defined harvest schedule (a list of stands to be harvested, sorted by the year in which harvest is to take place) and 2) a model-defined schedule. The harvest scheduling process begins by applying the user-defined harvest schedule, if specified. The model-defined schedule queues stands for harvest in order to satisfy user-defined harvest quotas, according to the user-defined harvest rule and operability limits. Minimum operable volume limits may be specified for both the stand and the individual species being harvested (McCallum 1993).

On completion of the harvest scheduling, HSG simulates the allocation and scheduling of silvicultural treatments. The silvicultural and successional rules of the state table describe regeneration alternatives and new stand conditions that would result from the application of each treatment. Stands to be treated in the current iteration of the simulation are sorted and treated according to user-specified treatment priority lists (Appendix II) (McCallum 1993).

The treatment priority list contains records specifying the order of treatments to be applied to stands of specific species and site-class combinations. When the stand update process encounters a stand that has been recently harvested, it searches the state table for a matching species, site-class and treatment code. When a match is found, the state table record redefines the stand record and species sub-component fields. Allocation of silvicultural treatments begins with stands at the top of the sorted list, and continues until the area treated exceeds the specified limit (using the SILVA command). If harvested stands do not match records in the treatment priority list, or if the treatable area limit is reached, these stands default to extensive silviculture (e.g., natural regeneration) (Moore and Lockwood 1990; McCallum 1993).

Output from an HSG run is stored in summary, inventory, and schedule files. The summary file contains time series data describing forest conditions and management treatments at each time step; the inventory files contain snapshots of the FRI at some point in the future; and the schedule files describe the proposed stand-level treatments implemented by HSG. The summary file contains all of the information contained in the inventory and schedule files, but averaged for the whole forest without geographic identifiers. The data in the summary file tell 'how much' happened in the forest, while the inventory and schedule files record 'where' (Dendron Resource Surveys Inc. 1993).

AREA OF STUDY: THE TIMMINS FOREST

The Timmins Forest is located in Ontario's boreal forest region (Figure 4.2). It was recently managed under a Forest Management Agreement (FMA) by QUNO Corporation, and is now a Sustainable Forest License (SFL) under the Crown Forest Sustainability Act of 1994. The SFL, signed first in 1982 between QUNO and the province of Ontario, was created to produce a long-run sustained forest yield for QUNO (McCallum 1993). The SFL consists of 35 (whole or partial) townships, of which four have been examined in this thesis.

The Forest Estate

During the 1970's, the Timmins Forest suffered substantial tree mortality due to an Eastern Spruce Budworm (*Choristoneura fumiferana*) outbreak, resulting in over 61% of the current Balsam fir inventory being under the age of 70 years. The forest in 1993 (Table 4.1) was dominated by black spruce, with significant components of poplar, white birch, jack pine and balsam fir.

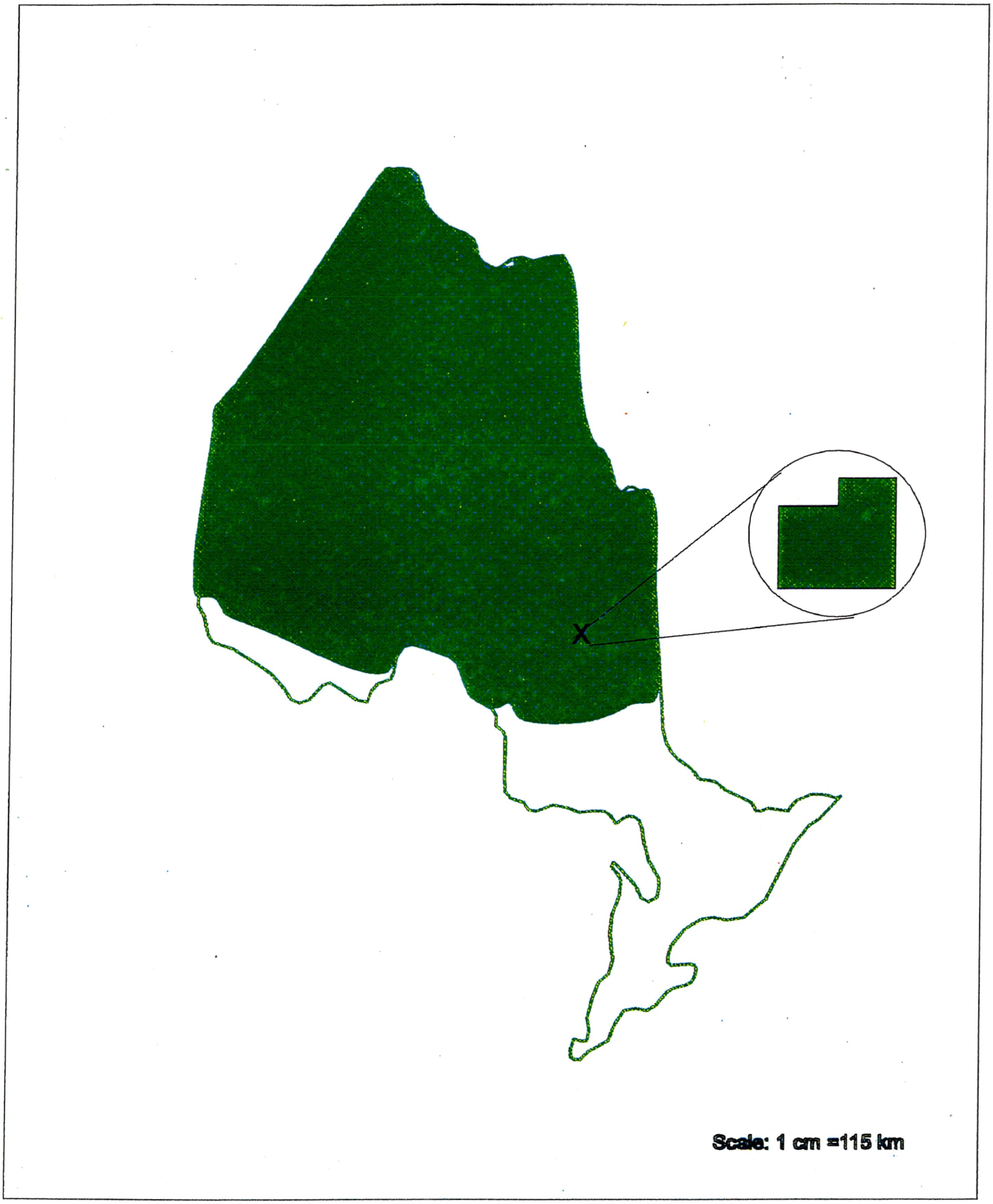


Figure 4.2 Location of the Timmins Forest in Ontario's Boreal Forest.

Table 4.1. Species inventory summary as of 1993
(Source: Dendron Resource Surveys 1993).

Species	Area (ha)
White pine (Pw)	87
Red pine (Pr)	0
Jack pine (Pj)	3,019
Black spruce (Sb)	16,546
White spruce (Sw)	401
Balsam fir (Bf)	2,977
Poplar (Po)	5,870
White birch (Bw)	3,485
Cedar (Ce)	265
Other Conifers (Oc)	53
Other Hardwoods (Oh)	6
Total	32,709

To reduce the complexity of the old-growth/wood supply analyses, the Cedar, Other Conifers and Other Hardwoods have been ignored in all simulation runs. Red Pine is also excluded, as it does not occur naturally in the four townships under investigation. Similarly, the non-productive and non-forested sites, such as water, rock, and treed muskeg, have been left out of the simulation. The exclusion of Red Pine, Cedar, Other Conifer and Other Hardwoods reduced the total area under examination to 32,385 ha.

The following species were examined in this analysis of the forest estate: Sb, Sw, Pj, Pw, Bf, Po and Bw. These species were further divided in subsequent analysis by site class: X, 1, 2, 3 and 4 (with X being the most productive, and 4 the least productive). The FRI database classifies stand age in five year increments. For display and summary purposes, stand age was grouped into twenty year age classes: 0-20, 20-40, 40-60, 60-80, 80-100, 100-120, 120-140, and 140 plus (140p). The forest age-class structure was dominated in 1993 by stands of 60-120 years of age (Figure 4.3).

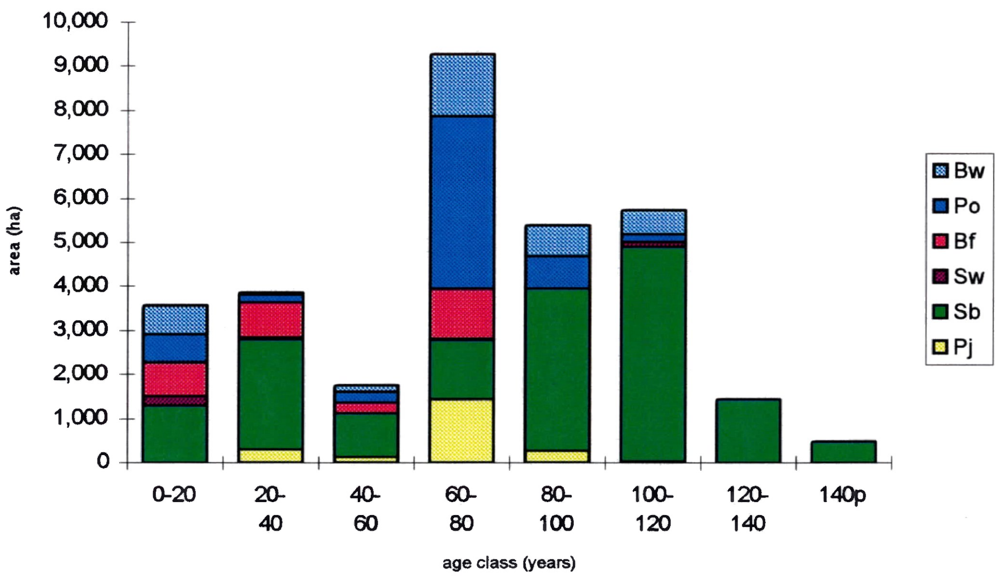


Figure 4.3. Age-class structure by species of the study area in 1993. Note the significant proportion of black spruce (Sb) across all age classes.

HSG Dataset Preparation

The state table developed for The HSG Forest Modelling System User's Guide was used in this old-growth study (Appendix I). The table, originally created by

Moore and Lockwood (1990), was modified by QUNO personnel to reflect better the harvest, silviculture and successional patterns found within the Timmins Forest (McCallum 1993). The harvest method simulated is clearcutting. The various forms of shelterwood and selection systems could not be modelled in the PC-version of HSG available for this study. Due to model limitations, catastrophic disturbances such as fire, insect and disease outbreaks, and stand blowdown could not be simulated.

Pure-species yield curves were used in the simulation runs and reflect Net Merchantable Volume (NMV). The curves, originally developed by Moore and Lockwood (1990), were updated and refined by QUNO to reflect local conditions, and field tested in the Timmins Forest itself (McCallum 1993) (Appendix III). Further refinements were made during this study to reflect the relationships between commercial timber and old-growth supply across the forest. The assumption made in using predefined yield curves is that species will behave in mixed species stands as they do in pure stands. Although HSG has the capability to represent mixed-species stands, yield curves have not been refined to do the same (Dendron Resource Surveys 1993).

Indicators and Scenarios

In this study of old growth and timber supply, indicators for analysis included: 1) long-run sustained yield (LRSY) versus growing stock (m^3/yr), and 2) percentage of the landscape in the old-growth condition per decade, per species. The old-growth criteria were based on the old-growth age derived from Brennan (1991) (Table 2.1). Six simulation scenarios were developed to forecast the provision of the timber/old-growth benefits in the area of the four townships (Table 4.2). The old-growth criteria were based on the old-growth age derived from Brennan (1991). All scenarios used 100-year simulation periods (in 10-year time steps) for analysis.

For each scenario, numerous simulations were run to determine a reasonable balance of LRSY, silvicultural effort and growing stock. When this balance had been achieved, the indicators were thus defined for each scenario and used for comparative purposes.

The scenarios were not constrained spatially across the landscape; stand access was not considered to be problematic due to the extensive road network already established in the Timmins Forest (McCallum 1993). Adjacency constraints on harvest blocks were not used in this study due to software limitations.

The scenarios were built upon the assumption of providing long-run sustainable yields measured over the 100-year simulation period. While recognizing that long-term forest health sustainability involves at least one rotation, and possibly up to several (Walters and Holling 1990), such an extended analysis is beyond the scope of this thesis.

All scenarios used a minimum operability limit of 40 m^3/ha across all species, in combination with a minimize-volume-loss harvest rule. This rule evaluated the potential change in volume in a stand over the next 10-year period. The stands that would decline the most in volume during the 10-year period were scheduled for harvest first. This allowed stands that would maximize volume increment over the next 10-year period to be scheduled for harvest last. The harvest rule was designed to capture incipient mortality (Dendron Resource Surveys 1993), but also served to keep stands at or older than the old-growth age standing, while turning over to younger age classes, those stands which would break apart fastest (Duinker 1996).

No-Harvest Scenario

The No-Harvest Scenario was designed to display the basic patterns of forest stand succession as outlined in the state table (Appendix I). This scenario forecasts the development of the forest in the absence of harvesting and regeneration treatments. In the absence of harvesting, stands eventually break up and regenerate naturally, as defined by the state table successional rules.

Table 4.2. Old growth/timber supply simulation scenarios.

Activity File	LRSY (m^3/yr)			Treatment Schedule	Declared Regeneration Silviculture (ha)	Actual Level of Regeneration Silviculture ha/yr*	Harvest Rule	Yield Curve File
	Sb/Sw	Pj	Po					
No Harvest	0	0	0	n/a	n/a	n/a	n/a	normal
No Regeneration Silviculture	14,000	0	0	n/a	n/a	n/a	2	normal
Benchmark	14,000	5,000	4,500	Basic	200	229	2	normal
Maximum Regeneration Silviculture	15,000	5,000	8,500	Basic	500	281	2	normal
Pause Yield Curve	10,500	700	2,000	Basic	200	150	2	pause
Concentrated Silviculture	14,000	5,000	4,500	Intensive	200	268	2	normal

* The actual level of silviculture in Table 4.2 is an average of the ha/yr treated. This value may differ from the SILVA command in the activity file (e.g., SILVA 200), as HSG applies silvicultural treatments equally to stands of various sizes to satisfy the SILVA limit. For example, if the SILVA command requires only 10 more hectares to fill a 200-ha limit, and it encounters the next stand to receive silvicultural treatment, regardless of whether that stand is only 10 ha or 100 ha, the total stand area is treated. For harvested areas less than the SILVA limit, HSG treats only those areas harvested.

Due to the lack of automated disturbance mechanisms in HSG, catastrophic mortality was not modelled. The sole force of change was that stands continue to track along the yield curves specified for each species. Long-lived species, such as black spruce, may grow in perpetuity, in the absence of natural disturbance mechanisms. Species dependent on disturbance for regeneration and establishment, such as jack pine, however, may be eliminated over the course of the 100-year simulation period (Day 1990; McCallum 1993).

For example, following the state table assumptions for stand successional behaviour, black spruce stands regenerate naturally to either pure black spruce or mixed black spruce stands (such as black spruce and poplar). In contrast, jack pine converts to mixed black spruce/balsam fir stands in the absence of disturbance.

No-Regeneration Silviculture Scenario

The No-Harvest Scenario is used as a baseline for comparative purposes with the No-Regeneration Silviculture Scenario. This scenario employs a LRSY of 14,000 m^3/yr for Sb/Sw; there is no harvest scheduled for Pj and Po. When HSG sought to satisfy the spruce harvest component, it was taken without preferential treatment from both black and white spruce stands. Hence, both species have been grouped together for purposes of analysis.

As with the No-Harvest Scenario, the No-Regeneration Silviculture Scenario assumes that stands regenerate according to natural successional patterns. Post-harvest Sb/Sw stand development, as controlled by the state table, also follows patterns associated with extensive silviculture. The harvest of Sb and Sw, in association with natural regeneration, is presented to demonstrate its impact on the supply of old growth. Application of an extensive silviculture program may be appropriate in managed timberlands and wilderness areas where forest management resources may be limited.

Benchmark Scenario

The Benchmark Scenario allocates LRSYs of 14,000 m^3/yr for Sb and, 5,000 m^3/yr for Pj, and 4,500 m^3/yr for Po (Appendix IV). The silvicultural limit is set to 200 ha/yr, applied in accordance with the basic treatment table (Appendix II). The basic treatment table concentrates intensive silviculture on site class X for Sb, Sw and Pj; basic silviculture on site classes 1 and 2 for Sb, Sw and Pj; and extensive silviculture on all site classes of poplar and white birch. The Benchmark Scenario was designed to examine the effect of commercial timber harvests of Sb/Sw, Pj and Po on the supply of old growth.

Maximum-Regeneration Silviculture Scenario

In this scenario, LRSY levels were increased from those found in the Benchmark Scenario. The new Sb/Sw harvest level was set at 15,000 m^3/yr; the Pj harvest level remained the same at 5,000 m^3/yr (harvest levels greater than 5,000 m^3/yr were not sustainable), and the Po harvest level increased to 8,500 m^3/yr.

The focus of silvicultural effort for this scenario remained identical to that of the Benchmark Scenario: intensive treatment on site class X for Sb, Sw, and Pj;

basic treatment on site classes 1 and 2 for Sb, Sw and Pj; and extensive treatment on all Po/Bw site classes.

To accommodate the increased harvest levels, the number of hectares treated with silviculture was increased to equal the number of hectares harvested. The purpose of this scenario was to demonstrate the impact of maximum-regeneration silviculture on both timber and old-growth supply.

Pause-Yield-Curve Scenario

To mimic the temporal preservation of old-growth, 20-30 year time windows were created for specific stand types during which harvesting did not occur. These "old-growth windows" commenced at the peak of each yield curve/site class combination per species (Figure 4.4) (Appendix V). A 'pause' yield curve file was created, in which the old-growth window was defined by setting the NMV to zero. This forced the harvesting algorithm to skip stands falling into the old-growth windows, and effectively created a system of old-growth reserves.

The LRSYs in this scenario were decreased from the Benchmark levels. The Sb/Sw level changed from 14,000 to 10,500 m^3/yr; Pj from 5,000 to 700 m^3/yr; and Po from 4,500 to 2,000 m^3/yr. The purpose of this scenario is to stress the act of old-growth preservation on the levels of sustainable timber harvests.

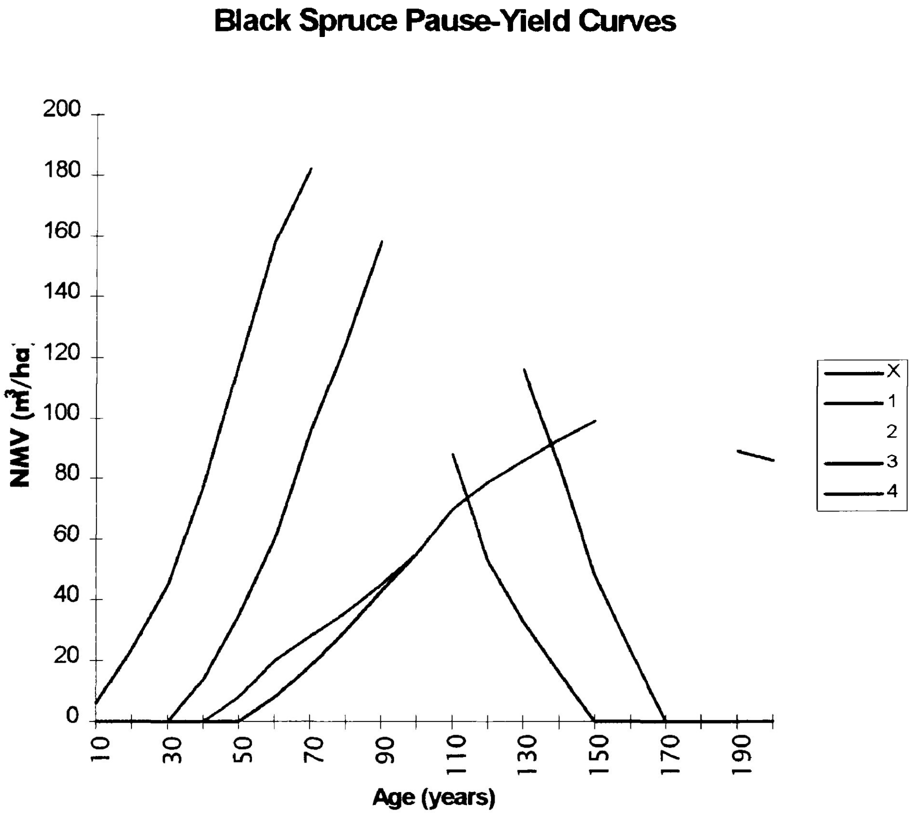


Figure 4.4. Modified black spruce yield curves; gaps in the NMV indicate the old-growth time window, where old-growth stands are protected from harvest.

Concentrated-Silviculture Scenario

The treatment table used in the Concentrated-Silviculture Scenario changes the focus of the silviculture program from extensive to intensive. As a result, intensive silviculture (e.g., management intervention before and after stand establishment) was applied to the following species/site class combinations: Sw X, 1, and 2; Sb X, 1, and 2; Pj X, 1, and 2. All Po and Bw site classes were treated with extensive silviculture.

For Sb and Sw, the use of intensive silviculture enabled the LRSY to be increased from 14,000 m^3/yr to 24,024 m^3/yr for the last 30 years of simulation, an increase of approximately 72%. The LRSYs for Pj and Po were kept at Benchmark levels (5,000 m^3/yr and 4,500 m^3/yr, respectively). The purpose of the Concentrated-Silviculture Scenario was to 1) demonstrate that intensive silviculture could support the use of a higher harvest level over time, and 2) explore the impact of intensive silvicultural interventions on the relationship between timber and old-growth supply.

A Closer Look

All six scenarios used a species-specific age factor to identify old growth (Table 2.1). This predetermined old-growth age was applied evenly to each species, regardless of the variations in site class. To get a more refined estimate of the provision of old growth per species, a modified old-growth age was assumed to occur at ten years past the peak of each site class/yield curve combination (Table 4.3). In Pw, however, the old-growth age of 140+ years was maintained, as ten years past the peak of the yield curves would have put the age at greater than 200 years. This was deemed to be impractical for analytic purposes and unrepresentative of the dynamics of the species. This refined perspective on the old-growth indicator was used to re-analyze the Benchmark and Concentrated-Silviculture Scenarios.

Table 4.3. Refined old-growth ages: a comparison between Brennan's (1991) ages and a point 10 years past the peak of each species- site class combination.

Species	Site Class	Brennan's Old-Growth Age	Modified Old-Growth Age
Sb	X	131+	90+
	1	131+	110+
	2	131+	150+
	3	131+	170+
	4	131+	170+
Sw	X	131+	80+
	1	131+	90+
	2	131+	100+
	3	131+	140+
	4	131+	150+
Pj	X	101+	90+
	1	101+	90+
	2	101+	100+
	3	101+	100+
	4	101+	100+
Pw	X	140+	140+
	1	140+	140+
	2	140+	140+
	3	140+	140+
	4	140+	140+
Bf	X	71+	60+
	1	71+	70+
	2	71+	70+
	3	71+	80+
	4	71+	80+
Po	X	81+	80+
	1	81+	90+
	2	81+	90+
	3	81+	90+
	4	81+	90+
Bw	X	91+	80+
	1	91+	80+
	2	91+	80+
	3	91+	80+
	4	91+	80+

Validity of Scenario Comparisons

The six simulation scenarios were compared against each other in the following manner:

- No-Regeneration Silviculture compared to No-Harvest Scenario (to monitor old-growth evolution when a major species (e.g., Sb/Sw) has a harvest with no regeneration silviculture,

- Benchmark compared to No-Harvest (for Pj, Po), and No-Regeneration Silviculture (for Sb/Sw, Pj,Po) Scenarios (to monitor old-growth evolution when all major species have harvests and some basic level of regeneration silviculture is achieved),

- Maximum-Silviculture compared only to the Benchmark Scenario (to monitor LRSY increases and old-growth changes when all harvested area is treated with a basic level of silviculture),

- Pause-Yield-Curve compared only to the Benchmark Scenario (to monitor reductions in LRSY and changes in old-growth supply with the use of old-growth windows, and/or extended rotations),

- Concentrated-Silviculture compared to the Benchmark Scenario (to monitor changes in old-growth supply when the silvicultural program is intensified).

To compare results of growing stock and old-growth supply for each species among the six scenarios, the formula:

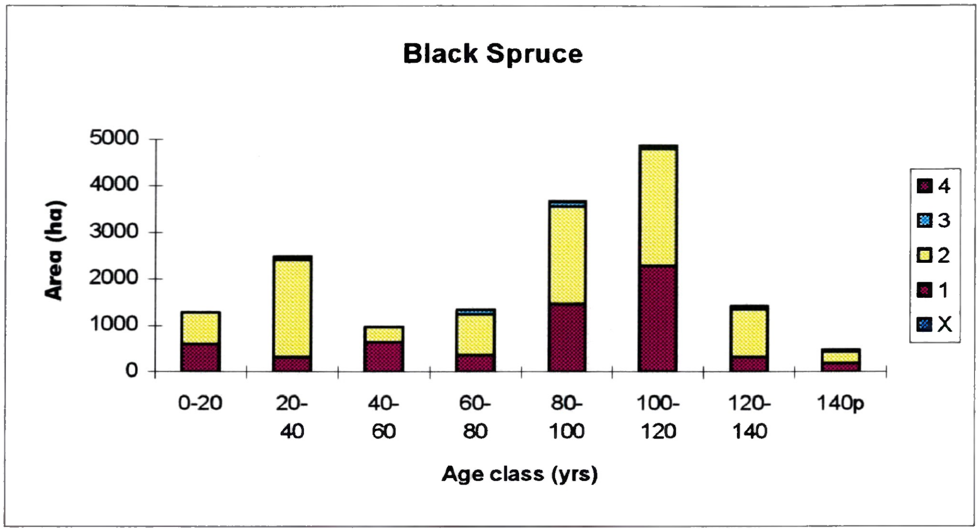
$$\frac{(\text{average } Y^2 - \text{average } Y^1) \times 100}{\text{average } Y^1}$$

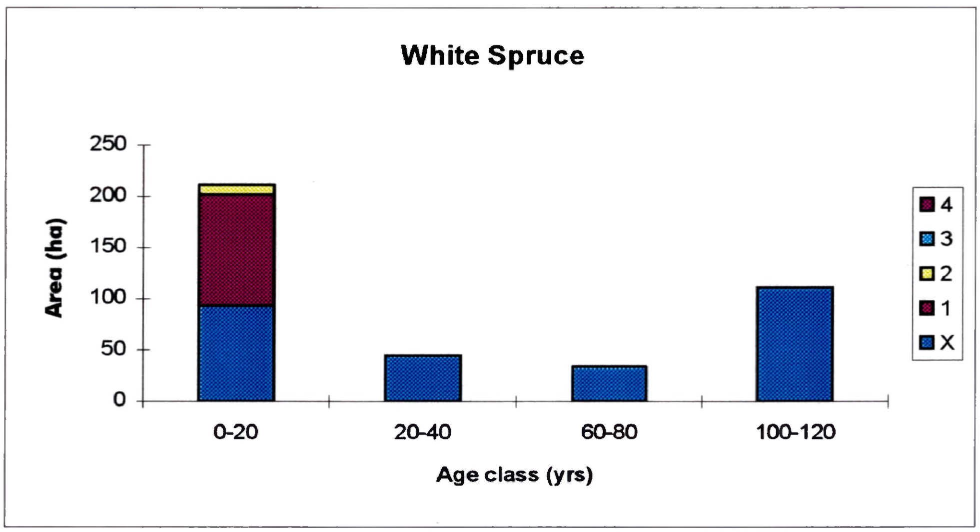
was used; where Y^2 represents the average of the scenario results to be compared, and Y^1 represents the average of the scenario whose results are being compared against. The result is expressed as a percent change, and is repeated for each decade of the 100-year simulation run.

1993: Summary of the Old-Growth Condition

An understanding of the initial 1993 forest structure is necessary to effectively interpret the simulation results presented in chapter five. Of the 32,385 ha under investigation, 23.4% is in the old-growth stage (7,564 ha). Poplar dominates this stage of forest development (41.5%), followed by black spruce (25.1%), white birch (16.2%), balsam fir (15.0%), white pine (1.2%) and jack pine (1.0%). White spruce does not contain any stands greater than 130+ years of age in 1993. The percentage of area in the old-growth stage per species (1993) is: black spruce - 11.5%, white spruce - 0%, jack pine - 2.3%, white pine - 100 %, balsam fir - 38.2%, poplar - 53.5%, and white birch - 35.2% (Figure 4.5(a), (b), and (c)).

It is important to note the age-class distribution pattern in balsam fir (Figure 4.5(b)). Knowing the history of the species (e.g., the large mortality loss to the eastern spruce budworm outbreak in the 1970's), it can be observed that as the





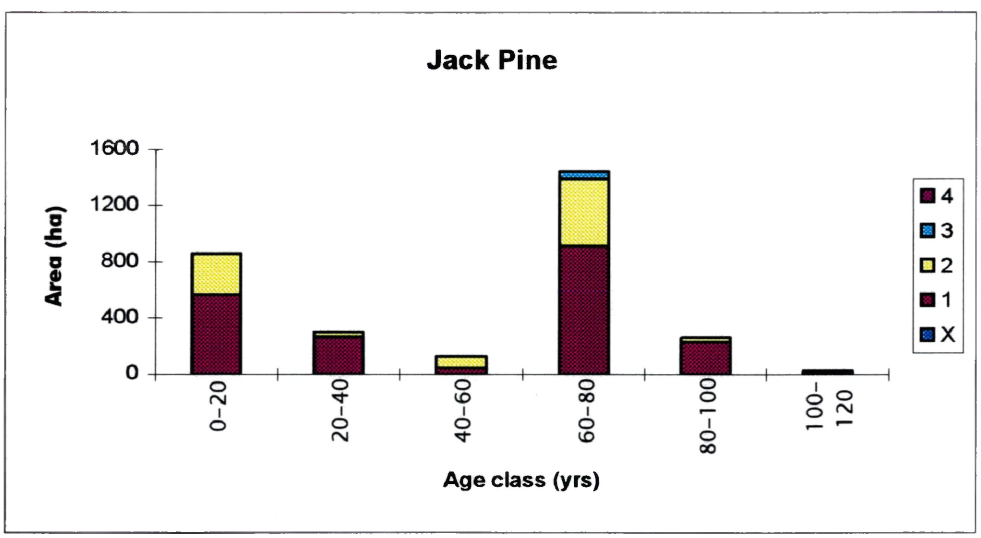


Figure 4.5(a). Age class structure by site class of black spruce, white spruce and jack pine in 1993.

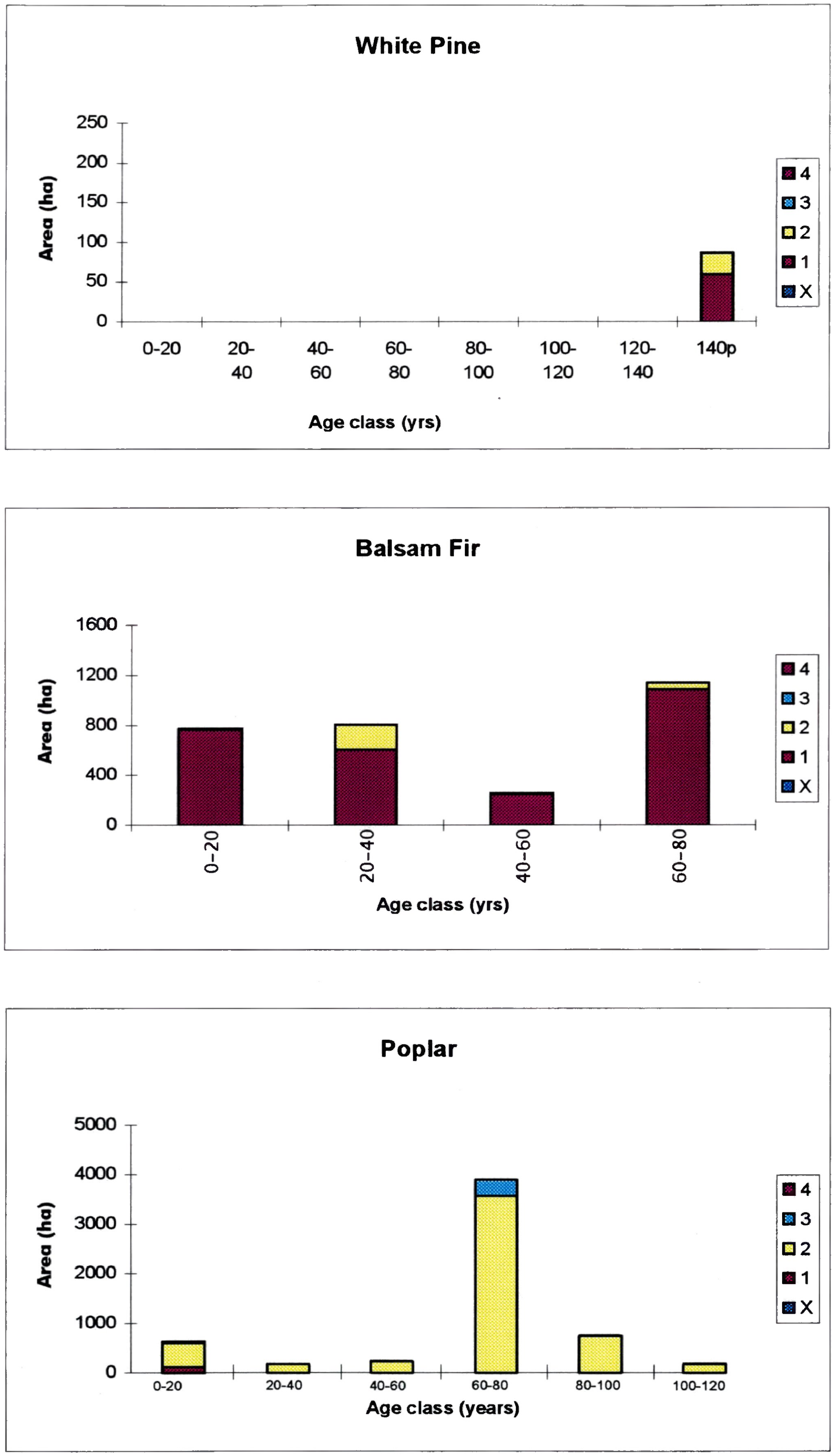


Figure 4.5(b). Age class structure by site class of white pine, balsam fir, and poplar in 1993.

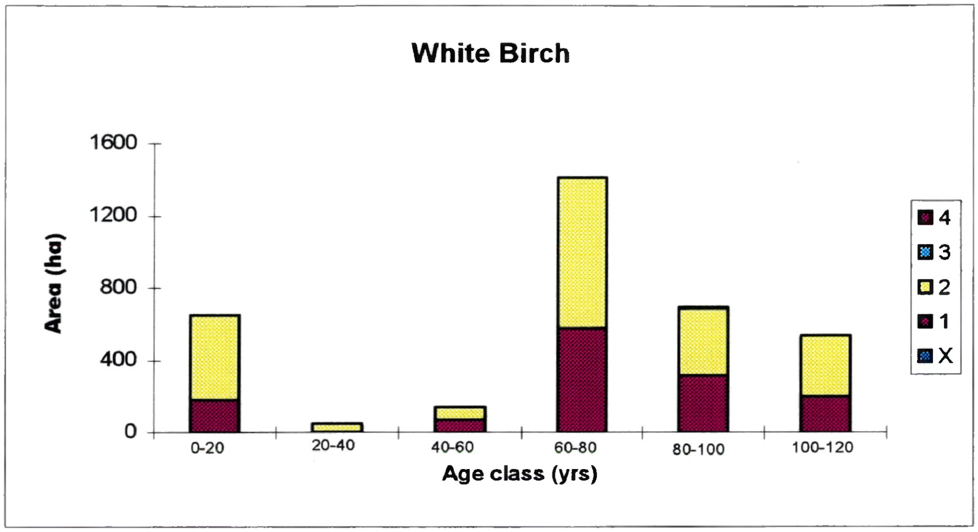


Figure 4.5(c). Age-class structure by site class of white birch in 1993.

age classes cycle through time, the old-growth age class will become increasingly more significant. This pattern will continue, in the absence of management interventions and automated disturbance mechanisms, until these old-growth age classes breakup and return as younger age classes. This budworm-driven age-class structure mimics reality in the forest closely, as the budworm cycle tends to cause waves of development over time (Moore 1996).

Heavily imbalanced age-class distributions are also present in jack pine, poplar, and white birch. For all three species, fire disturbance has played an important role in driving the current age-class structure. In the early 1900's, severe fires, burning from Haileybury to Cochrane, passed through the area, causing detrimental effects to the forest (Day 1990). At the same time, logging for conifers commenced in the Timmins area, further adding pressure to jack pine and spruce, and contributing to the imbalance found in the age-class distributions (McCallum 1993).

In all cases, the Sw supply of old growth across the landscape is nil during the 100 years of simulation. Due to the initial age-class structure (approximately 72% of the area is less than 130 years), and the succession rules assumed in the state table (in the absence of intensive silviculture Sw stands regenerate heavily to Po), Sw stands will not reach the age of 130 years. Hence, Sw will be left out of further old-growth supply analyses.

The six scenarios were run through the simulation model; the results tabulated and presented in the next chapter. In chapter five, the reader is directed to the appendices, where graphical representations of results not considered critical to the discussion are presented.

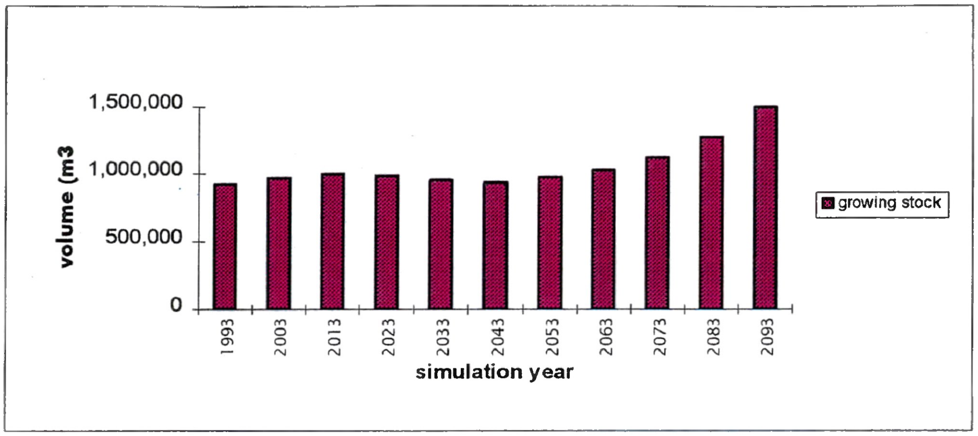
CHAPTER FIVE: RESULTS AND DISCUSSION

NO-HARVEST SCENARIO: Growing Stock

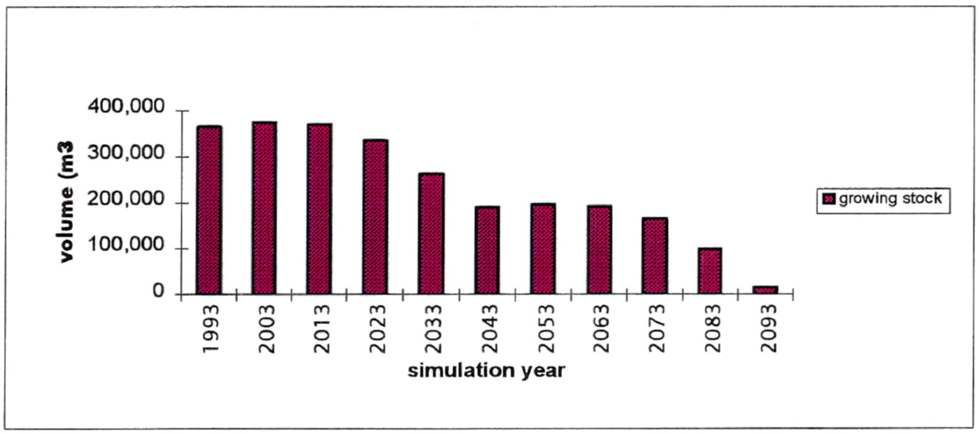
The No-Harvest Scenario growing stock curves outline the trend each species exhibits as it tracks through time, in the absence of management intervention (Figure 5.1(a), (b)).

Black and white spruce are combined, as they are jointly harvested. Over the 100-year simulation period, the Sb/Sw growing stock is maintained at or above 910,000 m^3. Jack pine growing stock, however, decreases significantly over time, and does not appear to be sustainable past 100 years into the future (e.g., from 365,319 m^3 in 1993 to 16,014 m^3 in 2093; a 96% decrease). This result is due to the Pj succession rules contained in the state table, whereby, in the absence of disturbance, Pj converts to mixed Sb and Bf stands. The assumption contained in the state table rules is that of a complete fire exclusion policy for Pj. However, in reality, fire is often the disturbance mechanism that triggers the regrowth of Pj on Pj sites. It is a limitation of the model, that what is reality on the ground cannot be modelled in this situation.

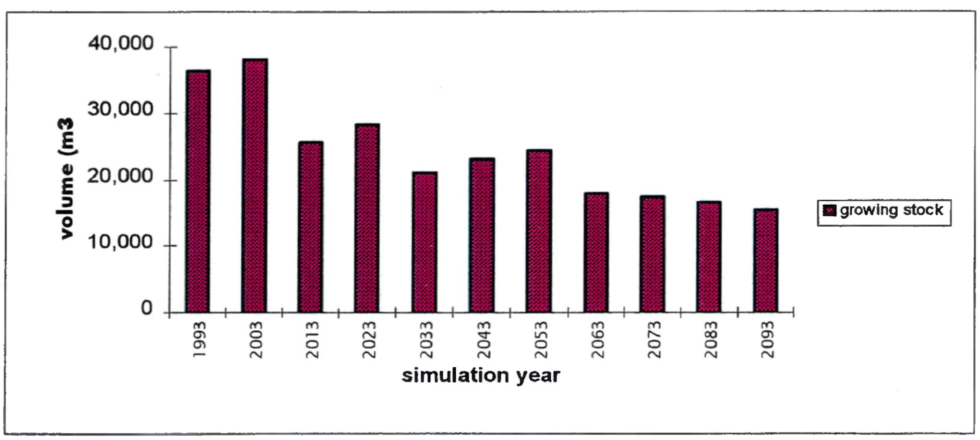
Growing stock levels for white pine, although sustainable over 100 years, gradually decease as the old-growth stands, which compose 100 % of the age classes, break up over time. The assumptions built into the state table for Pw



Black and white spruce

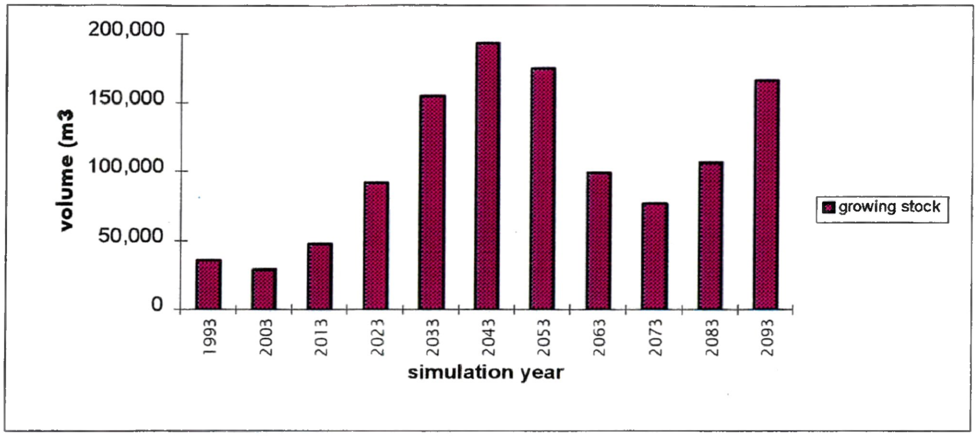


Jack pine

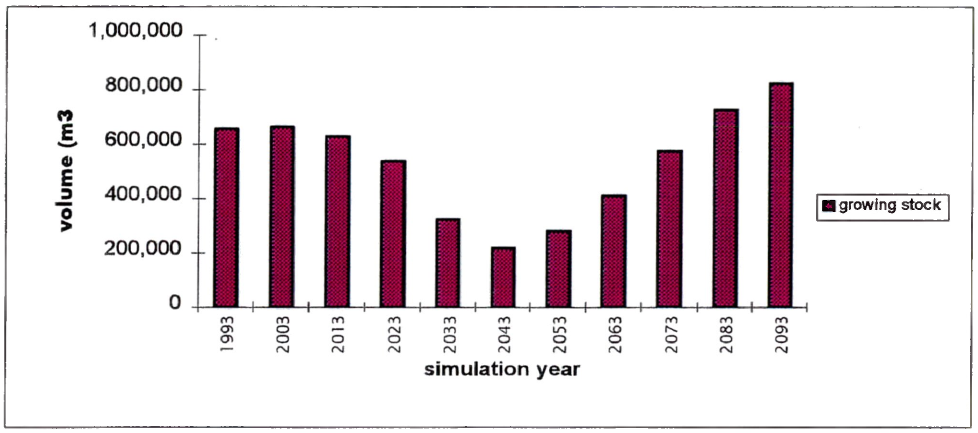


White pine

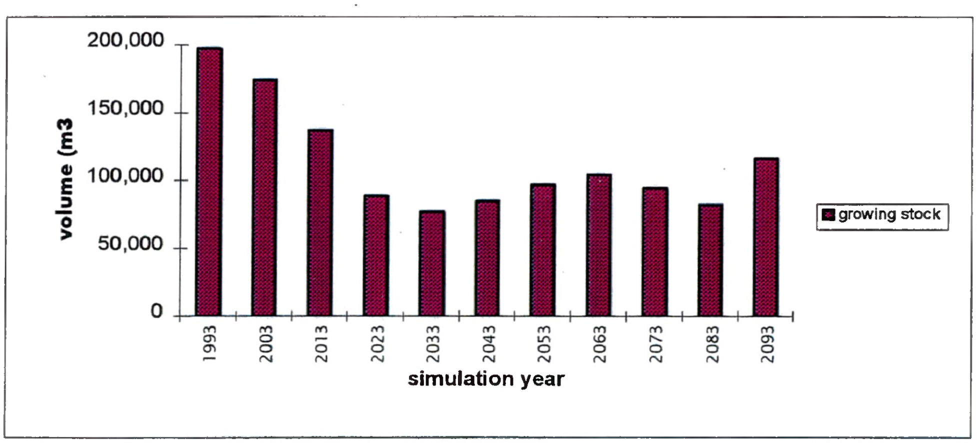
Figure 5.1 (a). Growing stock curves for black and white spruce, jack pine and white pine (No-Harvest Scenario).



Balsam fir



Poplar



White birch

Figure 5.1 (b). Growing stock curves for balsam fir, poplar, and white birch (No-Harvest Scenario).

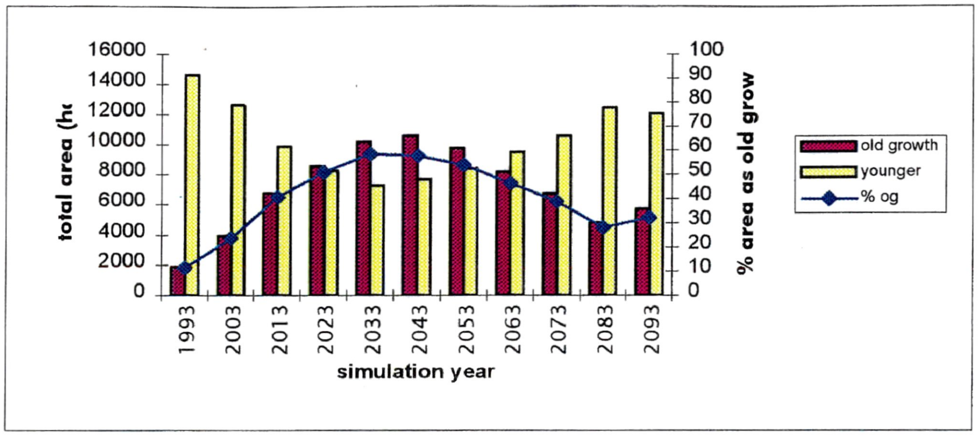
(Pw regenerates itself after 190 years only on site class X and 1), in combination with the limited area of the forest as Pw stands (87 ha), works to severely limit future growing stock volumes in this four-township sample of the Timmins Forest.

The balsam fir, poplar and white birch growing stock curves show significant fluctuations over time. Although sporadic, all growing stock values are sustainable for 100 years. The fluctuations in growing stock are controlled by the original age-class structure of these species. These curves show the cumulative forest-level effect of how the stands age over time, in the absence of disturbance, timber harvests and management interventions.

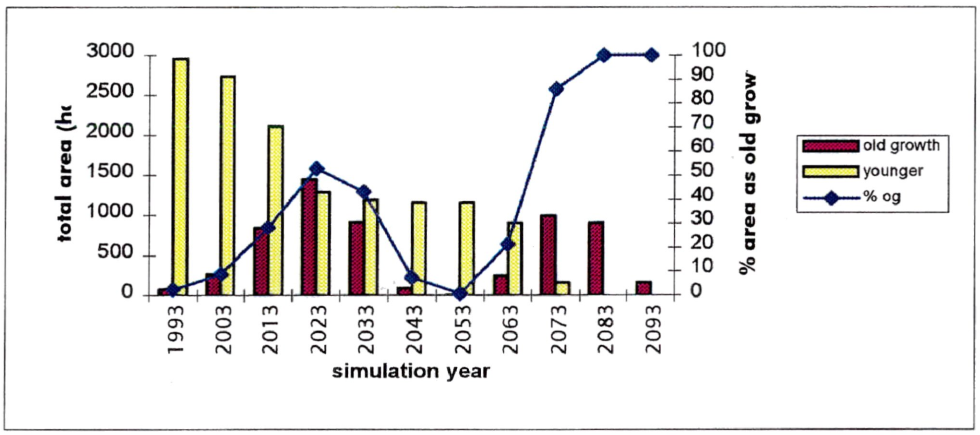
NO-HARVEST SCENARIO: Old Growth

The old-growth supply by species is variable, and dependent on the rules contained in the state table and the 1993 forest structure (Figure 5.2(a), (b)). In the analysis of old-growth area supply, black and white spruce are analyzed individually (only harvest levels are specified jointly).

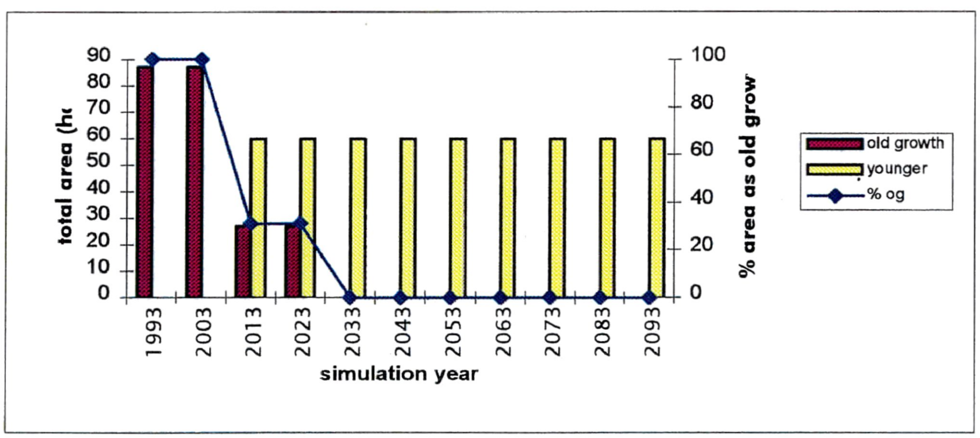
Black spruce old growth is predicted to fall to a minimum 11.5% by area during the 100-year simulation period. The peak of 58% occurs in the year 2033, when the majority of the Sb age classes are older than 130 years of age. The relationship between old-growth supply and stand age is clearly outlined; as the stands reach 130 plus



Black spruce

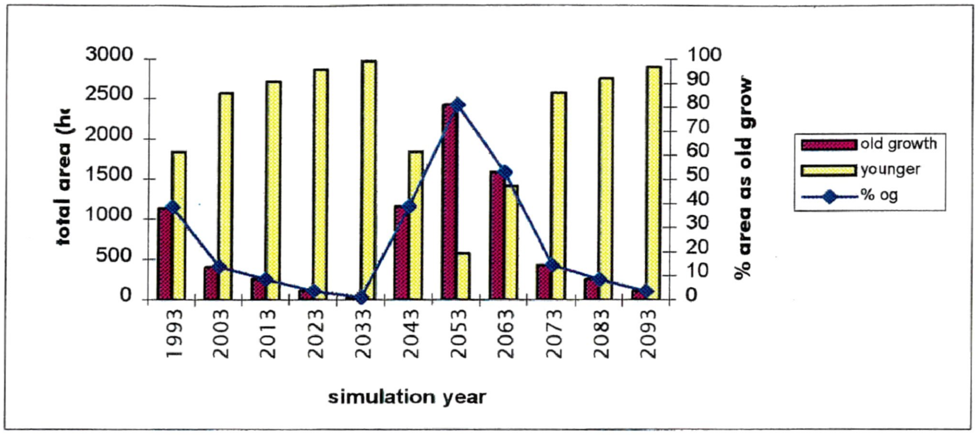


Jack pine

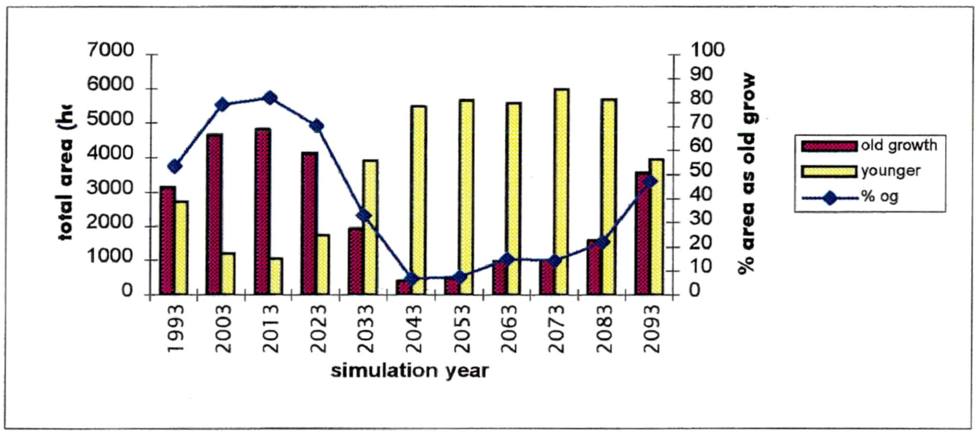


White pine

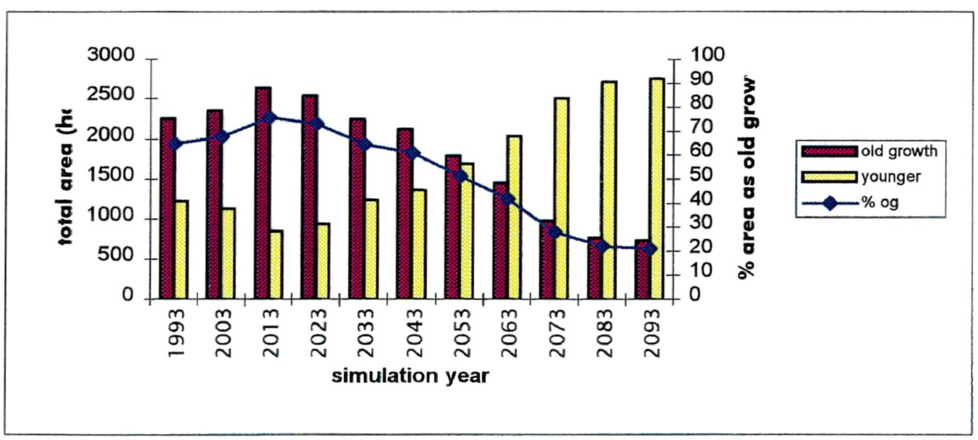
Figure 5.2 (a). Supply of old growth over time for black spruce, jack pine, and white pine (No-Harvest Scenario).



Balsam fir



Poplar



White birch

Figure 5.2 (b). Supply of old growth over time for balsam fir, poplar, and white birch (No-Harvest Scenario).

years of age, old growth increases in supply, especially on site classes 2 and 3. This supply decreases when the old-growth stands break up and return to the younger age classes. Black spruce's slow growth and longevity assures it to be the most elastic supplier of old growth.

As the growing stock of Pj decreases over time, the old-growth contribution varies from approximately 2% to 100%. This highly variable indicator is driven solely by the original age-class structure and state table rules. For example, as of 1993, approximately 48% of the species by area was 60-80 years of age, with a range of 1% to 28% in any other age class. As a result, when these age classes cycle through time, the old-growth supply fluctuates.

Although the supply fluctuates over time and may reach 100% during the last twenty years of simulation, the underlying pattern to observe is that, due to the lack of a disturbance mechanism in the state table, Pj will eventually be eliminated from the landscape in time. The per cent old-growth supply indicator thus loses its meaning when examined in the context of a rapidly decreasing Pj area. Hence, in order to keep Pj in a non-harvest forest, there must be a disturbance agent at work in the modeling process.

The growing stock of Pw decreases over time due to the decline and break up of the Pw stands. The supply of old growth follows a similar pattern. Ranging from 100% to 0% in the first fifty years of simulation, the supply of old growth is not sustainable (the scale of supply is less than 100 ha). Due to the length of time required to reach the old-growth state (140+ years), the old-growth supply does not increase from 0% for the last seventy years of simulation. When Pw on site class 1 reaches the age of 190+ years, it regenerates to mixed Pw and Bf stands. White pine on site class 2 regenerates to mixed Bf and Po, once stand age has reached 200 years. Hence, as a result of the original age-class structure, in which 100% of the Pw stands are at least 140 years of age, and 69% of the Pw area is site class 1 and 31% as site class 2, the old-growth supply decreases from 100 % of the landscape, to 31% of the landscape (2013), to 0% by the simulation year 2033.

The Pw state table rules assume that after stand break up occurs at 190 years, the old-growth component is replaced by advanced-regenerative mixed Pw stands of 35 years. If however, stand break up does not occur until much later (e.g., 250 years), then the old-growth supply indicator may be in serious error. Old-growth species such as Pw, which tend to garner more attention, especially from the general public, may need special attention to the designation of the old-growth age (this does not exclude the other boreal species)! This is also critical when Pw may be at the northern portion of its range in the Timmins Forest.

Similar to Pw, Bf and Po exhibit patterns of old growth during the simulation period that are dependent on the age-class structures and rules of succession. For Bf, almost 40% of the area is contained in the 60-80 year age class as of

1993. This dominant age class controls the pattern of old growth over time, for as it maintains stand age at 70+ years, the old-growth supply peaks. When these stands break up, the old-growth supply plummets (a budworm-driven age-class structure cycle). In addition, succession rules provide for new Bf stands that are mixed with black and white spruce, further limiting the area returning as Bf.

The Po old-growth supply also results from an uneven age-class structure. Approximately 67% of the Po area in 1993 belongs to the 60-80-year age class, a result of the severe fires which burned in the area during the early 1900's. This imbalance heavily skews the old-growth supply over the 100-year simulation period. In addition, once Po stands break up with age, they return as mixed Po and Sb/Bf stands, further reducing the Po area capable of reaching the Po old-growth age of 80+ years.

The response of the model to the dynamics of Po development seems realistic, considering the volatile nature of the initial age-class structure, the relatively "young" old-growth age, and the rapid volume gain/volume loss pattern exhibited in all site class-yield curve combinations.

The No-Harvest Scenario serves two main purposes: 1) it illustrates forest growth and decline on a species-by-species basis over time in the absence of management intervention, and 2) it assumes that forest behaviour is similar to species reactions at the field level. I would like to note that this assumption may or may not reflect on-the-ground reality. For species that perform to known growth patterns, the model serves its purpose. However, the limitations of the model (e.g., lack of natural catastrophic disturbance mechanisms) display weaknesses in the modeling process itself. All scenario comparisons, therefore, must be reviewed in light of the advantages and disadvantages unique to the chosen simulation model, in this case HSG. The No-Harvest Scenario is useful in illuminating these advantages and disadvantages prior to adding levels of detail found in subsequent simulation runs.

NO-REGENERATION SILVICULTURE SCENARIO: Growing Stock

The No-Regeneration Silviculture Scenario introduces a commercial harvest for Sb and Sw. If other species, such as Pj and Pw are present in the harvested Sb/Sw stands, they are also removed from the growing stock inventory. As with the No-Harvest Scenario, all regeneration is natural, including post-harvest treatment of Sb/Sw (e.g., extensive silviculture) (Appendix VII).

The establishment of a 14,000 m^3/yr Sb/Sw harvest automatically draws down the Sb/Sw growing stock over time by approximately 48%. A new sustainable growing stock level is maintained at the 505,000 m^3 level, with an approximate 10% increase in the last year of simulation over the No-Harvest Scenario.

As with the Pj growing stock levels in the No-Harvest Scenario, the growing stock decreases here to less than 40,000 m^3 in the final simulation year. Beyond the 100 years, the growing stock appears not to be sustainable. This trend confirms the need for disturbance across the landscape to perpetuate the presence of species such as jack pine. Harvested volume for Pj is a result of naturally-occurring Pj in harvested Sb/Sw stands.

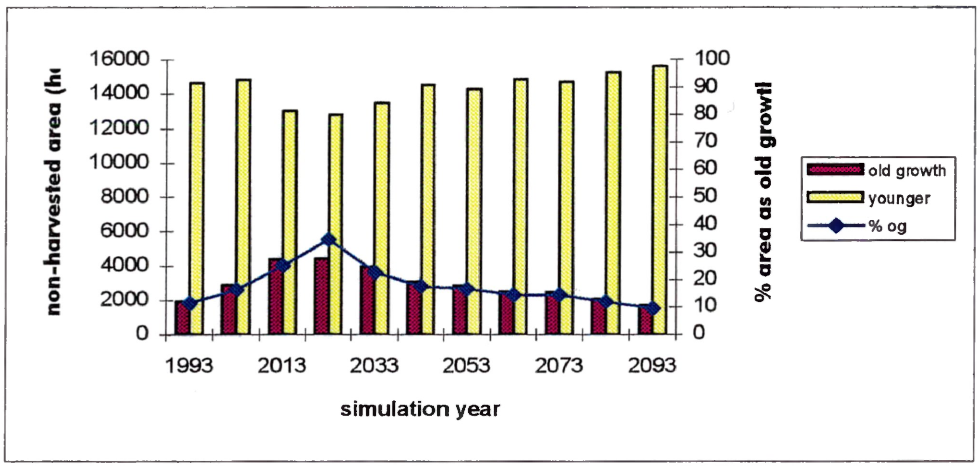
The harvested volume found in Pw is a result of the presence of Pw in harvested Sb/Sw stands. Growing stock levels decrease by approximately 55% to a sustainable level of approximately 16,000 m^3/yr for the last fifty years of simulation.

Growing stock levels for balsam fir, poplar, and white birch vary little from levels found in the No-Harvest Scenario. The curves exhibit minor amounts of growing stock depletion from within Sb/Sw stand harvests, and maintain the fluctuations derived from the 1993 age-class structure.

NO-REGENERATION SILVICULTURE SCENARIO: Old Growth

The introduction of a Sb/Sw harvest not only decreases the level of growing stock in the landscape, but also influences the supply of old-growth (Figure 5.3). The harvest rules target the elimination of the older age classes of Sb, and as a result, the Sb old-growth supply is significantly decreased over the duration of the simulation period. The maximum level of old growth decreases by 40% from

No-Harvest levels, to a new maximum of 34.8% of the landscape in the old-growth condition (down from 58.5%). The supply continues to decrease from the peak in the year 2023 to 9.7% in the year 2093 (a decrease of 70% from No-Harvest level of 32.2%). The overall effect of the Sb/Sw harvest is to reduce not only the amount of Sb/Sw old growth on the landscape, but also to narrow the range between the peaks and the lows.



Black spruce

Figure 5.3 Supply of old growth over time for black spruce (No-Regeneration Silviculture Scenario).

The Sw old-growth supply, while still maintained at zero for this scenario, is reinforced by the assumptions that define successional rules of the state table, such that when Sw stands break up, in combination with a Po content of greater than 30%, mixed species stands of Po and Sw regenerate. This reduction in Sw area further limits the hectares available to reach the old-growth state over time (Appendix VIII).

For Pj, Bf, and Bw, the introduction of a Sb/Sw harvest has minimal effect on their respective supplies of old growth. When HSG harvests only stands classified as Sb and Sw, stand subcomponents such as Pj, Bf and Bw may be removed through harvest. However, stands classified as Pj, Bf, and Bw will not be harvested for their Sb/Sw subcomponents, hence the minimal change in their respective old-growth supplies over time (Appendix VIII).

For Po however, the Sb/Sw harvest produces a decrease in the supply of Po old growth over time. In mixed Po/Sw stands, HSG schedules for harvest the Sb/Sw subcomponent, and as a result, decreases the frequency of older Po stands across the forest.

BENCHMARK SCENARIO: Growing Stock

To increase the harvest level from 14,000 m^3/yr, the harvesting algorithm was expanded to include Pj and Po. Basic and intensive silviculture was applied to the harvested areas through the use of the BASIC treatment table. This scenario was designed to model more realistically the harvest and regeneration patterns in a commercial forest and show the effects of conventional timber operations on old-growth supply (Appendix VIX).

In a trend similar to that of the No-Regeneration Silviculture Scenario, the growing stock for Sb and Sw decreased during the first 50 years of Sb/Sw harvests of, on average, 14,450 m^3/yr, to a minimum sustainable level of

502,500 m^3. In contrast, however, the introduction into the model of basic silviculture increased the growing stock approximately 37% to 690,000 m^3 in the last decade of simulation (2083-2093).

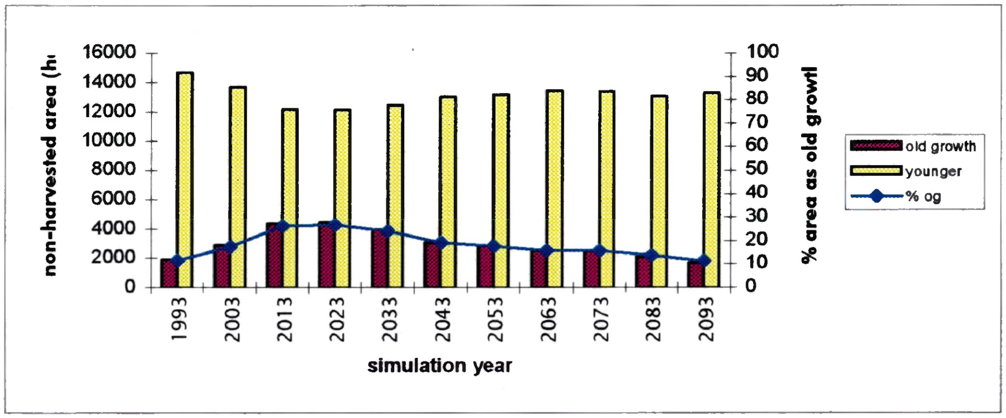
The Pj growing stock underwent a significant draw down as the Pj LRSY harvest of 5,000 m^3/yr was modelled. The first 50 years of simulation saw the growing stock decrease by approximately 58% to accommodate for the average harvest level of 5,800 m^3/yr. Pj growing stock was maintained at a sustainable level of approximately 131,000 m^3 for the remaining 50 years of simulation.

The effect of adding Pj and Po annual harvests in this scenario resulted in negligible change to the Pw, Bf and Bw growing stock levels. This indicates that the Sb/Sw, Pj and Po harvests were obtained from the landscape with minimal intrusion into Pw, Bf, and Bw stands.

The Po harvest averaged 6,050 m^3/yr. The effect of this harvest on growing stock was to reduce growing stock by approximately 18% over No-Regeneration Silviculture results.

BENCHMARK SCENARIO: Old Growth

The addition of Pj and Po harvests had little or no impact on the supply of Sb old growth. The peak of supply, occurring at 2023, with 34.8% old growth in the No-Silviculture Scenario, decreased by 8% to 26.8% in this scenario. This decrease was the maximum change; most differences between the two scenarios were in the 1-2% range (Figure 5.3 vs. Figure 5.4).

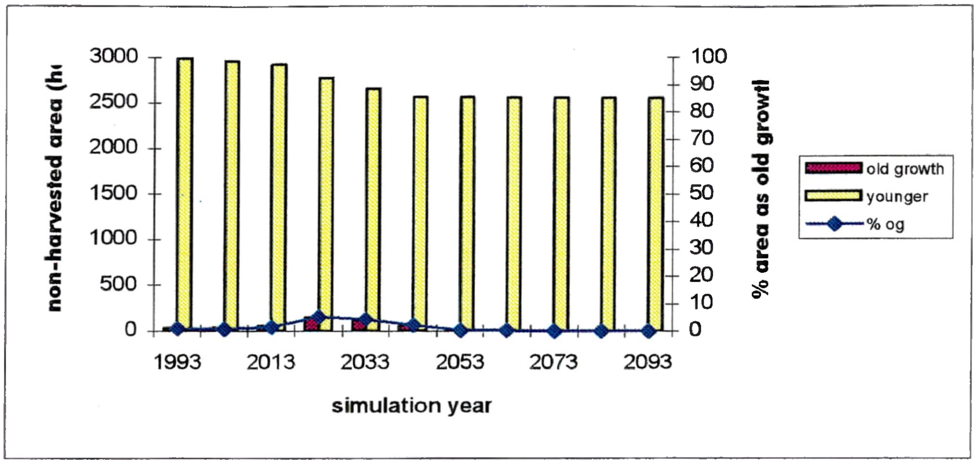


Black spruce

Figure 5.4 Supply of old growth over time for black spruce (Benchmark Scenario).

The establishment of a Pj LRSY of 5,000 m^3/yr had a deleterious impact on the supply of old growth (Figure 5.5). The supply decreased from a peak 85.4% of the landscape as Pj old growth to less than 6%. The first 20 and the last 30 years of simulation produced 0% to 1% of the landscape in the old-growth condition. The combination of a Pj LRSY and the reduction in Pj area due to the lack of an automated disturbance mechanism, virtually eliminates Pj old growth as a viable landscape component in this simulation scenario.

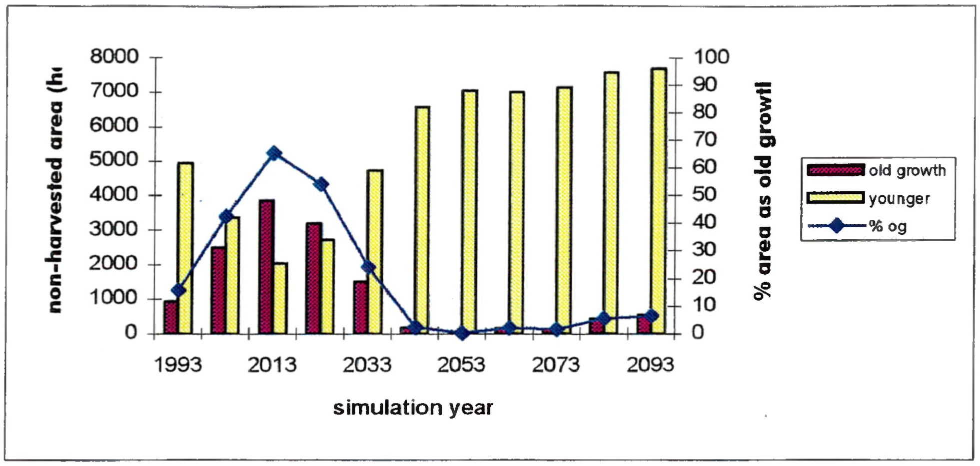
The Pw, Bf, and Bw supplies of old growth did not alter from the percentages found in the No-Silviculture Scenario.



Jack pine

Figure 5.5 Supply of old growth over time for jack pine (Benchmark Scenario).

As expected, the introduction of a Po harvest decreased the Po old-growth supply (Figure 5.6). The first 20-year peak decreased from approximately 56.5% of the landscape as Po old growth to 40%. The last 60 years decreased in supply from roughly 11% old growth to less than 4%. The Po supply of old growth in this scenario is not sustainable, as having less than 1% old growth (in the year 2053) constitutes a danger when natural disturbances may interrupt and eliminate the old-growth classes.



Poplar

Figure 5.6 Supply of old growth for poplar (Benchmark Scenario).

MAXIMUM-REGENERATION SILVICULTURE SCENARIO: Growing Stock

Using the growing stock and old-growth supply values from the Benchmark Scenario as a guide, the level of regeneration silviculture was increased such that every hectare harvested was also treated with silviculture. For Sb/Sw, this allowed a 21% increase in the average annual harvest (LRSY) from 14,445 m^3/yr to 17,479 m^3/yr. The shift to intensive management resulted in a decrease in growing stock: a 3% decrease in the first year of harvest, by 13% in 2033, and by a significant 54% in the year 2093 (Appendix X).

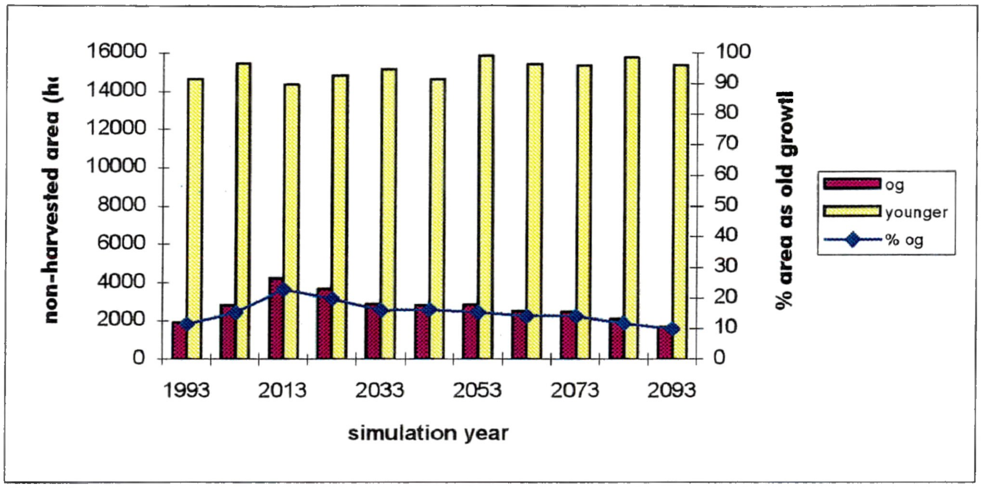
The Pj LRSY remained constant at 5,000 m^3/yr, as attempts to increase this limit caused the 10-year harvest level to exceed the available growing stock. Similar to the growing stock values obtained in the Benchmark Scenario, the Pw, Bf, and Bw growing stock curves did not change with the increase in the amount of area treated with silviculture.

Increased silviculture allowed the Po LRSY to be increased to 8,930 m3/yr (compared to 6,050 m3/yr, as found in the Benchmark Scenario). Like Sb/Sw, this increase in harvest volume came as a result of a decrease in the growing stock over time. The growing stock reductions averaged 5% in 2003, 25% in 2043, and 14.7% in 2093.

MAXIMUM-SILVICULTURE SCENARIO: Old Growth

Increasing the amount of silviculturally-treated area to match the harvest area increased harvest levels for target species such as Sb/Sw, Pj, and Po, and produced no change in growing stock for the non-harvested species (Pw, Bf, and Bw). However, it had quite a different effect on the provision of old growth in each of the species.

The supply of Sb old growth decreased by approximately 17% over the 100-year period as a result of intensive forest management. The pattern of old growth remained the same, increasing to a peak at 2013, and then gradually decreasing, but sustainable to the year 2093 (Figure 5.7).



Black spruce

Figure 5.7 Supply of old growth over time for black spruce (Maximum-Silviculture Scenario).

Jack pine old growth increased 2.5%, while Bf experienced a 2% reduction in supply. White birch exhibited no change in supply from the Benchmark Scenario. Poplar, like Sb, exhibited a 28% decrease in the percentage of old growth on the landscape from 1993 to 2093. This decrease was caused by the increased silviculture which allowed the Po LRSY to be increased to 8,930 m^3/yr, (compared to 6,050 m^3/yr - Benchmark Scenario), at the expense of Po old growth (Appendix XI).

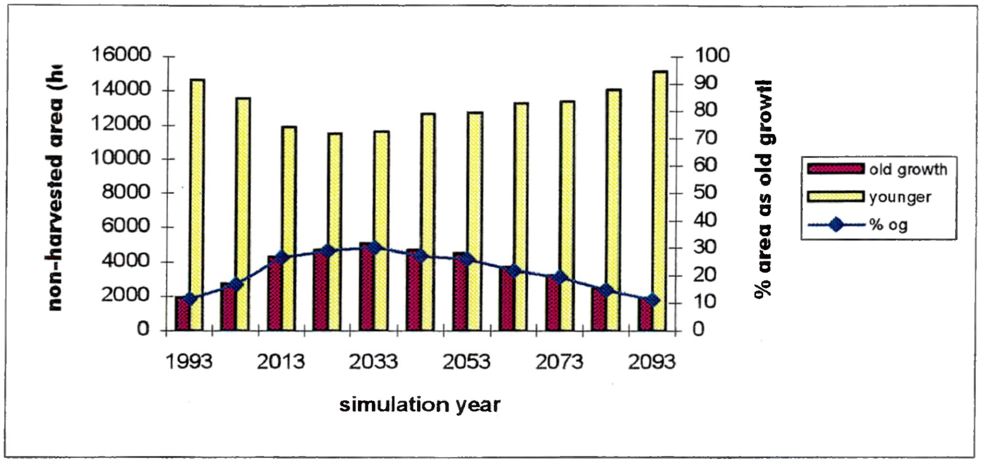
The overall effect of changing the management regime to intensive forest management was to increases timber supply at the cost of old growth. For species that were ignored in the harvesting algorithm, little or no change resulted.

PAUSE-YIELD-CURVE SCENARIO: Growing Stock

The Pause-Yield-Curve Scenario provided windows of opportunity in which stands in the old-growth condition would be protected from harvesting for a 20-30 year time period. At the end of the old-growth window, the stands once more became eligible for harvest. This scenario changes management focus from the production of utilitarian landscape benefits to include a conservationist perspective. Decreases in growing stock due to the use of old-growth windows are artefacts of the modelling process, and do not reflect reality at the stand level. As a result, there are no growing stock discussions to follow in this section.

PAUSE-YIELD-CURVE SCENARIO: Old Growth

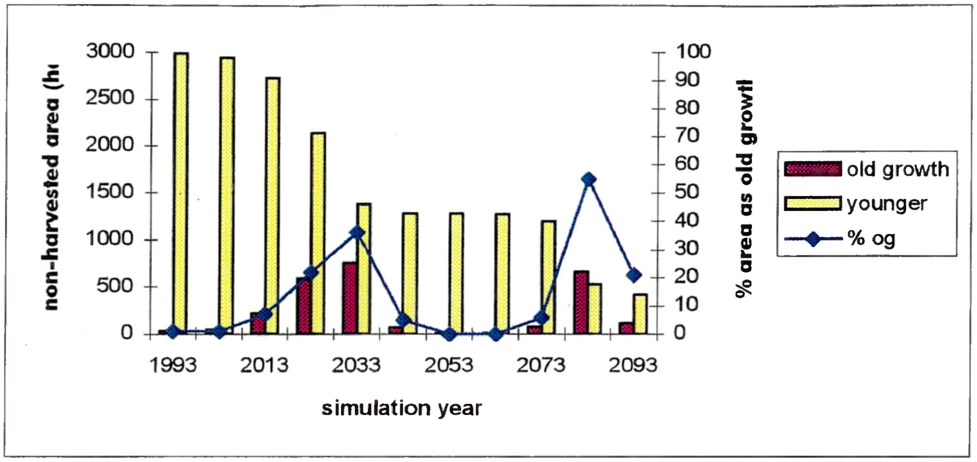
As expected, the use of the old-growth window produced positive results for Sb old-growth supply. Although this scenario exhibits a similar pattern when compared to the Benchmark run, the Sb old-growth supply increased a significant 17.6% (Figure 5.8). The window had no effect on Sw - the supply of old growth remained at zero.



Black spruce

Figure 5.8 Supply of old growth over time in black spruce (Pause-Yield-Curve Scenario).

The most significant increase with the use of the simulated old-growth window occurred in Pj; ranging from 22% of the landscape in the old-growth condition (in 2033) to 36% (in 2083). As can be observed in Figure 5.9, lows of zero (2053-2063) to less than 1% (1993-2003) occurred between the peaks. For disturbance-driven species such as Pj, the delaying of harvests beyond conventional economic rotation ages (modelled through the use of old-growth windows) may be the only viable source of old growth over time. This may be the case, even with a highly volatile old-growth supply, as influenced by the original age-class structure of the species.



Jack pine

Figure 5.9 Supply of old growth over time in jack pine (Pause-Yield-Curve Scenario).

Due to the advanced age at which Pw becomes classified as old growth (140+ years), and the original age-class structure of the species, the use of an old-growth window has no effect on the supply of Pw old growth in this simulation.

In pure Bf stands, the old-growth window has no effect on the Bf old-growth supply, as Bf volume is not targeted. However, when Bf reaches 80 years of age on site classes 1,2, and 3, and 90 years of age on site class 4, former pure Bf stands revert to mixed Bf (70%) and Sb/Sw (30%) stands. If the Sb/Sw harvest quota cannot be satisfied from stands classified as Sb/Sw, then the model seeks to harvest Sb/Sw from any stands in which Sb/Sw occurs, such as mixed Bf/Sb/Sw stands. Hence, the minimal decrease to the Bf old-growth supply of 2.4% on average, over 100 years (compared to Benchmark Scenario).

In Po, the use of a 20-year old-growth reserve window increases the supply of old growth by almost 13%. This increase comes at the expense of the harvest volume, which decreased by 61% over the simulation period. Similar to Po, the Bw old growth supply increases with the imposition of an old-growth reserve window. On average, 8.8% more of the Bw landscape is found in the old-growth condition (compared to Benchmark Scenario).

CONCENTRATED-SILVICULTURE SCENARIO: Growing Stock

The aim of changing management focus from basic to intensive silviculture is to increase harvest and growing stock levels, but focus the silviculture on Sb site class X, 1, and 2, Sw X, 1, and 2, and Pj, X, 1, and 2. In this scenario, the Sb/Sw harvest level was increased for the last 30 years of simulation, Pj and Po harvests stayed constant (e.g., Benchmark levels) (Appendix XII).

For Sb/Sw, concentrating silviculture on the site class X, 1, and 2 resulted in a forecasted 72% increase in harvest level: from 14,000 m^3/yr to a sustainable 24,024 m^3/yr for the last 30 years of simulation. This increase is a result of the harvested stands regenerating according to the managed yield curves (Appendix VI). The impact on growing stock was limited to a 2.4% decrease over the last 60 years of simulation (2033-2093).

The use of intensive silviculture on harvested Pj stands benefited both growing stock and subsequent harvest levels. As the intensively-regenerated stands grew and became contributors to the annual harvest, the average harvest level rose approximately 4%. This increase resulted from the harvest obtaining more volume per hectare due to the conversion of stand succession from growing along normal yield curves to intensive yield curves. The yield curves for intensively-managed stands predict significantly higher volumes per unit time than do the normal yield curves (Appendix VI).

The concentrated-silviculture program increased the average growing stock value from 185,030 m^3/yr to 314,400 m^3/yr, an increase of approximately 70%. As the growing stock decreases with the first 50 years of harvesting, the minimum value for this scenario produced 18% more volume than the equivalent Benchmark level. In addition, the growing stock for the last 50 years, including the elevated harvest levels, rose by 64% over Benchmark levels.

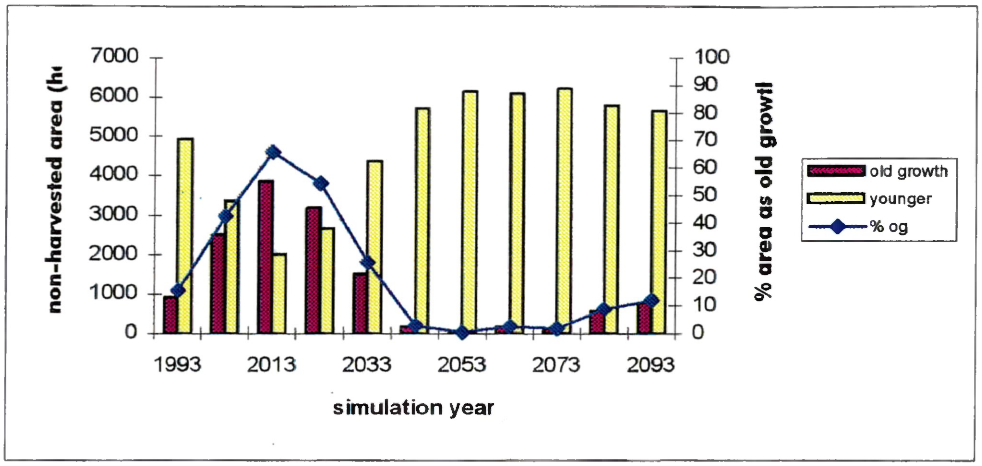
For Pw, Bf, and Bw, the use of an intensive silviculture program did not alter growing stock and incidental harvest levels from Benchmark levels: harvested Bw, Pw and Bf stands are subject to extensive silviculture only (Appendix II).

For Po, the use of intensive silviculture on Sb, Sw and Pj harvested sites is detrimental to future forecasts of Po growing stock and harvest levels. According to succession assumptions employed in these scenarios, basic silviculture on Sb/Sw/Pj sites results in a significant portion of the new stand regenerating to Po species. However, under intensive silviculture, only Sb, Sw, or Pj regenerates with no Po colonization. Hence, the almost 8% decrease in growing stock over the 100-year simulation period. The Po harvest is not significantly affected by the program of intensive silviculture, decreasing on average by 0.5%.

CONCENTRATED-SILVICULTURE SCENARIO: Old Growth

The impact of intensive silviculture on old-growth supply varies by species. For Sb, a decrease of 4% in old-growth supply over the 100 years resulted (compared to Benchmark Scenario). For Pj, there was negligible impact on old-growth supply with the introduction of intensive silvicultural practices. For both the Benchmark and Concentrated-Silviculture Scenarios, the average Pj old-growth component remained constant at 1.4%. Balsam fir and white birch old-growth levels did not change with the use of intensive silviculture from Benchmark levels.

The most significant change in old-growth supply occurred in Po (Figure 5.10). Over the 100 years of simulation, on average, Po old-growth supply was 22% less than the Benchmark Scenario (Figure 5.6 vs. 5.10). This decrease resulted from the increased silviculture on Sb/Sw, and Pj sites precluding Po as a regenerative stand component.



Poplar

Figure 5.10 Supply of old growth over time for poplar (Concentrated-Silviculture Scenario).

The use of intensive silviculture to increase harvest levels was most effective in species where harvested stands were assumed to grow along high-yielding managed yield curves. This strategy not only increased the volume per unit time, but also eliminated the presence of secondary species' volumes in regenerating stands. For example, with Sb, the use of intensive silviculture increased both m^3/ha and percentage of desired species.

The elimination of stand conversion from Sb to Po significantly reduced the level of Po old growth on the landscape. For Pj, intensive silviculture significantly increased growing stock levels, but did not affect the supply of old growth.

SCENARIO COMPARISON: GROWING STOCK AND HARVEST VOLUME

In further analysis, the LRSY's for the harvested species Sb/Sw, Pj, and Po, and the growing stock levels for Pw, Bf and Bw, for all six simulation scenarios were compared against each other (Appendix XIII).

For black and white spruce, the minimum LRSY averaged slightly above 10,500 m^3/yr (Pause-Yield-Curve Scenario) to roughly 18,100 m^3/yr (Concentrated-Silviculture Scenario) (Appendix XIII). All six runs, with the exception of intensive silviculture, produced harvests in a relatively narrow range. This range was defined by initial age-class structures, assumptions of successional development, the harvest scheduling policy (e.g., Sb/Sw harvests from other species stands), and the intensity of silviculture (e.g., basic versus extensive).

Long-run sustained yields for jack pine also exhibited a fairly narrow range of values (Appendix XIII). This range was limited not only by initial age-class structure, successional rules and a relatively limited area, but also by the behaviour of Pj in the absence of disturbance. The simulation model was unsuited for generating natural disturbances such as fire, windthrow or insect infestation, jack pine regeneration, and subsequently LRSYs, are restricted in scope. The Pause-Yield-Curve Scenario produced the least amount of harvest volume over the simulation period. The impact of the old-growth window on Pj was significant.

For poplar, the Maximum-Regeneration Silviculture Scenario provided the highest level of harvest volume over time (Appendix XIII). As found in Pj, the lowest harvest level occurred under the implementation of the Pause-Yield Curve Scenario. The Benchmark and Concentrated-Silviculture scenarios produced similar results for the first 60 years, comprising the middle ground between the Pause-Yield-Curve and Maximum-Regeneration Silviculture scenarios.

For white pine, the six simulations produced similar results, with variations in growing stock arising from differences in incidental harvests (Appendix XIII). The lowest level of Balsam fir growing stock was produced under the management of the Pause-Yield-Curve Scenario. The remaining simulation scenarios produced similar amounts of volume over the landscape. White birch growing stock values exhibited patterns similar to balsam fir; all scenarios were relatively similar, with the exception of the Pause-Yield-Curve Scenario.

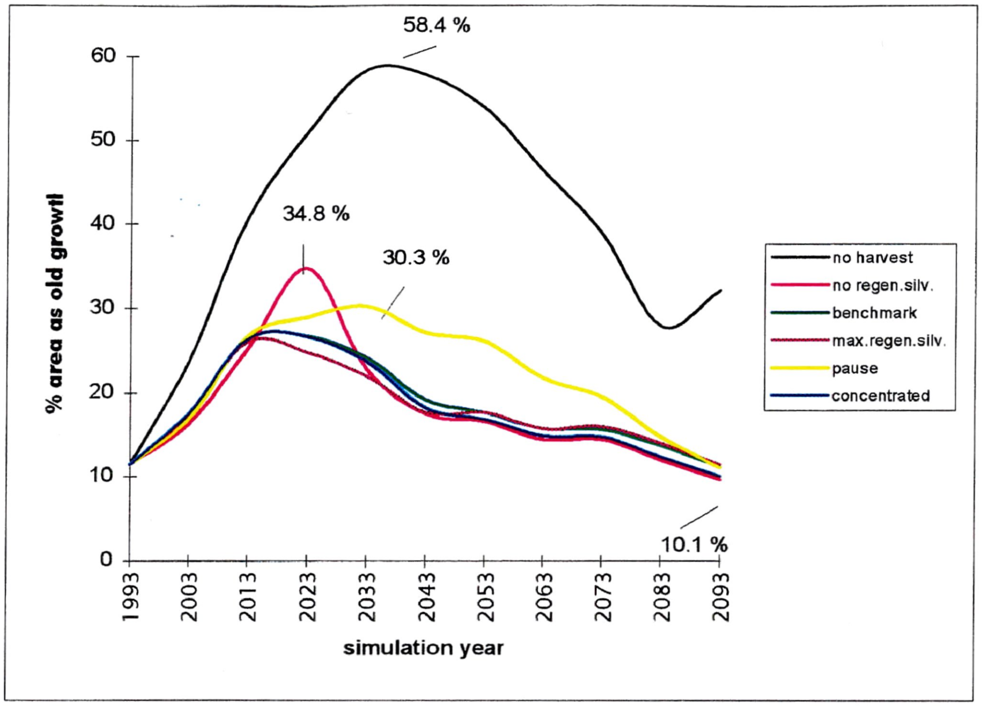
SCENARIO COMPARISON: OLD GROWTH

As with the comparison for LRSYs and growing stock levels, Figure 5.11(a),(b), and (c) illustrates the different old-growth supply results achieved between the simulation scenarios. With Sb, the best option for providing relatively high levels of old-growth on the landscape is the No-Harvest run. The remaining five scenarios produce significantly less old growth, and within these five, the Pause-Yield Curve Scenario maximises supply over time. When elevated harvest levels are used in conjunction with intensive silviculture, there is no benefit to the old-growth supply.

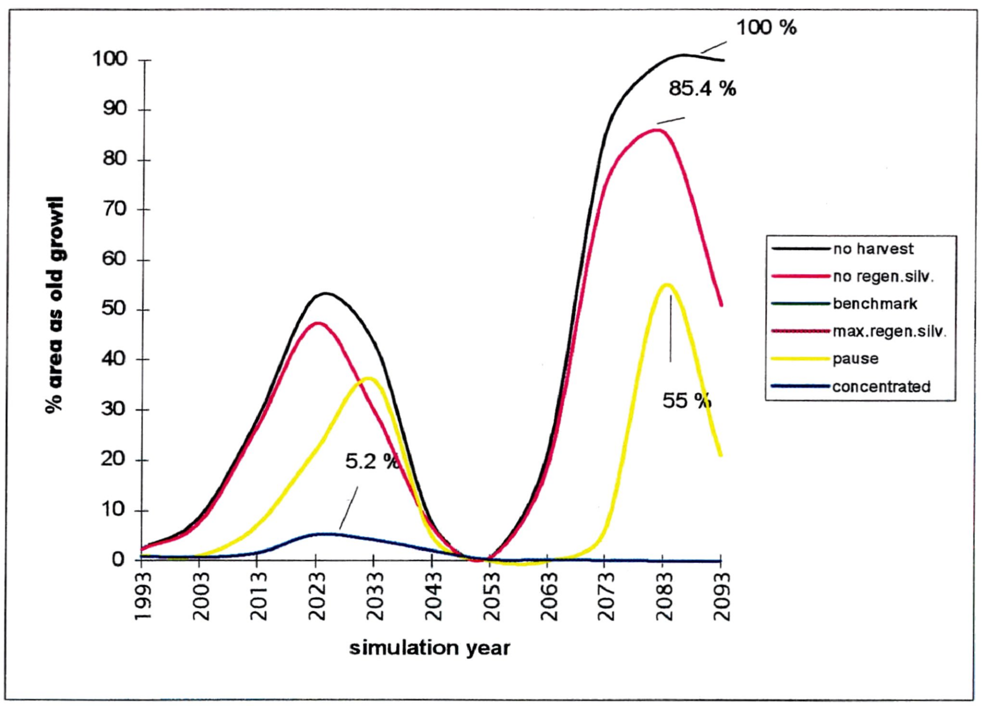
The best alternative for providing Pj old growth across the landscape in this study is the No-Harvest Scenario. However, when trying to balance the forest basket of benefits, this option becomes restrictive. The next highest provider of old growth is the No-Regeneration Silviculture Scenario. Again, this option may not be reflective of a management program designed to provide more than one benefit. The least effective run for providing Pj old growth across the landscape is the Concentrated-Silviculture scenario, as the harvest algorithm obtains more volume per hectare (due to the stands now tracking along the managed yield curves), reduces stand age at break up, and subsequently reduces the number of stands reaching the old-growth condition.

In the case of Pw old growth, all six scenarios produced identical amounts (though there is so little Pw, this is a weak test). This pattern of supply shows the relationship between the original age-class structure of Pw (in 1993), and the great age required to be reached prior to be declared in the old-growth condition (140+ years). Due to the limited supply of hectares occupied by Pw, and the fact that the old-growth age is 40% greater than the total length of the simulation period, this species does not get a chance to have stands reach the old-growth condition after the first 30 years (1993-2023).

Similar to Pw, Bf old growth is not responsive to the range of management regimes that were tested due to its short life cycle and relative dependence on automated disturbances (such as budworm infestations). As expected, the maximum proportion of old growth is achieved with the implementation of the

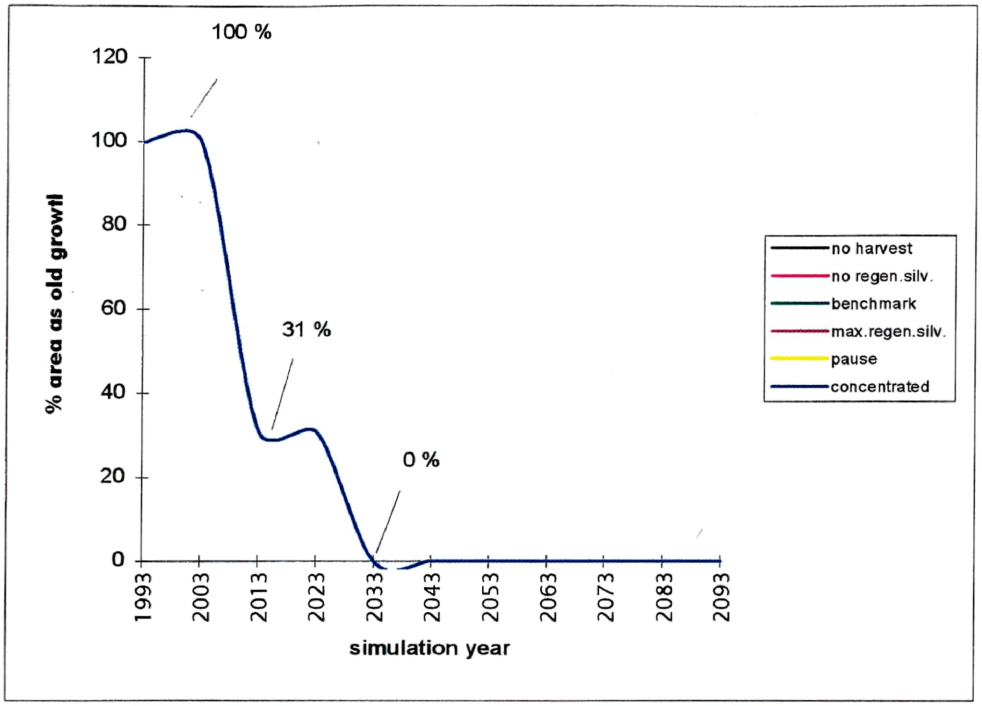


Black spruce

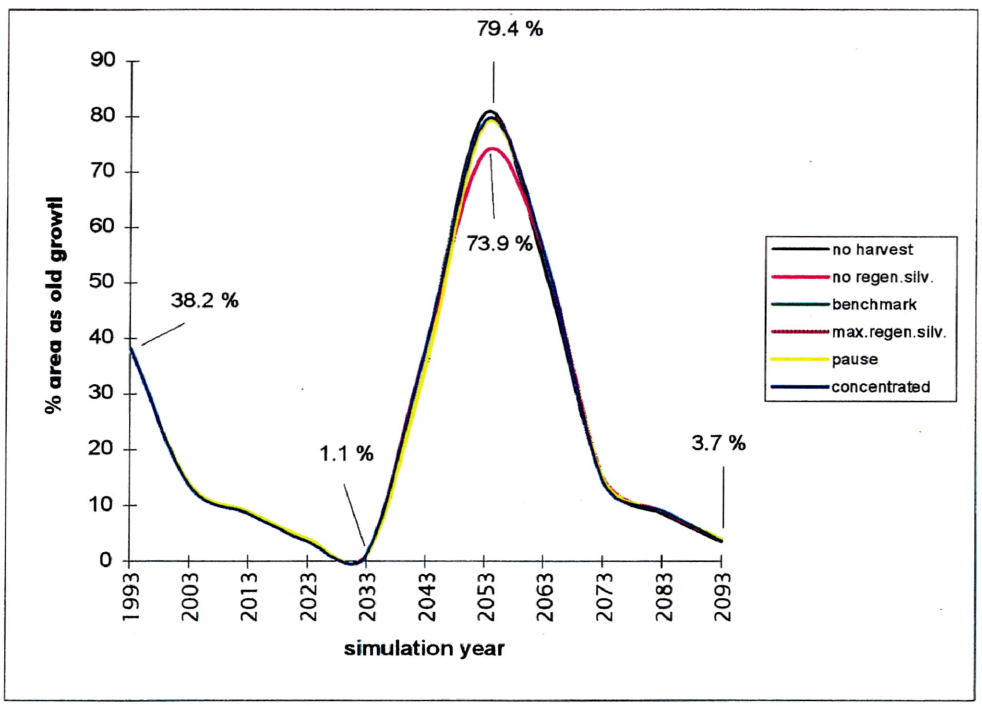


Jack pine

Figure 5.11(a) Percentage of the landscape in the old-growth condition: a comparison between simulation scenarios for black spruce and jack pine.

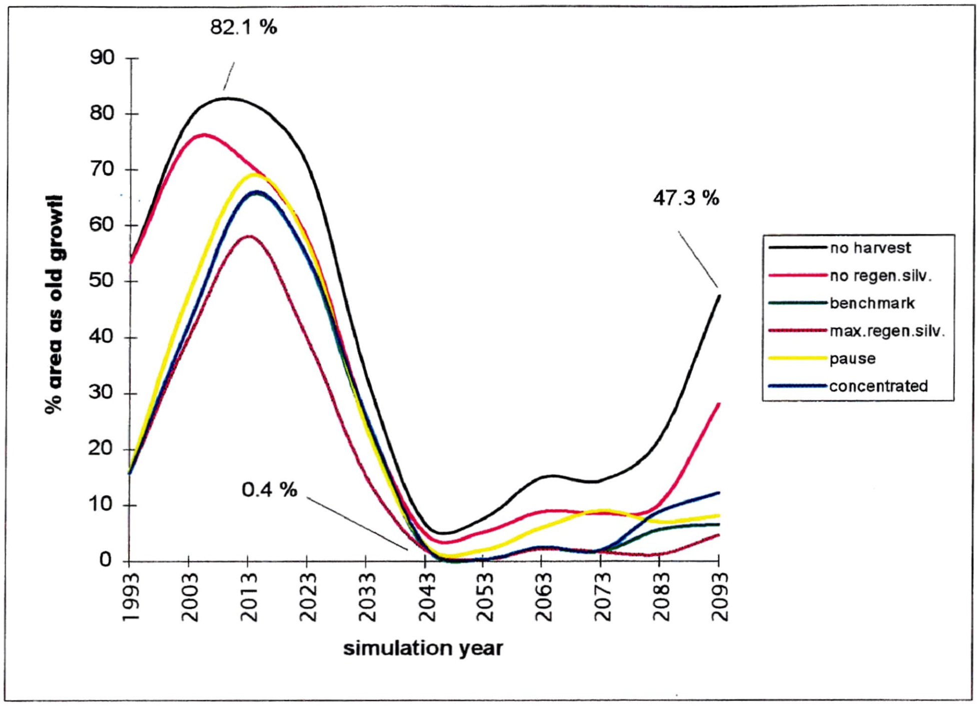


White pine

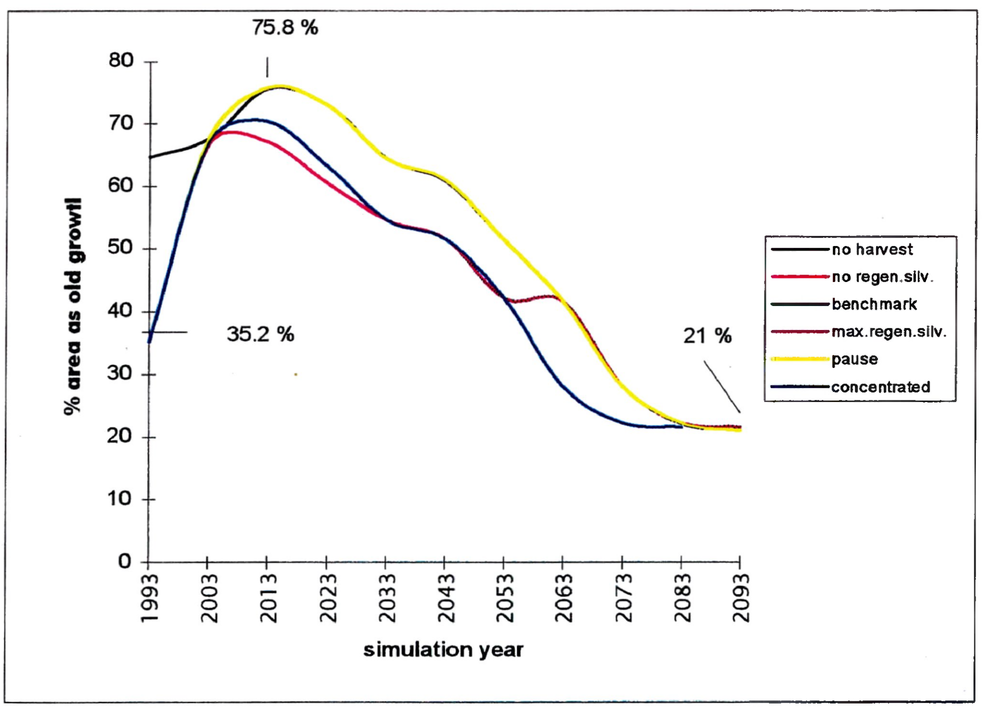


Balsam fir

Figure 5.11(b) Percentage of the landscape in the old-growth condition: a comparison between simulation scenarios for white pine and balsam fir.



Poplar



White birch

Figure 5.11(c) Percentage of the landscape in the old-growth condition: a comparison between simulation scenarios for poplar and white birch.

No-Harvest Scenario. For species not scheduled for harvest, but in which slight incidental harvests may occur with minimal growing stock disruption, this option may be useful when trying to fulfil old-growth objectives at the landscape level.

As with preceding species, the No-Harvest Scenario provides the best alternative for increasing the supply of old growth across the landscape for both Po and Bw. Variations in supply for Po are relatively restricted and are reflective of the 1993 age-class structure as it cycles through the 100 years, with and without scheduled harvests. The minimum values for Po old growth occur not in the Concentrated-Silviculture run, but the Maximum-Regeneration Silviculture Scenario, where the Po LRSY is highest and stand conversion from Sb to Po is minimal.

A maximum old-growth supply level of almost 76% to a minimum 21% characterizes Bw. Contained within a relatively narrow supply range, most simulation scenarios produce comparable results. In general, the Concentrated-Silviculture Scenario produces the least amount of old growth while simultaneously pushing the Bw growing stock levels to their maximum.

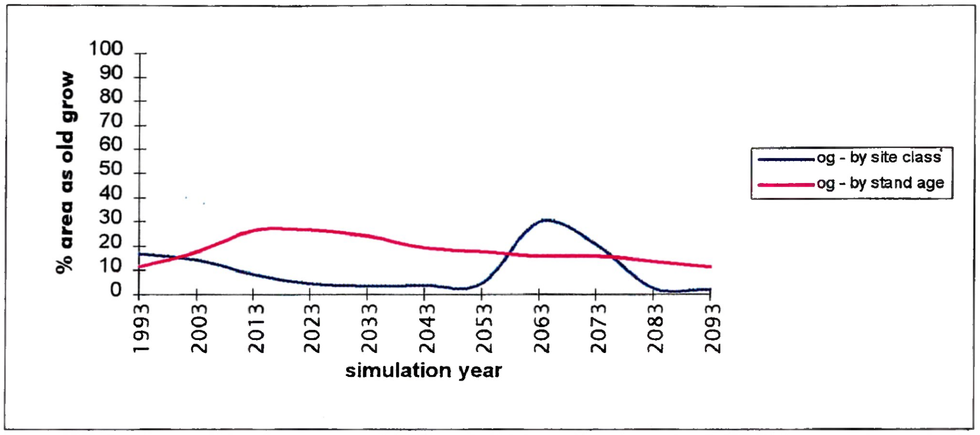
UNDER THE MICROSCOPE

For practical purposes, one common indicator of the old-growth condition (e.g., age) for each species was used in previous analyses. To refine that indicator and perhaps bring it more in line with the thinking of creating old-growth indexes, the monitored indicator of the old-growth condition was calibrated to each yield curve/site class combination for each species (Table 4.3). This approach was designed to allow for variation in the rate of development of old-growth structures by site class. The Benchmark Scenario was reassessed as to its provision of old growth per species; the results are presented below.

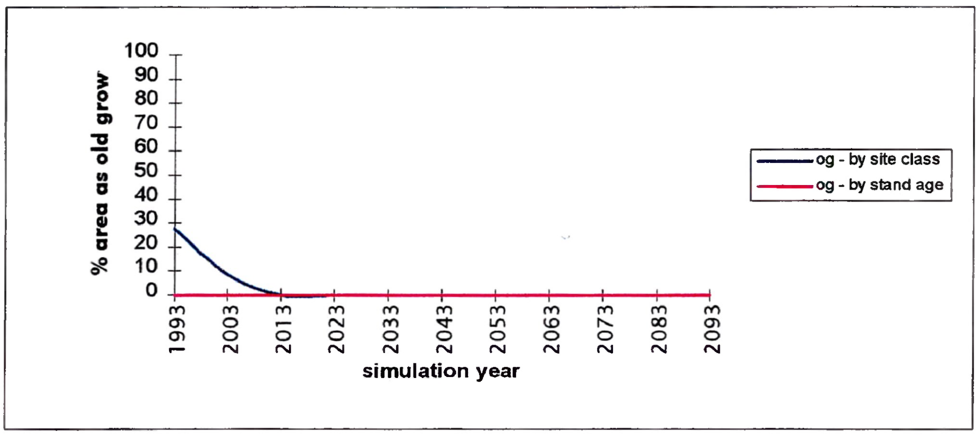
Benchmark Scenario

For Sb, the refinement of the old-growth age significantly decreases the supply of old growth across the landscape (by 45% on average). A review of the Sb yield curves reveals that the explanation lies in the poorer site classes (3 and 4). For these site classes, the Brennan (1991) old-growth age of 130+ years is 40 years sooner than the refined old-growth age (170+ years), thus an additional 40-year period exists in which stands in these age classes are not considered to be old growth. Following this pattern, the amount of old growth calculated by HSG is reduced (Figure 5.12 (a),(b), (c)).

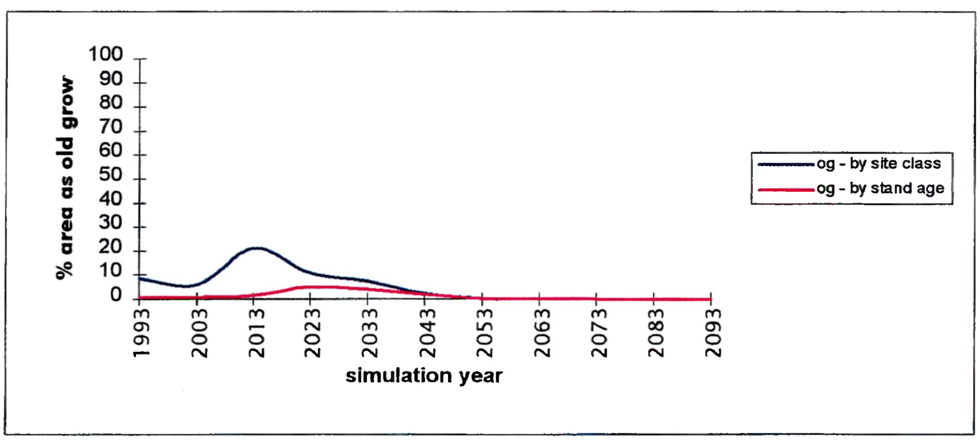
The opposite effect occurs in Sw. The refinement of the old-growth age permits additional area that exists on site classes X, 1, and 2 to be included in the old-growth class. Note, however, that although the old-growth supply increases from 0% to an average of 18% for the first twenty years of simulation, the old-growth supply decreases once again to 0% for the last 80 years. When species such as



Black spruce

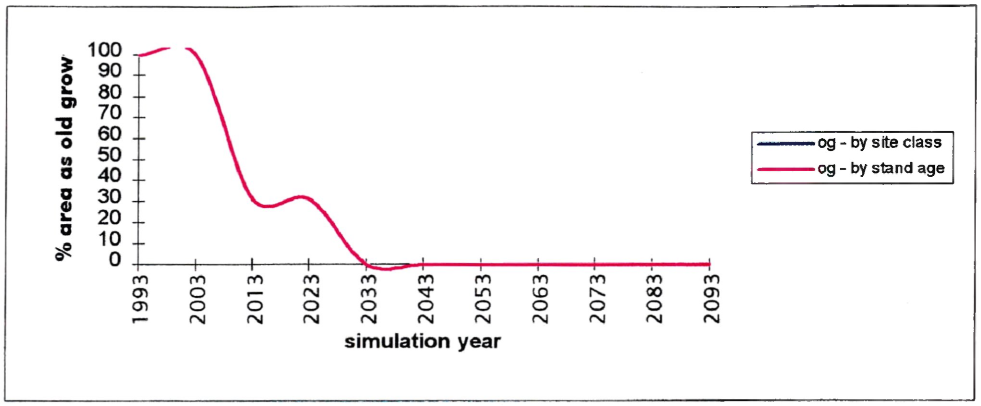


White spruce

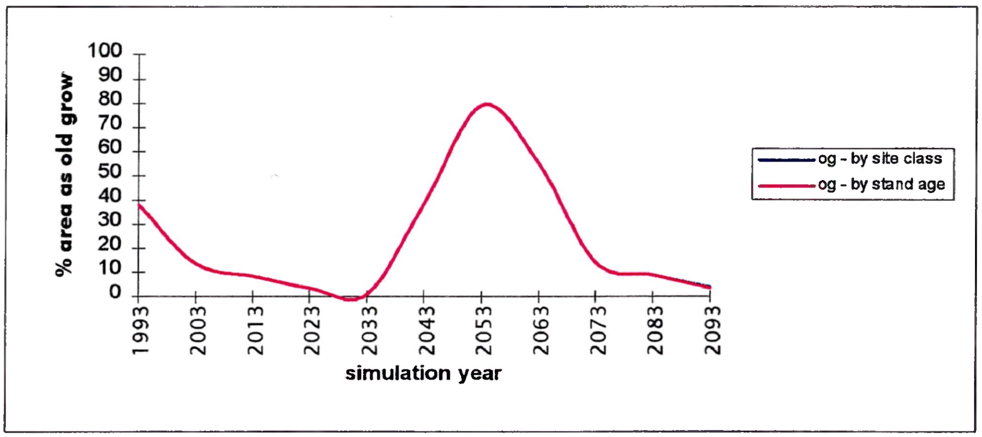


Jack pine

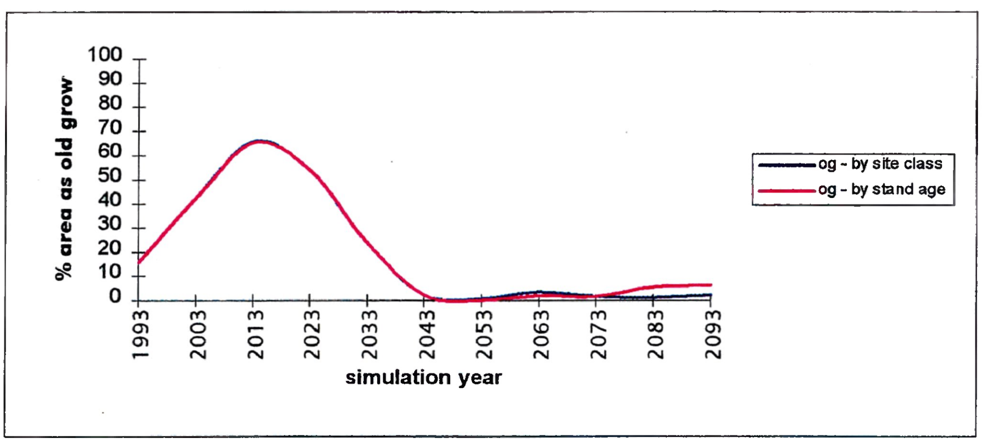
Figure 5.12 (a) Percentage of the landscape in the old-growth condition: a comparison between old-growth indicators for black spruce, white spruce, and jack pine (Benchmark Scenario).



White pine

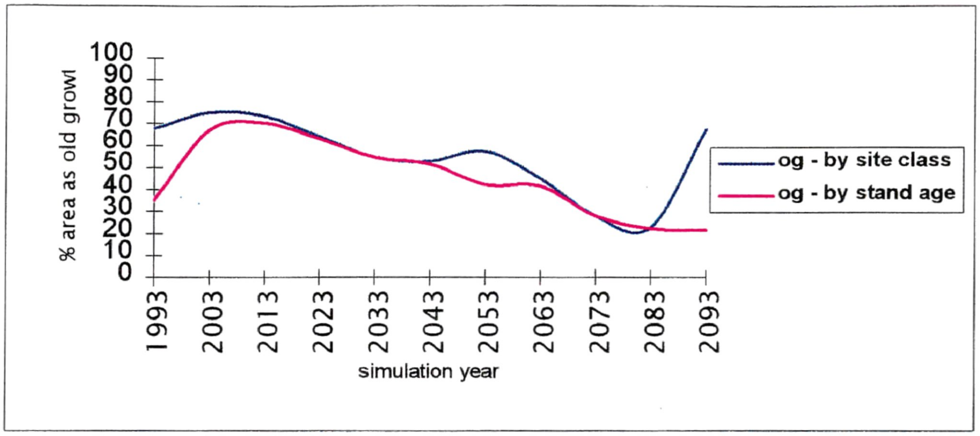


Balsam fir



Poplar

Figure 5.12 (b) Percentage of the landscape in the old-growth condition: a comparison between old-growth indicators for white pine, balsam fir, and poplar (Benchmark Scenario).



White birch

Figure 5.12 (c) Percentage of the landscape in the old-growth condition: a comparison between old-growth indicators for the white birch working group (Benchmark Scenario).

Sw are limited in area (401 ha out of a possible 32,385 ha), even the most refined old-growth criteria are only weakly tested.

For Pj, the refined indicator age increased the Pj old-growth supply over the landscape (from an average of 1.4% to 5.2% for the first 50 years). The last 50 years under both interpretations of the old-growth criteria produced insignificant amount of old growth (usually less than 1/2 of 1%).

The arbitrary use of 140+ years of age as the old-growth indicator for Pw was maintained in this exercise. To choose a point ten years past the peak of the yield curve would have pushed the old-growth age to 210 years of age; this was deemed to be not an accurate reflection of the dynamics of the species given the current level of information on old-growth ages for the boreal forest.

The Bf old-growth supply did not change with the refinement in the old-growth indicator. The change in the indicator for this species affected only site class X (moving the old-growth age from 70 to 60 years). In Po, little change occurred in the old-growth supply as a result of refining the age criteria. With the exception of site class X, where the ages remained the same, site classes 1 through 4 old-growth ages were adjusted to be ten years older than the general age factor. As expected, the refined old-growth age indicated fewer hectares of Po old growth on the landscape than did the general old-growth age of 80+ years.

The Bf old-growth supply did not change with the refinement in the old-growth indicator. The change in the indicator for this species affected only site class X (moving the old-growth age from 70 to 60 years). In Po, little change occurred in the old-growth supply as a result of refining the age criteria. With the exception of site class X, where the ages remained the same, site classes 1 through 4 old-growth ages were adjusted to be ten years older than the general age factor. As expected, the refined old-growth age indicated fewer hectares of Po old growth on the landscape than did the general old-growth age of 80+ years.

The predicted old-growth supply for Bw increased with the use of the refined old-growth age. By decreasing the old-growth age factor from 90 to 80 years across all site classes, the quantity of old growth increased significantly; 92% in 1993, 36% in 2053, and a very significant 214% in 2093.

Benchmark Summary

The effect of refining the old-growth age indicator to match site characteristics is intended to provide a more accurate accounting of the old-growth inventory by species. In some cases, the use of the refined indicator reveals a decrease (e.g., Sb); insignificant change (e.g., Pw, Bf, Pj, Po); or a significant increase (e.g., Sw, Bw) compared to the Brennan (1991) ages. For species that previously did not contain old-growth stands, this refinement illustrates the sensitivity of the old-growth forecasts to the definition of the indicator. This point is critical when trying to create an old-growth inventory across the landscape.

CHAPTER SIX: CONCLUSIONS

Six simulation scenarios were modelled for 32,385 ha of the Timmins Forest. The first one, the No-Harvest Scenario, did not have a scheduled harvest for any of the species, so that basic patterns of predicted forest stand succession could be displayed over the 100-year simulation period (1993-2003). The No-Regeneration Silviculture Scenario introduced an annual harvest for black and white spruce with natural regeneration, and was compared against the No-Harvest Scenario to track the effect of harvest on the evolution of old-growth supply.

The Benchmark Scenario was used as the guideline against which the remaining three scenarios were assessed; commercial harvest levels (LRSYs) for jack pine and poplar were established, and results compared to the No-Harvest Scenario. Old-growth supply for black and white spruce, jack pine and poplar, with basic silviculture was contrasted to the No-Regeneration Silviculture Scenario.

The Maximum-Regeneration Silviculture Scenario examined the impact of elevated LRSYs and old growth when all treatable regenerating areas were treated with basic silviculture. The Pause-Yield-Curve Scenario introduced the concept of old-growth windows, where rotation ages were extended to exclude harvests in stands of certain ages. These old-growth windows were used to measure the impact of old-growth preservation on commercial timber activities.

The Concentrated-Silviculture Scenario changed the management focus from basic to intensive silviculture, with the intent of showing the impact of an intensified silvicultural program on old-growth supply .

Indicators used to analyse timber and old-growth supply (two benefits of many that may be obtained from the forest landscape basket) from the simulation scenarios included growing stock, harvest levels and number of hectares of forest found in the old-growth condition. Initially, the old-growth indicators were based on current information regarding Boreal/Great Lakes-St. Lawrence species, but were later refined to reflect differences in site quality.

To further examine the comparisons between simulation scenarios, the best- and worst-case scenarios for each species are presented in Table 6.1.

For the all of the boreal species examined in this study, the best old-growth option is the No-Harvest Scenario. This scenario maximises the old-growth supply across the landscape, across all species. However, the assumption that all further timber harvest activities are to be stopped to fulfil old-growth supply objectives is unrealistic in a commercial forest. Hence, the second best option per species is also included. For harvested species, the best option for maximising LRSY is presented, along with the worst option, for comparative purposes. It is evident that all species' LRSYs do not perform well when old-growth reserve windows are employed to protect stands from harvest.

Table 6.1. Best and worst options for the old-growth, harvest level (for harvested species), and growing stock (for species not harvested) indicators between the six simulation scenarios.

	OLD GROWTH		GROWING STOCK/HARVEST LEVEL*	
Species	**BEST**	**WORST**	**BEST**	**WORST**
Sb	1) No Harvest 2) Pause-Yield Curve	No-Regeneration Silviculture	* Concentrated Silviculture	Pause-Yield Curve
Sw	n/a	all the same	* Concentrated Silviculture	Pause-Yield Curve
Pj	1)No Harvest 2) No-Regeneration Silviculture	Concentrated Silviculture	* Concentrated Silviculture	Pause-Yield Curve
Pw	all the same	n/a	Pause-Yield Curve	Concentrated Silviculture
Bf	1) No Harvest 2) Concentrated Silviculture	No-Regeneration Silviculture	No Regeneration Silviculture	Pause-Yield Curve
Po	No Harvest	Benchmark	* Maximum-Regeneration Silviculture	Pause-Yield Curve
Bw	1) No Harvest 2) Pause-Yield Curve	Concentrated Silviculture	No-Regeneration Silviculture & Concentrated Silviculture	Pause-Yield Curve

In black spruce, the Pause Yield Curve Scenario provides the next highest level of black spruce old growth across the landscape. In comparison, the No-Silviculture Scenario provides the least amount of black spruce old growth. At the same time, the best scenario for maximising LRSY in black spruce is the Concentrated-Silviculture Scenario, while the worst option for LRSY is the Pause Yield Curve Scenario.

For white spruce, using the old-growth age of 130+ years of age, there is no best scenario for providing old growth. All six scenarios deliver the same results; no white spruce old growth for the duration of the 100 years of simulation. Hence, all scenarios are also the worst option. For white spruce, as for black, the best option for maximising harvest levels is the Concentrated-Silviculture Scenario. The worst is the Pause Yield Curve Scenario.

The jack pine old-growth supply is maximised under the No-Harvest and No-Regeneration Silviculture Scenarios. The application of intensive silviculture decreases the old-growth supply. In contrast, intensive silviculture maximises harvest level. For white pine, all six scenarios provide the same amounts of old growth over time. All six runs show that the white pine old growth is not sustainable 40 years past 1993. The best option for white pine growing stock is the Pause-Yield Curve Scenario.

The Concentrated-Silviculture Scenario provides the greatest supply of balsam fir old growth, while the No-Regeneration Silviculture Scenario provides the least. In contrast , the No-Regeneration Silviculture Scenario provides the best management opportunity for growing stock. For poplar, old-growth supply is greatest under the No-Harvest Scenario, and worst under the Benchmark Scenario. Poplar LRSY is greatest with the use of maximum silviculture and least with the Pause Yield Curve Scenario. White birch old growth performs best under the Pause-Yield-Curve Scenario, while the growing stock performs worst under this scenario.

The information contained in Table 6.1 indicates that old-growth supply is often obtained at the cost of commercial timber extraction. This conflict with traditional harvesting and associated silvicultural activities must be analyzed at the landscape level. To achieve sustainable ecosystem management, a long-term assessment of benefits and impacts must be employed. The spatial and temporal distribution of timber harvests are more important indicators than the volumes of harvests planned for and removed (Clayoquot Sound Scientific Panel 1995). Spatial planning of timber harvests may help reduce forest fragmentation, such that the old-growth supply is sustainable (Hardt et al. 1995).

Planning for old-growth must start at the landscape level, not on a single-site basis in isolation. When society demands multiple benefits from the forest, it is at the landscape level that such goals are meaningfully set. Goals from this level are transferred to the stand level, where specific stand structures may be created, maintained and/or restored using various silvicultural and tending programs.

To commence an accurate accounting of forest benefits such as old growth, an ecological database must exist. In combination with a history of past disturbances and silvicultural treatments, and quantified patterns of future forest development, silvicultural programs may be set in place at the stand level to fulfil landscape-level patterns of forest structures (Jimerson et al. 1994). To use an ecological database effectively, detailed ecological data must be measured across all forest site types. Old-growth data to be measured include: gaps and larger openings, the presence and quantity of structural features such as snags and CWD-down, ages at which old-growth characteristics are produced in each forest type, mean stand diameters, and special features (such as wolf trees). Monitoring these old-growth features gives managers the opportunity to gauge current landscape patterns and plan for desired landscape patterns (Lewis et al. 1992; Boyce 1995; Clayoquot Sound Scientific Panel 1995).

Forest models, such as HSG, are useful tools to model the implications of providing multiple baskets of benefits. Only with an opportunity to forecast future supplies of old growth and timber, and their associated temporal and spatial distributions, can managers explore options that try to meet desired landscape patterns and goals. Continual monitoring of the behaviour of forest benefits such as old growth needs to be undertaken to measure actual results with forecasted ones (Currie 1994). Where goals have not been met, it is here, at the modelling stage, that additional information may be taken into account, assumptions of behaviour changed, and landscape goals adjusted.

Although the benefits of using simulation models are significant, one must consider the limitations as well. In this study, HSG was used to forecast multiple harvest, regeneration and old-growth time window scenarios over a period of time. A significant limitation to this process involved the inability of HSG to incorporate automated disturbance mechanisms (such as fire, insect infestations). This resulted in a limited ability to mimic boreal growth, disturbance and mortality patterns, which in turn, reduced the accuracy of the model results. For species such as jack pine, which requires the use of disturbance mechanisms to survive in the boreal landscape, the absence of the mechanism is absolutely critical to the viability of the species across the landscape.

In addition, HSG could not take into account within-stand management activities (such as shelterwood harvests). This meant that I could not model the implementation of activities that support the creation, maintenance or restoration of old growth on a within stand basis. The final limitation to HSG I found to be prevalent in this study was the awkward and cumbersome presentation style of simulation run results. This greatly extended the time required to accurately review the run results and make conclusions regarding assumptions used in the model.

POLICY/PLANNING IMPLICATIONS AND RECOMMENDATIONS

Forest resource managers have the basic tools to measure and manage for old growth, but to complete the analysis, they need to perform cost/benefit analyses of the non-commensurable values of old growth and other non-timber resources. This additional information would facilitate the degree to which managers are capable of providing, and society willing to accept, landscape baskets of benefits such as old growth.

In the interim, I conclude that the provision of old growth on the landscape does not require financial investment in intensive silviculture. Hence, the intent to create, maintain and/or restore the old-growth condition should be incorporated into current forest landscape planning processes. The results of such planning exercises should contribute to landscape-level ecological databases and lead to desired baskets of benefits and landscape patterns.

RESEARCH NEEDS

The 1980s and early 1990s were characterised by highly divisive, single issues such as old-growth preservation and clearcutting (often symbolised by the fate of the spotted owl). These issues are now seen as symptoms of more complex problems with global implications: the assurance that our forest resources are sustainable and provide a more complete spectrum of benefits (of which old growth is only one).

In keeping with the 1992 United Nations' Convention on Biological Diversity goal of establishing and supporting the protection of natural heritage areas, links to criteria and indicators of biodiversity need to be established in the forest resources sector (van Kooten 1995). The Canadian Council of Forest Ministers (1995) produced a framework by which national progress toward a sustainable forest management program could be measured. The six principle criteria of forest sustainability include: 1) conservation of biological diversity; 2) maintenance and enhancement of forest ecosystem condition and productivity; 3) conservation of soil and water resources; 4) forest ecosystem contributions to global ecological cycles; 5) multiple benefits to society; and 6) accepting society's responsibility for sustainable development.

Hence, old-growth indicators must not be defined in isolation. The results and landscape options obtained from detailed old-growth studies should feed into national and international frameworks for sustainable forest management.

Refinement of ecological data used to drive forest simulation models such as HSG, and indeed, refinement of the models themselves (e.g., such as the inclusion of the role of disturbance) should be constantly undertaken, results measured against desired goals, and alternatives monitored.

LITERATURE CITED

ABCPF. 1993. (Association of British Columbia Professional Foresters). Position statement: old growth forests. pp. 55-57 *in* Forestry on the Hill: Special Issue, Old Growth Forests (A Cross-Section of Perspectives for Informed Public Participation and Decision Making). Canadian Forestry Association. Ottawa, Ontario. 90 pp.

ALABACK, P.B. 1984. A comparison of old-growth forest structure in the western hemlock-sitka spruce forest of southeast Alaska. *in* W.R. Meehan, T.R. Merrell, Jr., and T.A. Hanley (eds.). Fish and wildlife relationships in old-growth forests: proceedings of a symposium. American Institute of Fishery Research Biologists. (*Cited in* Oliver and Larson, 1990).

ALEXANDER, M.E. and D.E. DUBE. 1983. Fire management in wilderness areas, parks and other nature reserves. pp. 273-297 *in* Wein, R.W. and D.A. MacLean (eds.). 1983. The Role of Fire in Northern Circumpolar Ecosystems. John Wiley and Sons on behalf of the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU). Toronto. 322 pp.

ALEXANDER, R.R. 1986. Silvicultural Systems and Cutting Methods for Old-Growth Spruce-Fir Forests in the Central and Southern Rocky Mountains. USDA Forest Service General Technical Report RM-126. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colorado. 36 pp.

ANDERSON, H.M. 1988. Old-growth forests: a conservationist's perspective. Natural Areas Journal 8(1):13-16.

ANONYMOUS. 1992. Sustainable Forestry: What Is It? What's It All About? Ontario Ministry of Natural Resources. Toronto, Ontario. 8 pp.

BARNES, B.V. 1989. Old-growth forests of the northern lake states: a landscape ecosystem perspective. Natural Areas Journal 9(1):45-57.

BEANLANDS, G.E. and P.N. DUINKER. 1983. An Ecological Framework for Environmental Impact Assessment in Canada. Institute for Resource and Environmental Studies, Dalhousie University. Halifax, Nova Scotia. 132 pp.

BELL, F.W. 1991. Critical Silvics of Conifer Crop Species and Selected Competitive Vegetation in Northwestern Ontario. Canada-Ontario Forest Resource Development Agreement (COFRDA) Report 3310. 177 pp.

BENZIE, J.W. and J.E. MCCUMBER. 1983. Red pine. pp. 89 - 91 *in* Burns, R.M. (Technical Compiler). 1983. Silvicultural Systems for the Major Forest Types for the United States. USDA Forest Service Agriculture Handbook No. 445. USDA Timber Management Research. Washington, D.C. 191 pp.

BENZIE, J.W., T.M. SMITH and R.M. FRANK. 1983. Balsam fir. pp. 102-104 *in* Burns, R.M. (Technical Compiler). 1983. Silvicultural Systems for the Major Forest Types for the United States. USDA Forest Service Agriculture Handbook No. 45. USDA Timber Management Research. Washington, D.C. 191 pp.

BLACHFORD, C.L. and P.N. DUINKER. 1992. On Planning For Boreal Old Growth. A Draft Discussion Paper of the Chair, Forest Management and Policy, School of Forestry, Lakehead University. Thunder Bay, Ontario, Canada. 42 pp.

BLUM, B.M., J.W. BENZIE and E. MERSKI. 1983. Eastern spruce-fir. pp. 128-130 *in* Burns, R.M. (Technical Compiler). 1983. Silvicultural Systems for the Major Forest Types for the United States. USDA Forest Service Agriculture Handbook No. 445. USDA Timber Management Research, Washington, D.C. 191 pp.

BOYCE, S.G. 1995. Landscape Forestry. John Wiley & Sons, Inc. New York, New York. 239 pp.

BRAND, D.G. 1992. The use of vegetation management in Canadian forest regeneration programs. Pp. 113-124 *in* Proceedings of a Conference on Vegetation Management in Forestry, Amenity and Conservation Areas; Aspects of Applied Biology 29. April 7-9, 1992. Association of Applied Biology. Warwick, U.K.

BRENNAN, P.J. 1991. An Interim Strategy for Dealing with Old-Growth Forests in Temagami for the Purposes of Comprehensive Planning (A Discussion Paper). Ontario Ministry of Natural Resources. Temagami, Ontario. 26 pp.

BURNS, R.M. (Technical Compiler). 1983. Silvicultural Systems for the Major Forest Types for the United States. USDA Forest Service Agriculture Handbook No. 445. USDA Timber Management Research, Washington, D.C. 191 pp.

CIF. 1993. Ontario Issues Old Growth Strategy Report. pp. 512 *in* Cayford, J.H. and D.M. Burgess (eds.). 1993. The Forestry Chronicle 69(5). Canadian Institute of Forestry. Ottawa, Ontario. 116 pp.

CPPA. 1993. Old growth forests. pp. 37-39 *in* Forestry on the Hill: Special Issue, Old Growth Forests (A Cross-Section of Perspectives for Informed Public Participation and Decision Making). Canadian Forestry Association. Ottawa, Ontario. 90 pp.

CANADIAN COUNCIL OF FOREST MINISTERS. 1995. Defining Sustainable Forest Management: A Canadian Approach to Criteria and Indicators. Canadian Forest Service, Natural Resources Canada. Ottawa, Canada. 22 p.

CAREY, A.B. 1989. Wildlife associated with old-growth forests in the Pacific Northwest. Natural Areas Journal 9(3):151-162.

CHASE, A. 1995. In A Dark Wood: The Fight over Forests and the Rising Tyranny of Ecology. A Richard Todd Book; Houghton Mifflin Company. Boston, MASS. 535 pp.

CLAYOQUOT SOUND SCIENTIFIC PANEL. 1995. Report 5: Sustainable Ecosystem Management in Clayoquot Sound: Planning and Practices. The Scientific Panel for Sustainable Forest Practices in Clayoquot Sound. Vancouver, British Columbia. 296 pp.

CUMMING, S.G., P.J. BURTON, S. PRAHACS, and M.R. GARLAND. 1994. Potential conflicts between timber supply and habitat protection in the boreal mixedwood of Alberta, Canada: a simulation study. Forest Ecology and Management 68(1994):281-302.

CUNDIFF, B. 1990. Vanishing old growth. Borealis 2(2):16-21.

Currie, D.J. 1994. CANFOR presentation to the Annual RISI Conference *in* Resource Information Systems, Inc. 1994. 9th Annual Conference. World Fibre Markets in Turmoil: How Will the Forest Industry Prosper? October 23-25, 1994. Cambridge, Massachusetts. 170 pp.

CWYNAR, L.C. 1978. Recent history of fire and vegetation from laminated sediment of Greenleaf Lake, Algonquin Park, Ontario. Canadian Journal of Botany 56:10-21.

DAVIS, L.S. and K.N. JOHNSON. 1987. Forest Management (Third Edition). McGraw-Hill Book Company. Toronto, Ontario. 790 pp.

DAY, R.J. 1990. The dynamic nature of Ontario's forests from post-glacial times to the present day. pp. 63-122 *in* Faculty of Forestry, University of Toronto. 1990. Old Growth Forests...What Are They? How Do They Work? Proceedings of a Symposium held at the University of Toronto, January 20, 1990. Toronto, Ontario. 197 pp.

DAY, R.J. and J.V. CARTER. 1991. Stand Structure and Successional Development of the White and Red Pine Communities in the Temagami Forest. One of Four Reports in The Temagami White and Red Pine Ecology and Silviculture Study. Ontario Ministry of Natural Resources, Northeastern Region. Sudbury, Ontario. 203 pp.

DEBELL, D.S. 1990a. Sustainable forestry: social, economic, and ecological considerations. pp. 307-312 *in* Society of American Foresters. 1990. Are Forests the Answer? Proceedings of the Society of American Foresters National Convention, July 29-August 1, 1990. Washington, D.C. 614 pp.

DEBELL, D.S. 1990b. Silvicultural practices and "new forestry". pp. 1-5 *in* Society of American Foresters and Southwestern Oregon Community College. 1990. "New Forestry" in the 90's. Proceedings of a Workshop sponsored by Coos Chapter, Society of American Foresters. Coos Bay, Oregon.

DEBELL, D.S. and R.O. CURTIS. 1991. The role of silviculture in new forestry. pp. 34-56 *in* Proceedings of the 12th Annual Forest Vegetation Management Conference, May 14-16, 1991. Shasta County Opportunity Centre. Redding, California.

DEBELL, D.S. and R.O. CURTIS. 1993. Silviculture and new forestry in the Pacific Northwest. Journal of Forestry 91(12):25-30.

DOAK, D. 1989. Spotted owl and old growth logging in the Pacific Northwest. Conservation Biology 3(4):389-396.

DUINKER, P.N. and G.L BASKERVILLE. 1986. A systematic approach to forecasting in environmental impact assessment. Journal of Environmental Management (1986) 23:271-290.

DUINKER, P.N. 1996. Personal communication. 11/07/96.

EARTHROOTS COALITION. 1991. Ancient Forest Survival Guide: An Old Growth Strategy for Ontario. Earthroots Coalition. Toronto, Canada. 33 pp.

FLANAGAN, G.C. 1989. Old-growth Douglas-fir: "Old growth ... cannot be preserved forever". Journal of Forestry 89(8):64.

FORESTRY CANADA. 1988. Forest Inventory Terms in Canada (Haddon, B.D. ed.). 3rd ed. Petawawa National Forestry Institute. Chalk River, Ontario. 109 pp.

FORESTRY CANADA. 1991a. Backgrounder: Model Forests Program. Pamphlet. Ottawa, Ontario. 3 pp.

FORESTRY CANADA. 1991b. Partners in Sustainable Development of Forest Programs. Booklet. Ottawa, Ontario 4 pp.

FOSS, T. 1990. New forestry - a state of mind. Inner Voice 2(1):4-6.

FRANKLIN, J.F., K. CROMACK, JR., W. DENISON, A.W. MCKEE, C. MASER, J. SEDELL, F. SWANSON, and G. JUDAY. 1981. Ecological Characteristics of Old-Growth Douglas-fir Forests. USDA Forest Service General Technical Report PNW-118. 48 pp.

FRANKLIN, J.F., F. HALL, W. LAUDENSLAYER, C. MASER, J. NUNAN, J. POPPINE, C.J. RALPH, and T. SPIES. 1986. Interim Definitions for Old-Growth Douglas-fir and Mixed-Conifer Forests in the Pacific Northwest and California. USDA Forest Service Research Note PNW-447. 7 pp.

FRANKLIN, J.F. 1990. Old-growth forests and the new forestry (Keynote Address). pp. 1-26 *in* Pearson, A.F. and D.A. Challenger (eds.). 1990. Forests - Wild and Managed: Differences and Consequences. Students for Forestry Awareness, Faculty of Forestry, U.B.C. Vancouver, B.C. 196 pp.

FRANKLIN, J.F. 1993. Lessons from old-growth. Journal of Forestry 91(12):11-13.

GODBEY, G.C. 1988. Human values and the non-timber values of forests or if no tree falls in the forest and someone hears it. pp. 67-78 *in* J.E. Johnson (ed.). Managing North Central Forests for Non-Timber Values: Proceedings of the Fourth Society of American Foresters Region V Technical Conference. Society of American Foresters SAF Publication 88-04. 437 pp.

GRAHAM, R.T., T.B. JAIN, R.T. REYNOLDS, AND D.A. BOYCE. 1994. From single species management to ecosystem management, "the goshawk". pp. 113 - 123 *in* Louise H. Foley. (ed.). 1993. Silviculture: From the Cradle of Forestry to Ecosystem Management. Proceedings of the National Silviculture Workshop, Hendersonville, N.C., November 1-4, 1993. Asheville, N.C. USDAFS Southeastern Forest Experiment Station. GTR SE-88. 258 pp.

GULDIN, J.M. 1991. Silvicultural practices applied to old-growth stand management. pp. 171-190 *in* D. Henderson and L.D. Hedrick (eds.). 1991. Restoration of Old Growth in the Interior Highlands of Arkansas and Oklahoma. Ouachita National Forest and Winrock International Institute for Agricultural Development. Morrilton, Arkansas. 190 pp.

HAIDER, W. 1992. Scenic Beauty and Other Values of Red and White Pine Old-Growth Forests. Forest Fragmentation and Biodiversity Project; 4. Ontario Forest Research Institute, Ontario Ministry of Natural Resources: Queen's Printer for Ontario. 134 pp.

HALL, T.H. 1977. WOSFOP, instruction manual. New Brunswick Department of Natural Resources, Fredericton, N.B. (*Cited in* Moore and Lockwood 1990).

HAMBLY, S. 1992. Personal correspondence. 12/08/92.

HANLEY, T.A., F.L. BUNNELL, E.E. STARKEY, S.K. STEVENSON and A.S. HARESTAD. 1984. Habitat relationships of Cervidae (deer) in old-growth forests. pp. 361-367 *in* K.A. Sabol, (ed). New Forests for a Changing World. Proceedings of the 1983 Convention of the Society of American Foresters, 16-20 October, Portland, Oregon. SAF Publication 84-03, Bethesda, Maryland. 640 pp.

HARDT, R.A. and D.H. NEWMAN. 1995. Regional policies for national forest old-growth planning. Journal of Forestry 93(6):32-35.

HARRIS, L.D. 1984. The Fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity. The University of Chicago Press. Chicago, Illinois. 211 pp.

HAWKES, B.C., M.C. FELLER and D. MEEHAN. 1990. Site preparation: fire. pp. 131-149 *in* Lavender, D.P., R. Parish, C.M. Johnson, G. Montgomery, A. Vyse, R.A. Willis, and D. Winston (eds.). 1990. Regenerating British Columbia's Forests. University of British Columbia Press. Vancouver, B.C. 372 pp.

HEINRICHS, J. 1984. The owl and old growth (rare birds and big trees: west). American Forests 90(3):22-23.

HEINSELMAN, M.L. 1981. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems. pp. 7-57 *in* USDA Forest Service. 1981. Fire Regimes and Ecosystem Properties. A Symposium held December 11-15, 1978, Honolulu, Hawaii. USDA Forest Service General Technical Report WO-26.

HENDERSON D. and L.D. HEDRICK (eds.). 1991. Restoration of Old Growth in the Interior Highlands of Arkansas and Oklahoma. Ouachita National Forest and Winrock International Institute for Agricultural Development. Morrilton, Arkansas. 190 pp.

HOPWOOD, D. 1991. Principles and Practices of New Forestry: A Guide for British Columbians. Report Commissioned by the Old-Growth Strategy Working Group, B.C. Ministry of Forests. Land Management Report Number 71. Victoria. 95 pp.

HOUGH, A.F. 1936. A climax forest community on East Tionesta Creek in northwestern Pennsylvania. Ecology 17:9-28 (*Cited in* Oliver and Larson 1990).

HUNTER, M.L. JR. 1990. Wildlife, Forests, and Forestry: Principles of Managing Forests for Biological Diversity. Prentice Hall. Englewood Cliffs, New Jersey. 368 pp.

JIMERSON, T.M. and D.W. JONES. 1994. Combining ecological classification and silviculture prescriptions to achieve desired future forest conditions. pp. 99-112 *in* Louise H. Foley. (ed.). 1993. Silviculture: From the Cradle of Forestry to Ecosystem Management. Proceedings of the National Silviculture Workshop, Hendersonville, N.C., November 1-4, 1993. Asheville, N.C. USDAFS Southeastern Forest Experiment Station. GTR SE-88. 258 pp.

JOHNSTON, W.F. and T.M. SMITH. 1983 spruce. pp. 96-98 *in* Burns, R.M. (Technical Compiler). 1983. Silv al Systems for the Major Forest Types for the United States. USD est Service Agriculture Handbook No. 445. USDA Timber Managem Research, Washington, D.C. 191 pp.

KAUFMANN, M.R., W.H. MOIR and W.W. COVINGTON. 1992. Old-growth forests: what do we know about their ecology and management in the southwest and rocky mountain regions? pp. 1-11 *in* Kaufmann, M.R., W.H. Moir and R.L. Bassett. 1992. Old-Growth Forests in the Southwest and Rocky Mountain Regions: Proceedings of a Workshop. USDA Forest Service General Technical Report RM-213. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colorado. 201 pp.

KIMMINS, J.P. 1992. Balancing Act: Envir nental Issues in Forestry. University of British Columbia Press. Vancouve C. 244 pp.

KLINKA, K., R.E. CARTER and M.C. FELLER 90. Cutting old-growth forests in British Columbia: ecological considerations for forest regeneration. The Northwest Environmental Journal 6:221-242.

KUUSELA, K. 1990. The Dynamics of Boreal Coniferous Forests. Sitra 112, Finnish National Fund for Research and Development. Helsinki. 172 pp.

LEAK, W.B. 1973. Species and Structure of a Virgin Northern Hardwood Stand in New Hampshire. USDA Forest Service Research Note NE-81. 4 pp.

LENNARTZ, M.R. 1988. The red-cockaded woodpecker: old-growth species in a second-growth landscape. Natural Areas Journal 8(3):160-165.

LERTZMAN, K. 1990. From stands to landscapes: processes and consequences of spatial structure. pp. 115 - 131 *in* Pearson, A.F. and D.A. Challenger (eds.). 1990. Forests - Wild and Managed: Differences and Consequences. Proceedings of a Symposium to Discuss the Ecology of Wild Forests and Plantations. Students for Forestry Awareness and Forestry Undergraduate Society, Faculty of Forestry, UBC. Vancouver, B.C. 196 pp.

LUKEN, J.O. 1990. Directing Ecological Succession. Chapman and Hall. New York, New York. 251 pp.

LUTZ, H.J. 1930. The vegetation of Heart's Content, a virgin forest in northwestern Pennsylvania. Ecology 11:1-29.

M'GONIGLE, M.R. and B. PARFITT. 1994. Forestopia: A Practical Guide to the New Forestry Economy. Harbour Publishing. Madeira Park, British Columbia. 119 pp.

MOF. 1992. An Old Growth Strategy for British Columbia. Old Growth Strategy Project, Ministry of Forests. Victoria, British Columbia. 74 pp.

MANN, J.W. 1990. Proposals for alternative silvicultural practices and "new forestry": are we on the right track? pp. 313-317 *in* Society of American Foresters. 1990. Are Forests the Answer? Proceedings of the Society of American Foresters National Convention, July 29-August 1, 1990. Washington, D.C. 614 pp.

MANNAN, R.W. and E.C. MESLOW. 1984. Bird populations and vegetation characteristics in managed and old-growth forests, northeastern Oregon. Journal of Wildlife Management 48(4):1219-1238.

MACKINNON, A. 1993. B.C.'s old growth forests (British Columbia Forest Service, Research Branch). pp. 87-90 *in* Forestry on the Hill: Special Issue, Old Growth Forests (A Cross-Section of Perspectives for Informed Public Participation and Decision Making). Canadian Forestry Association. Ottawa, Ontario. 90 pp.

MARCHAK, M.P. 1995. Logging the Globe. McGill-Queen's University Press. Montreal and Kingston, Canada. 404 pp.

MAREK, G.T. 1993. Understanding Ontario's boreal forest ecosystem . pp. 1-2 *in* Salamat, R. (ed.). 1993. Boreal Bio-Facts: An Introduction to the Boreal Forest Ecosystem. Earthroots. Toronto, Ontario. 4 pp.

McANINCH, C.D., R.L. HOOVER, and R.C. KUFELD. 1987. Silvicultural treatments and their effects on wildlife. pp. 213 - 241 *in* Hoover, R.L. and D.L. Wills (eds.). 1987. Managing Forested Lands For Wildlife. USDA Forest Service, Rocky Mountain Region.: Colorado Division of Wildlife. Denver, Colorado. 459 pp.

McCALLUM, I.R. 1993. Long-term effects of timber management on marten habitat potential in an Ontario boreal forest. Graduate Thesis, School of Forestry, Lakehead University. Thunder Bay, Ontario, Canada. 215 pp.

McNEEL, J.F. and R.L. COPSTEAD. 1994. Operational factors affecting the implementation of ecosystem management objectives. pp. 167 - 177 *in* Louise H. Foley. (ed.). 1993. Silviculture: From the Cradle of Forestry to Ecosystem Management. Proceedings of the National Silviculture Workshop, Hendersonville, N.C., November 1-4, 1993. Asheville, N.C. USDAFS Southeastern Forest Experiment Station. GTR SE-88. 258 pp.

MARTIN, W.H. 1991. Defining old-growth deciduous forests: seeing the forest and the trees. pp. 139-145 *in* D. Henderson and L.D. Hedrick (eds). 1991. Restoration of Old Growth Forests in the Interior Highlands of Arkansas and Oklahoma: Proceedings of the Conference. Ouachita National Forest and Winrock International Institute for Agricultural Development. Morrilton, Arkansas. 190 pp.

MESLOW, E.C., C. MASER and J. VERNER. 1981. Old-growth forests as wildlife habitat. Transactions of the North American Wildlife and Natural Resources Conference 46:329-335.

MEYER, H.A. and D.D. STEVENSON. 1943. The structure and growth of virgin beech-birch-maple-hemlock forests in northern Pennsylvania. Journal of Agricultural Research 67:465-484 (*Cited in* Oliver and Larson 1990).

MINCKLER, L.S. 1971. A Missouri forest of the past. Transactions of the Missouri Academy of Science 5:48-56 (*Cited in* Oliver and Larson 1990).

MITCHELL, A.K. 1992a. Research solutions to problems in the management of established stands. Forest Ecology and Management 49:119-132.

MITCHELL, W. 1992b. New forestry and the old growth issue. pp. 21-22 *in* Canadian Forest Industries/CPPA Woodlands Paper, March.

MOIR, W.H. 1992. Ecological concepts in old-growth forest definition. pp. 18-23 *in*

MOORE, T.G.E., and C.G. LOCKWOOD. 1990. The HSG Wood Supply Model: Description and User's Manual. Petawawa National Forestry Institute. Forestry Canada Information Report PI-X-98. 31 pp.

MOORE, T.G.E. 1996. Personal communication. 15/10/96.

MOREY, H.F. 1936. Age-size relationships of Heart's Content, a virgin forest in northwestern Pennsylvania. Ecology 17:251-257.

MORTON, R.T. 1990. A modelling primer. pp. 18-20 *in* Boughton, B.J. and J.K. Samoil (eds).1990. Forest Modelling Symposium. Forestry Canada, Northwest Region. Northern Forestry Centre Information Report NOR-X-308. 180 pp.

MUSTIAN, A.P. 1976. History and management of silviculture management systems in use today. pp. 1 - 17 *in* USDA Forest Service. 1976. Uneven-Aged Silviculture and Management in the United States. USDA Forest Service General Technical Report WO-24. Timber Management Research. Washington, D.C. 234 pp.

NEWTON, M. And E.C. COLE. 1987. A sustained-yield scheme for old-growth Douglas-fir. Western Journal of Applied Forestry 2(1): 22-25.

NICHOLS, G.E. 1913. The vegetation of Connecticut. Torreya 13:199-215 (*Cited in* Oliver and Larson 1990).

NOSS, R.F. 1987. Protecting natural areas in fragmented landscapes. Natural Areas Journal 7(1): 2-13.

Noste, N.V., E.D. Reinhardt and R.A. Wilson, Jr. 1987. Fire Effects on *Amelanchier alnifolia* Shrubs During Phenological Development Stages. Paper Presented at the Symposium on Shrub Ecophysiology and Biotechnology June 30-July2, 1987. Logan, Ut. 6 pp.

NYBERG, J.B., A.S. HARESTAD and F.L. BUNNELL. 1987. "Old Growth" by design: managing young forests for old-growth wildlife. pp. 71 - 81 *in* Transactions of the 52nd North American Wildlife and Natural Resources Conference. Wildlife Management Institute. Washington, D.C. 748 pp.

NYBERG, J.B., F.L. BUNNELL, D.W. JANZ and R.M. ELLIS. 1986. Managing young forests as black-tailed deer winter ranges. Land Management Report No. 37. Ministry of Forests. Victoria, British Columbia. 49 pp.

O'KEEFE, T. 1990. Holistic (new) forestry: significant difference or just another gimmick? Journal of Forestry 88(4):23-24.

OLIVER, C.D. 1981. Forest development in North America following major disturbances. Forest Ecology and Management 3:153-168.

OLIVER, C.D. and B.C. LARSON. 1990. Forest Stand Dynamics. McGraw-Hill, Inc. Toronto, Ontario. 467 pp.

OLIVER, C.D., D.R. BERG, D.R. LARSON and K.L. O'HARA. 1994. Integrating management tools, ecological knowledge, and silviculture. pp. 361-382 *in* Naiman, R.J. (ed.). Watershed Management: Balancing Sustainability and Environmental Change. Springer-Verlag .New York, N.Y. 542 pp.

OMNR. 1978. Ontario Provincial Parks Policy. Pamphlet 5739/1987. Provincial Parks Branch, Whitney Block. Toronto, Ontario. 4 pp.

OMNR. 1992. A Natural Heritage Areas Strategy For Ontario: Responding to the Endangered Spaces Challenge (Draft for Discussion). Provincial Parks and Natural Heritage Policy Branch. Toronto, Ontario. 29 pp.

OMNR. 1983. Management of tolerant hardwoods in Algonquin Provincial Park. OMNR Publication No. 5281. Toronto, Ontario. 72 pp.

OMNR. 1986. Timber Management Planing Manual for Crown Lands in Ontario. Ontario Ministry of Natural Resources. Toronto, Ontario. 218 pp.

OMNR. 1993a. Interim Report on Conserving Old Growth Red and White Pine. The Old Growth Policy Advisory Committee. Sudbury, Ontario. 35 pp.

OMNR. 1993b. What We Heard: A Report on Public Consultations on Conserving Old Growth Red and White Pine. The Old Growth Policy Advisory Committee. Sudbury, Ontario. 43 pp.

OMNR. 1994a. Conserving Ontario's Old-Growth Forest Ecosystems: Final Report of the Policy Advisory Committee on Conserving Ontario's Old Growth Forest Ecosystems. Queen's Printer for Ontario. Toronto, Ontario. 90 pp.

OMNR. 1994b. Keep it wild: our natural heritage areas & Ontario's Keep It Wild Campaign. Queen's Printer for Ontario. Toronto, Ontario. 6 pp.

ORIANS, G.H. 1990. "New Forestry" and the old-growth forests of northwestern North America: a conversation with Jerry F. Franklin. The Northwest Environmental Journal 6:445-461.

PEARSE, P.H. 1990. Lecture in Forest Policy 415, University of British Columbia. Vancouver, British Columbia. April 1990.

PERALA, D.A. and J.RUSSELL. 1983. Aspen. pp. 113-115 *in* Burns, R.M. (Technical Compiler). 1983. Silvicultural Systems for the Major Forest Types for the United States. USDA Forest Service Agriculture Handbook No. 445. USDA Timber Management Research. Washington, D.C. 191 pp.

POJAR, J. 1991. Old growth forests in British Columbia. pp. 15-21 *in* International Symposium on Geographic Information Systems (Schreier, H. ed.). 1991. GIS 91: Applications in a Changing World; Symposium Proceedings. Reid, Collins and Associates. Vancouver, British Columbia. 442 pp.

POWELL, G.R. 1987. Dendrology and Silvics: Notes on the Essential Silvical Characteristics of Species Studied in Forestry 2401. University of New Brunswick, Fredericton, New Brunswick. Unpublished manuscript.

RICE, R.E. 1990. Old-growth logging myths: the ecological impact of the US Forest Service's management policies. The Ecologist 20(4):141-146.

ROEMER, H.L., J. POJAR, and K. JOY. 1988. Protected old growth forests in coastal British Columbia. Natural Areas Journal 8:146-159.

RUDOLPH, T.D. 1983. Jack pine. pp. 92 - 95 *in* Burns, R.M. (Technical Compiler). 1983. Silvicultural Systems for the Major Forest Types for the United States. USDA Forest Service Agriculture Handbook No. 445. USDA Timber Management Research. Washington, D.C. 191 pp.

RUNKLE, J.R. 1981. Gap regeneration in some old-growth forests of the eastern United States. Ecology 62(4):1041-1051.

RUNKLE, J.R. 1984. Development of woody vegetation in treefall gaps in a beech-sugar maple forest. Holarctic Ecology 7:157-164.

RUST, S.K. 1990. Process based attributes: a key to the conservation of old-growth forest communities. Research Notes, Northwest Environmental Journal 6(2):425-427.

RUSTERHOLZ, K. A. 1989. Old-Growth Forests in Minnesota: A Preliminary Report. Natural Heritage Program, Minnesota Department of Natural Resources. Minneapolis, Minnesota. 13 pp.

RYDELIUS, J.A. 1984. Practical aspects of managing old growth forest habitats: comments of a panel member. p. 70 *in* K.A. Sabol, (ed). New Forests for a Changing World. Proceedings of the 1983 Convention of the Society of American Foresters, 16-20 October, Portland, Oregon. SAF Publication 84-03, Bethesda, Maryland. 640 pp.

SCHOEN, J.W., M.D. KIRCHHOFF and J.H. HUGHES. 1988. Wildlife and old-growth forests in southeastern Alaska. Natural Areas Journal 8(3):138-145.

SCHROEDER, H.W. 1992. The tree of peace: symbolic and spiritual values of the white pine. p. 73-83 *in* R.A. Stine and M.J. Baughman, (eds). White Pine Symposium Proceedings; History, Ecology, Policy and Management. University of Minnesota. St. Paul, Minnesota. NR-BU-6044-S. 202 pp.

SHUGART JR., H.H. and D.C. WEST. 1980. Forest succession models. Bioscience 30(5):308-313.

SIMS, R.A., H.M. KERSHAW and G.M. WICKWARE. 1990. The Autecology of Major Tree Species in the North Central Region of Ontario. Canada-Ontario Forest Resource Development Agreement (COFRDA) Report 3302. 126 pp.

SIRMON, J. 1982. Managing old growth forests. pp. 73-77 *in* Bureau of Governmental Research and Service. 1982. Old Growth Forests: A Balanced Perspective (Proceedings of a Conference). University of Oregon. Eugene, Oregon. 111 pp.

SMITH, D.M. 1986. The Practice of Silviculture (8th ed.). John Wiley and Sons, Inc. New York, New York. 527 pp.

SMITH, O.D., JR. 1991. Older stands of the Ozark-St. Francis National Forests; type, extent, location, and condition. pp. 115-120 *in* D. Henderson and L.D. Hedrick (eds). 1991. Restoration of Old Growth Forests in the Interior Highlands of Arkansas and Oklahoma: Proceedings of the Conference. Ouachita National Forest and Winrock International Institute for Agricultural Development. Morrilton, Arkansas. 190 pp.

SOCIETY OF AMERICAN FORESTERS. 1984. Scheduling the Harvest of Old-Growth Timber: Old-Growth Forests in the Pacific Northwest; A Position of the Society of American Foresters and Report of the SAF Taskforce on Scheduling the Harvest of Old-Growth Timber. Society of American Foresters SAF 84-09. Bethesda, MD. 44 pp.

SPIES, T.A. and J.F. FRANKLIN. 1988. Old growth and forest dynamics in the Douglas-fir region of western Oregon and Washington. Natural Areas Journal 8(3):190-201.

SPURR, S.H. 1979. Silviculture. Scientific American 240:76-82, 87-91.

STIELL, W. 1984. Improvement cut accelerates white pine sawlog growth. The Forestry Chronicle 60(1):3-9.

SUFFLING, R. 1988. Catastrophic disturbance and landscape diversity: the implications of fire control and climate change in subarctic forests. pp. 111-120 *in* Moss, M.R. (ed.). 1988. Proceedings of the First Symposium of the Canadian Society for Landscape Ecology and Management: University of Guelph, May 1987. Polyscience Publications Inc. Montreal, Quebec. 249 pp.

SWIFT, J. 1991. Ontario's search for a new way in the woods. Borealis 3(1):38-42.

TERASMAE, J. and N.C. WEEKS. 1979. Natural fires as an index of paleoclimate. Canadian Field-Naturalist. 93:116-125.

THOMPSON, I.D. 1991. Could marten become the spotted owl of eastern Canada? The Forestry Chronicle 67:136-140.

THOMPSON, R. 1993. Smokey's new hat. pp. 65-66 *in* Forestry on the Hill: Special Issue Forest Wildfires. Canadian Forestry Association. Ottawa, Ontario. 96 pp.

TITUS, S.J. and R.T. MORTON. 1985. Forest stand growth models: what for? The Forestry Chronicle 2:19-22.

TURPIN, T.C. and D.B. KARNES. 1994. Managing young Douglas-fir stands to foster the development of diverse stand structure and species composition. pp. 42-45 *in* Louise H. Foley. (ed.). 1993. Silviculture: From the Cradle of Forestry to Ecosystem Management. Proceedings of the National Silviculture Workshop, Hendersonville, N.C., November 1-4, 1993. USDAFS Southeastern Forest Experiment Station. Asheville, N.C. GTR SE-88. 258 pp.

UNIVERSITY OF TORONTO: FACULTY OF FORESTRY. 1990. Old Growth Forests...What Are They? How Do They Work? Canadian Scholars' Press Inc. Toronto, Canada. 197 pp.

VAN KOOTEN, G.C. 1995. Economics of protecting wilderness areas and old-growth timber in British Columbia. The Forestry Chronicle 71(1):52-58.

VIERECK, L.A. 1983. The effects of fire in black spruce ecosystems in Alaska and northern Canada. pp. 201-220 *in* Wein, R.W. and D.A. MacLean (eds.). 1983. The Role of Fire in Northern Circumpolar Ecosystems. John Wiley and Sons on behalf of the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU). Toronto, Ontario. 322 pp.

WALTERS, D.J., and C.S. HOLLING. 1990. Large-scale management experiments and learning by doing. Ecology 71:2060-2068.

WARD, P.C. and A.G. TITHECOTT. 1993. The impact of fire management on the boreal landscape of Ontario. pp. 80-84 *in* Forestry on the Hill: Special Issue Forest Wildfires. Canadian Forestry Association. Ottawa, Ontario. 96 pp.

WEETMAN, G.F. 1991. Biological Uncertainty in Growth and Yield Benefits of Second-Growth Silviculture Actions and Old-Growth Protection and Liquidation Strategies in British Columbia. University of British Columbia, Forest Economics and Policy Analysis (FEPA) Research Unit, Working Paper 148. Vancouver, B.C. 23 pp.

WEETMAN, G.F. and A. VYSE. 1990a. Natural regeneration. pp. 118 - 130 *in* Lavender, D.P., R. Parish, C.M. Johnson, G. Montgomery, A. Vyse, R.A. Willis, and D. Winston (eds.). 1990. Regenerating British Columbia's Forests. University of British Columbia Press. Vancouver, B.C. 372 pp.

WEETMAN, G.F., E. PANOZZO, M. JULL, and K. MAREK. 1990b. An Assessment of Opportunities for Alternative Silvicultural Systems in the SBS, ICH and ESSF Biogeoclimatic Zones of the Prince Rupert Forest Region. Contract Report, B.C. Ministry of Forests, Prince Rupert Forest Region. Smithers, B.C. 154 pp.

WELLBAUM, E.M. and L.M. DOYLE. 1991. Old-growth forest management for multiple use. pp. 722-728 *in* Coleman, S.S. and D.G. Neary (eds.). 1991. Proceedings of the Sixth Biennial Southern Silvicultural Research Conference, Volume 2. Southeastern Forest Experiment Station. Asheville, North Carolina. 868 pp.

WENDEL, G.W., L. DELLA-BIANCA, J. RUSSELL and K.F. LANCASTER. 1983. Eastern white pine including eastern hemlock. pp. 131-134 *in* Burns, R.M. (Technical Compiler). 1983. Silvicultural Systems for the Major Forest Types for the United States. USDA Forest Service Agriculture Handbook No. 445. USDA Timber Management Research. Washington, D.C. 191 pp.

WHITE, D.J. 1990. Preliminary Definitions and Evaluation of Old-Growth Forest in Eastern Ontario. Eastern Administrative Region, Ontario Ministry of Natural Resources. Kemptville, Ontario. 60 pp.

WHITNEY, G.G. 1987. Some reflections on the value of old-growth forests, scientific and otherwise. Natural Areas Journal 7(3):92-99.

WILLS, D.L. 1987. Creating wildlife habitat conditions. pp. 245 - 257 *in* Hoover, R.L. and D.L. Wills (eds.). 1987. Managing Forested Lands For Wildlife. USDA Forest Service, Rocky Mountain Region. Colorado Division of Wildlife .Denver, Colorado: 459 pp.

YUSKAVITCH, J. 1985. Old growth: a question of values. American Forests 91(3):22-25, 34.

APPENDICES

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APPENDIX 1

HSG State Table

HSG State Table

CODE	SITE	AGE	P_STKG(Po)	TYPE	TREATMENT	/	Sp #1	S.C.#1	Age #1	Stk. #1	Sp #2	S.C.#2	Age #2	Stk. #2
Bf	1	*	*	silv	extensive	/	Po	1	0	0.8	Sb	1	0	0.1
Bf	1	*	*	silv	intensive	/	Sb	1	0	0.7	Pj	1	0	0.3
Bf	1	>80	*	invt	none	/	Bf	1	20	0.8	Sw	1	20	0.2
Bf	2	*	*	silv	extensive	/	Po	2	0	0.8	Sb	2	0	0.1
Bf	2	*	*	silv	intensive	/	Sb	1	0	0.7	Pj	1	0	0.3
Bf	2	>80	*	invt	none	/	Bf	2	20	0.7	Sb	X	20	0.3
Bf	3	*	*	silv	extensive	/	Po	3	0	0.8	Sb	3	0	0.1
Bf	3	>80	*	invt	none	/	Bf	3	20	0.7	Sb	1	20	0.3
Bf	4	>90	*	invt	none	/	Bf	4	25	0.7	Sb	1	25	0.3
Bf	X	*	*	silv	extensive	/	Po	X	0	0.8	Sb	1	0	0.1
Bf	X	*	*	silv	intensive	/	Sw	X	0	0.9	Po	x	0	0.1
Bf	X	>80	*	invt	none	/	Bf	X	20	0.9	Sw	X	20	0.1
Bw	1	*	*	silv	extensive	/	Bw	1	0	0.7				
Bw	1	>150	*	invt	none	/	Bw	1	5	0.5	Bf	1	10	0.5
Bw	2	*	*	silv	extensive	/	Bw	2	0	0.7				
Bw	2	>140	*	invt	none	/	Bw	2	10	0.5	Bf	2	10	0.5
Bw	3	*	*	silv	extensive	/	Bw	3	0	0.7				
Bw	3	>130	*	invt	none	/	Bw	3	15	0.6	Bf	3	10	0.4
Bw	4	>130	*	invt	none	/	Bf	3	20	0.6	Bw	4	10	0.4
Bw	X	*	*	silv	extensive	/	Bw	X	0	0.7				
Bw	X	>150	*	invt	none	/	Bw	X	0	0.5	Bf	X	10	0.5
Pj	1	*	*	silv	basic	/	Pj	1	0	0.8				
Pj	1	*	*	silv	extensive	/	Pj	1	0	0.6	Bf	1	0	0.2
Pj	1	*	*	silv	intensive	/	Pj	M1	0	1				
Pj	1	>110	*	invt	none	/	Sb	1	30	0.8	Bf	1	15	0.2
Pj	2	*	*	silv	basic	/	Pj	2	0	0.8				
Pj	2	*	*	silv	extensive	/	Pj	2	0	0.6	Bf	2	0	0.1
Pj	2	*	*	silv	intensive	/	Pj	M2	0	1				
Pj	2	>110	*	invt	none	/	Sb	2	30	0.8	Bf	2	15	0.2
Pj	3	*	*	silv	extensive	/	Pj	3	0	0.6				
Pj	3	>110	*	invt	none	/	Sb	3	30	0.8	Bf	3	15	0.2
Pj	4	>100	*	invt	none	/	Sb	4	35	0.8	Bf	4	20	0.2
Pj	M2	*	*	silv	intensive	/	Pj	M2	0	1				
Pj	X	*	*	silv	basic	/	Pj	X	0	0.8				
Pj	X	*	*	silv	extensive	/	Pj	X	0	0.6	Bf	X	0	0.3
Pj	X	*	*	silv	intensive	/	Pj	MX	0	1				
Pj	X	>90	*	invt	none	/	Sb	X	30	0.8	Bf	X	15	0.2
Pj	M1	*	*	silv	intensive	/	Pj	M1	0	1				
Pj	M1	*	*	silv	extensive	/	Pj	M1	0	1				
Pj	MX	*	*	silv	intensive	/	Pj	MX	0	1				
Po	1	*	*	silv	extensive	/	Po	1	0	1				
Po	1	*	*	silv	intensive	/	Sb	M1	0	0.7	Po	1	0	0.3
Po	1	>110	*	invt	none	/	Po	1	15	0.8	Bf	1	15	0.2

CODE	SITE	AGE	P_STKG(Po)	TYPE	TREATMENT	/	Sp #1	S.C.#1	Age #1	Stk. #1	Sp #2	S.C.#2	Age #2	Stk. #2
Po	2	*	*	silv	extensive	/	Po	2	0	1				
Po	2	>110	*	invt	none	/	Po	2	15	0.5	Sb	1	20	0.5
Po	3	*	*	silv	extensive	/	Po	3	0	1				
Po	3	>110	*	invt	none	/	Po	3	15	0.5	Sb	2	20	0.5
Po	4	>120	*	invt	none	/	Po	4	15	0.5	Sb	2	25	0.5
Po	4	*	*	silv	extensive	/	Po	4	0	1				
Po	X	*	*	silv	extensive	/	Po	X	0	1				
Po	X	*	*	silv	intensive	/	Sb	MX	0	0.8	Po	X	0	0.2
Po	X	>110	*	invt	none	/	Po	X	15	0.9	Bf	X	15	0.1
Pw	1	*	*	silv	extensive	/	Pw	1	35	0.5	Bf	1	30	0.5
Pw	1	>190	*	invt	none	/	Pw	1	35	0.5	Bf	1	30	0.5
Pw	2	*	*	silv	extensive	/	Bf	2	35	0.5	Po	2	25	0.5
Pw	2	>200	*	invt	none	/	Bf	2	35	0.5	Po	2	25	0.5
Pw	3	*	*	silv	extensive	/	Bf	3	35	0.6	Po	3	25	0.4
Pw	3	>200	*	invt	none	/	Bf	3	35	0.6	Po	3	25	0.4
Pw	4	*	*	silv	extensive	/	Bf	4	35	0.7	Po	4	25	0.3
Pw	4	>200	*	invt	none	/	Bf	4	35	0.7	Po	4	25	0.3
Pw	X	*	*	silv	extensive	/	Pw	X	35	0.5	Bf	X	30	0.5
Pw	X	>190	*	invt	none	/	Pw	X	35	0.5	Bf	X	30	0.5
Sb	1	*	*	silv	intensive	/	Sb	M1	0	0.9				
Sb	1	*	0	silv	basic	/	Sb	1	0	0.8				
Sb	1	*	0	silv	extensive	/	Sb	1	0	0.3				
Sb	1	*	>.30	silv	basic	/	Po	1	0	0.6	Sb	1	0	0.5
Sb	1	*	>.30	silv	extensive	/	Po	1	0	1	Sb	1	0	0.1
Sb	1	*	>0&<.30	silv	basic	/	Sb	1	0	0.65	Po	2	0	0.4
Sb	1	*	>0&<.30	silv	extensive	/	Po	2	0	1	Sb	1	0	0.2
Sb	1	>170	0	invt	none	/	Sb	1	20	1				
Sb	1	>170	>.30	invt	none	/	Po	1	40	0.8	Sb	1	20	0.3
Sb	1	>170	>0&<.30	invt	none	/	Po	1	30	0.6	Sb	1	20	0.5
Sb	2	*	0	silv	basic	/	Sb	2	0	0.9				
Sb	2	*	0	silv	extensive	/	Sb	2	0	0.65				
Sb	2	*	0	silv	intensive	/	Sb	M2	0	1				
Sb	2	*	>0	silv	basic	/	Po	2	0	0.5	Sb	1	0	0.5
Sb	2	*	>0	silv	extensive	/	Po	2	20	0.7	Sb	2	0	0.5
Sb	2	*	>0	silv	intensive	/	Sb	M2	0	1				
Sb	2	>190	0	invt	none	/	Sb	2	55	1				
Sb	2	>190	>0	invt	none	/	Sb	2	50	0.7	Po	3	20	0.5
Sb	3	*	*	silv	basic	/	Sb	3	0	1				
Sb	3	*	*	silv	extensive	/	Sb	3	0	0.8				
Sb	3	>170	*	invt	none	/	Sb	3	180	*				
Sb	4	*	*	silv	extensive	/	Sb	4	0	0.8				
Sb	M1	*	*	silv	extensive	/	Sb	1	0	0.5	Po	2	0	0.55
Sb	M1	*	*	silv	intensive	/	Sb	M1	0	0.9				
Sb	MX	*	*	silv	extensive	/	Sb	X	0	0.5	Po	1	0	0.55
Sb	MX	*	*	silv	intensive	/	Sb	MX	0	0.9				
Sb	X	*	*	silv	intensive	/	Sb	MX	0	0.9				
Sb	X	*	0	silv	basic	/	Sb	X	0	0.8				
Sb	X	*	0	silv	extensive	/	Sb	X	0	0.3				
Sb	X	*	>.30	silv	basic	/	Po	1	0	0.65	Sb	X	0	0.4

CODE	SITE	AGE	P_STKG(Po)	TYPE	TREATMENT	/	Sp #1	S.C #1	Age #1	Stk. #1	Sp #2	S.C #2	Age #2	Stk. #2
Sb	X	*	>.30	silv	extensive	/	Po	1	0	1				
Sb	X	*	>0&<.30	silv	basic	/	Sb	X	0	0.6	Po	1	0	0.4
Sb	X	*	>0&<.30	silv	extensive	/	Po	1	0	1				
Sb	X	>120	0	invt	none	/	Sb	X	20	1				
Sb	X	>120	>.30	invt	none	/	Po	1	15	0.8	Sb	X	10	0.2
Sb	X	>120	>0&<.30	invt	none	/	Sb	X	10	0.6	Po	1	15	0.5
Sw	1	*	*	silv	intensive	/	Sw	M1	0	0.9				
Sw	1	*	0	silv	basic	/	Sw	1	0	0.8				
Sw	1	*	0	silv	extensive	/	Sw	1	0	0.3				
Sw	1	*	>.30	silv	basic	/	Po	1	0	0.6	Sw	1	0	0.5
Sw	1	*	>.30	silv	extensive	/	Po	1	0	1	Sw	1	0	0.1
Sw	1	*	>0&<.30	silv	basic	/	Po	1	0	0.55	Sw	2	0	0.4
Sw	1	*	>0&<.30	silv	extensive	/	Po	2	0	1	Sw	1	0	0.2
Sw	1	>170	0	invt	none	/	Sw	1	20	0.8				
Sw	1	>170	>.30	invt	none	/	Po	1	40	0.8	Sw	1	20	0.3
Sw	1	>170	>0&<.30	invt	none	/	Po	1	30	0.6	Sw	1	20	0.5
Sw	2	*	0	silv	basic	/	Sw	2	0	0.8				
Sw	2	*	0	silv	extensive	/	Sw	2	0	0.7				
Sw	2	*	0	silv	intensive	/	Sw	2	0	1				
Sw	2	*	>0	silv	basic	/	Sw	2	0	0.9				
Sw	2	*	>0	silv	extensive	/	Po	3	20	0.7	Sw	2	0	0.5
Sw	2	*	>0	silv	intensive	/	Sw	2	0	1				
Sw	2	>190	0	invt	none	/	Sw	2	55	1				
Sw	2	>190	>0	invt	none	/	Sw	2	50	0.7	Po	3	20	0.5
Sw	2	>220	*	invt	none	/	Sw	2	60	1				
Sw	3	*	*	silv	basic	/	Sw	3	0	1				
Sw	3	>170	*	invt	none	/	Sw	3	180	*				
Sw	M1	*	*	silv	extensive	/	Sw	1	0	0.5	Po	1	0	0.55
Sw	M1	*	*	silv	intensive	/	Sw	M1	0	0.9				
Sw	MX	*	*	silv	extensive	/	Sw	X	0	0.5	Po	1	0	0.55
Sw	MX	*	*	silv	intensive	/	Sw	MX	0	0.9				
Sw	X	*	*	silv	intensive	/	Sw	MX	0	0.9				
Sw	X	*	0	silv	basic	/	Sw	X	0	0.8				
Sw	X	*	0	silv	extensive	/	Sw	X	0	0.3				
Sw	X	*	>.30	silv	basic	/	Po	1	0	0.65	Sw	X	0	0.4
Sw	X	*	>.30	silv	extensive	/	Po	1	0	1				
Sw	X	*	>0&<.30	silv	basic	/	Sw	X	0	0.5	Po	1	0	0.5
Sw	X	*	>0&<.30	silv	extensive	/	Po	1	0	1				
Sw	X	>120	0	invt	none	/	Sw	X	20	0.8				
Sw	X	>120	>.30	invt	none	/	Po	1	15	0.8	Sw	X	10	0.2
Sw	X	>120	>0&<.30	invt	none	/	Sw	X	10	0.3	Po	1	15	0.7

APPENDIX II

Treatment Priority Lists

TREATMENT PRIORITY LISTS

BASIC TREATMENT TABLE:

Spp.*	S.C.	Treatment level
Sw	1	basic
Sw	2	basic
Sw	X	intensive
Sb	1	basic
Sb	2	basic
Sb	X	intensive
Pj	1	basic
Pj	2	basic
Pj	3	basic
Pj	X	basic
Po	1	extensive
Po	2	extensive
Po	3	extensive
Po	X	extensive
Bw	1	extensive
Bw	2	extensive
Bw	3	extensive
Bw	4	extensive

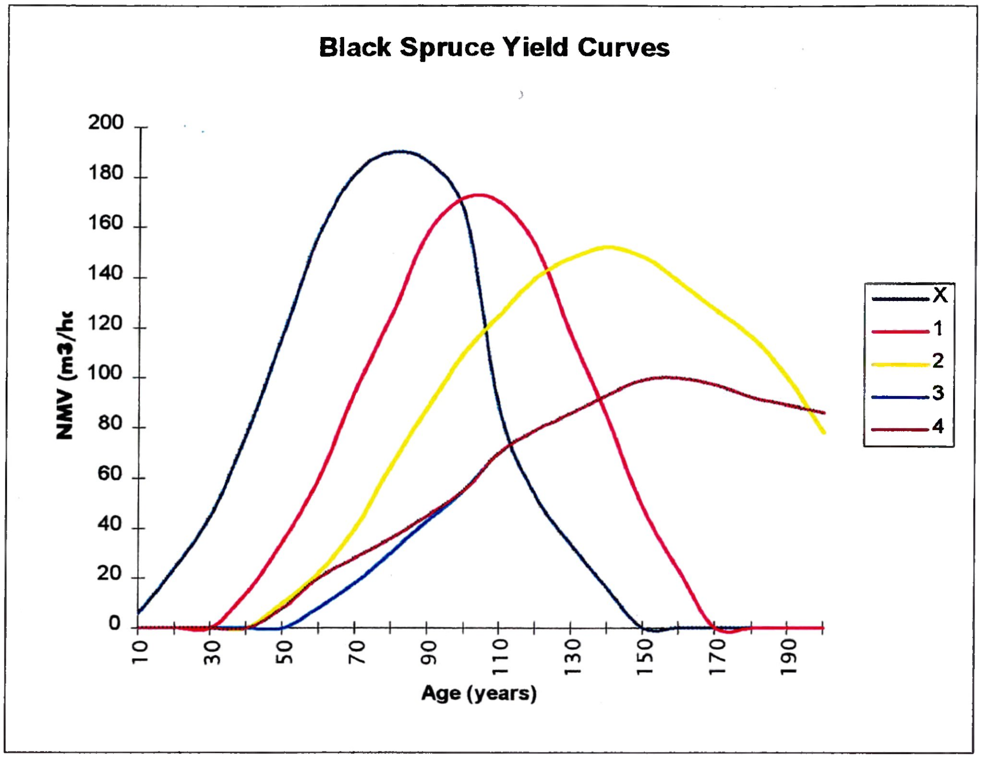
INTENSIVE TREATMENT TABLE:

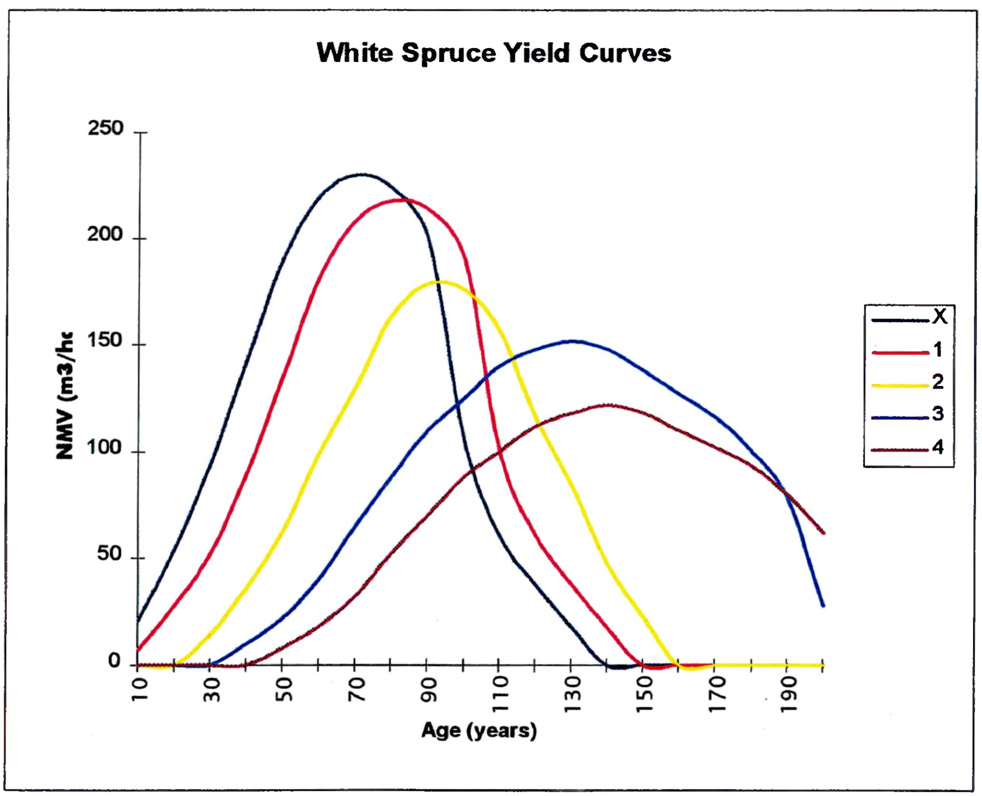
Spp.	S.C.	Treatment level
Sw	1	intensive
Sw	2	intensive
Sw	X	intensive
Sb	1	intensive
Sb	2	intensive
Sb	X	intensive
Pj	1	intensive
Pj	2	intensive
Pj	3	basic
Pj	X	intensive
Po	1	extensive
Po	2	extensive
Po	3	extensive
Po	X	extensive
Bw	1	extensive
Bw	2	extensive
Bw	3	extensive
Bw	4	extensive

* Note: Species and site class combinations not on this list that are harvested will be treated with extensive silviculture.

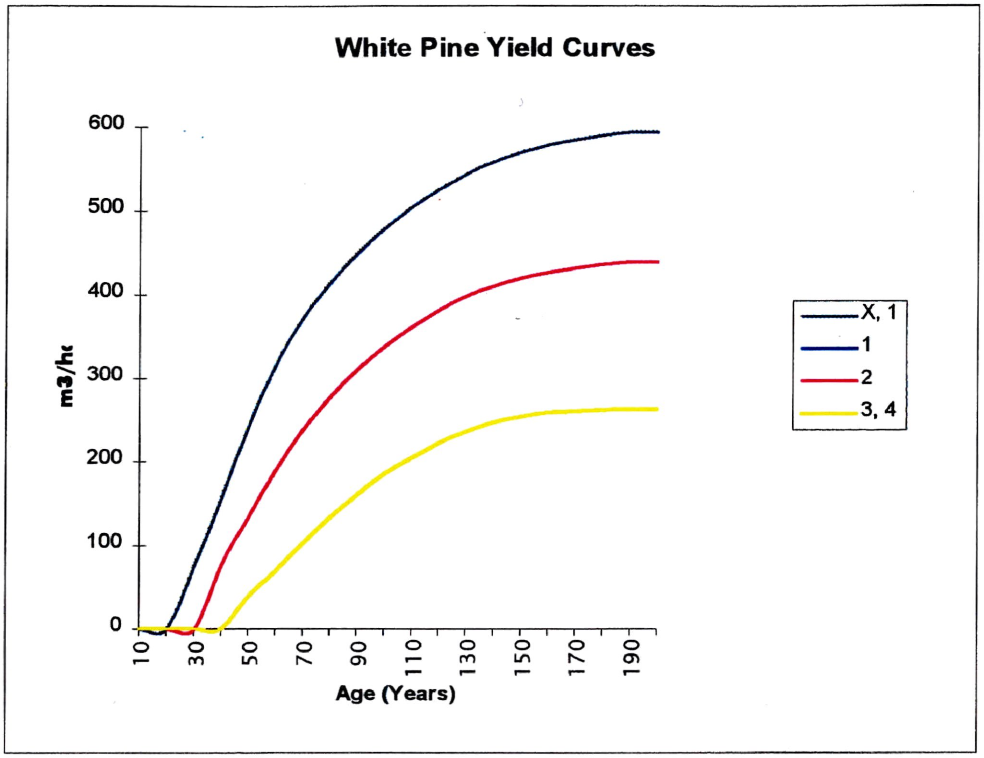
APPENDIX III

Normal Yield Curves

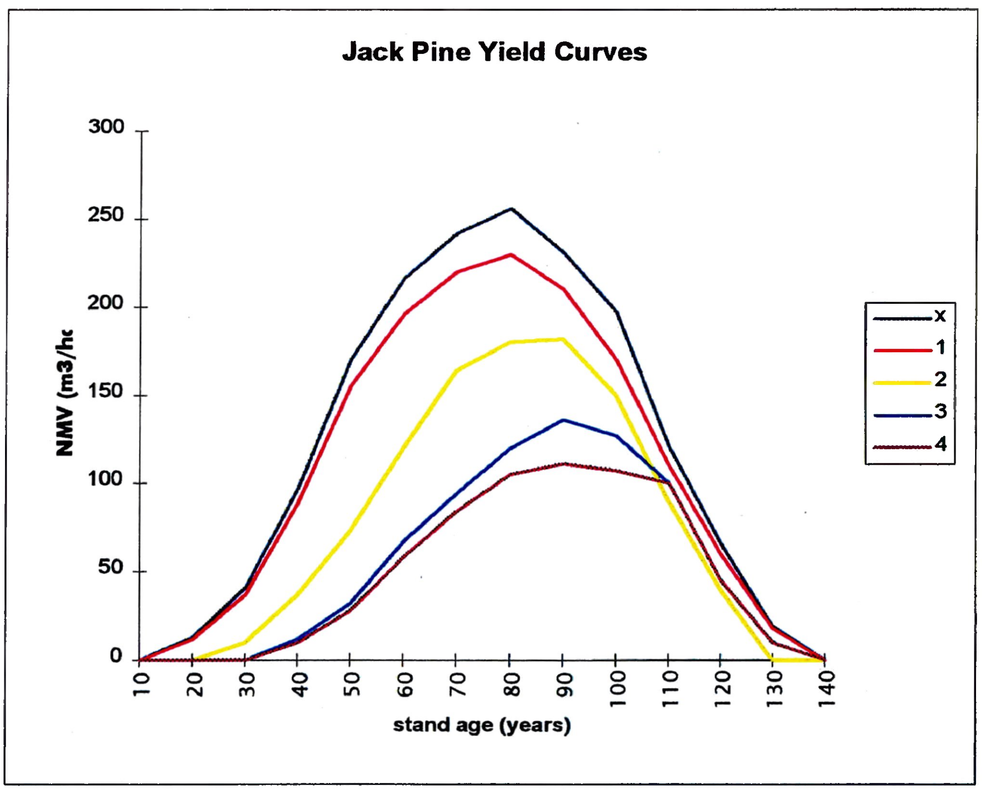

Black Spruce Yield Curves
200
180
160
140
120
100
80
60
40
20
0
NMV (m3/hc
10
30
50
70
90
110
130
150
170
190
Age (years)
X
1
2
3
4


White Spruce Yield Curves
250
200
150
100
50
0
NMV (m3/hc
10
30
50
70
90
110
130
150
170
190
Age (years)
X
1
2
3
4

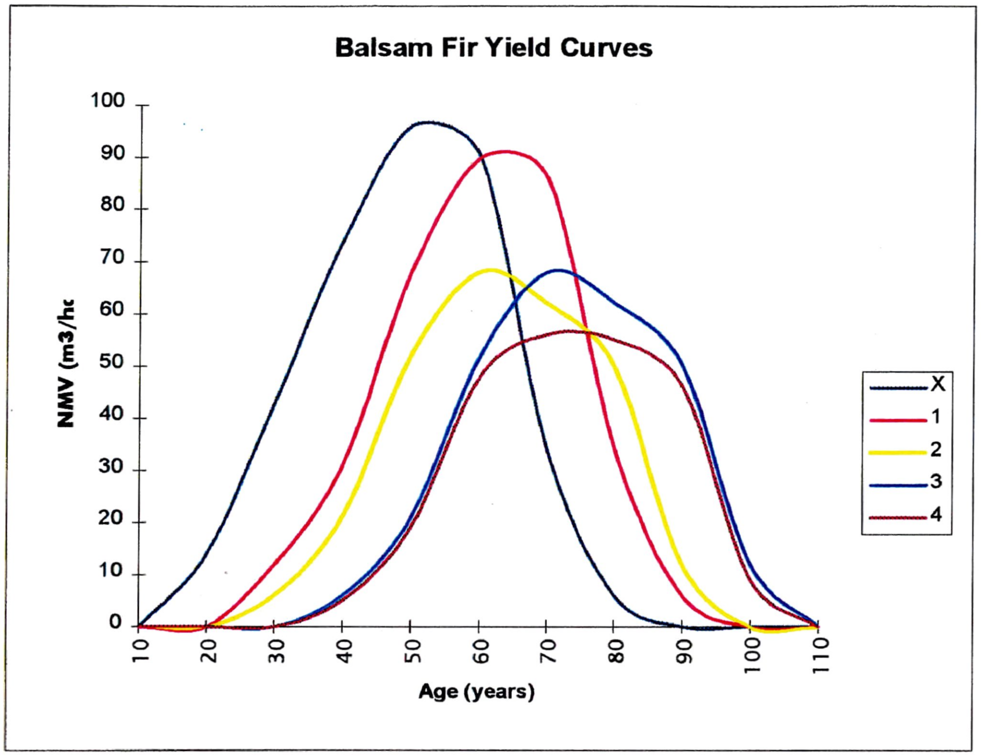
x

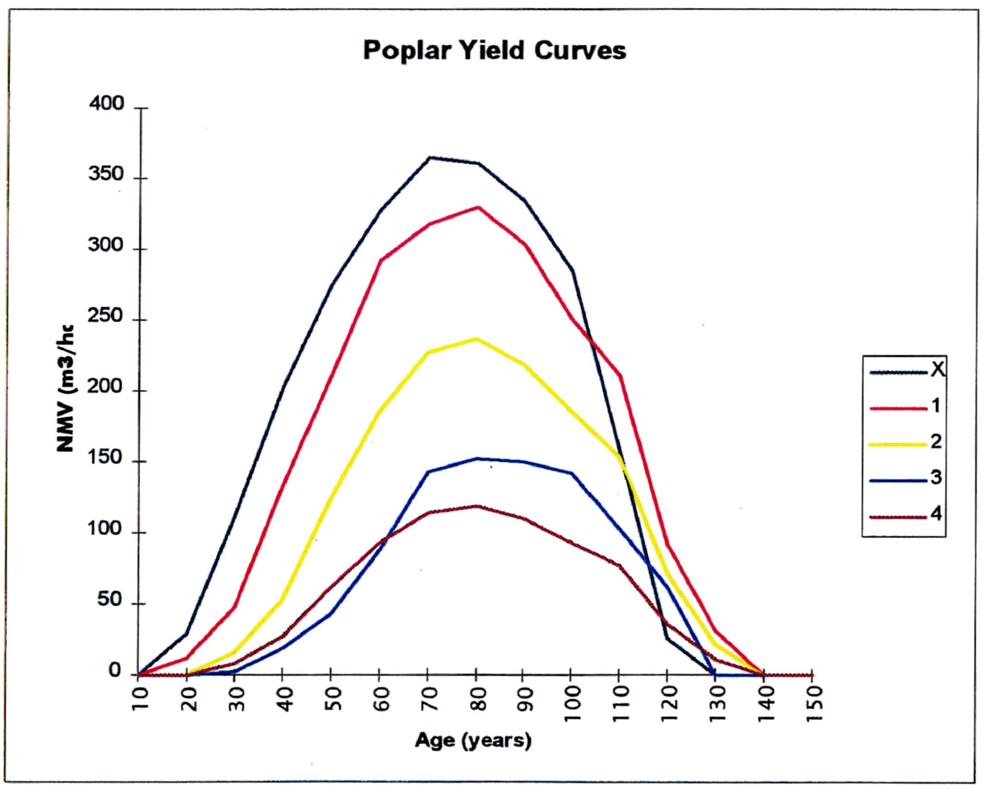


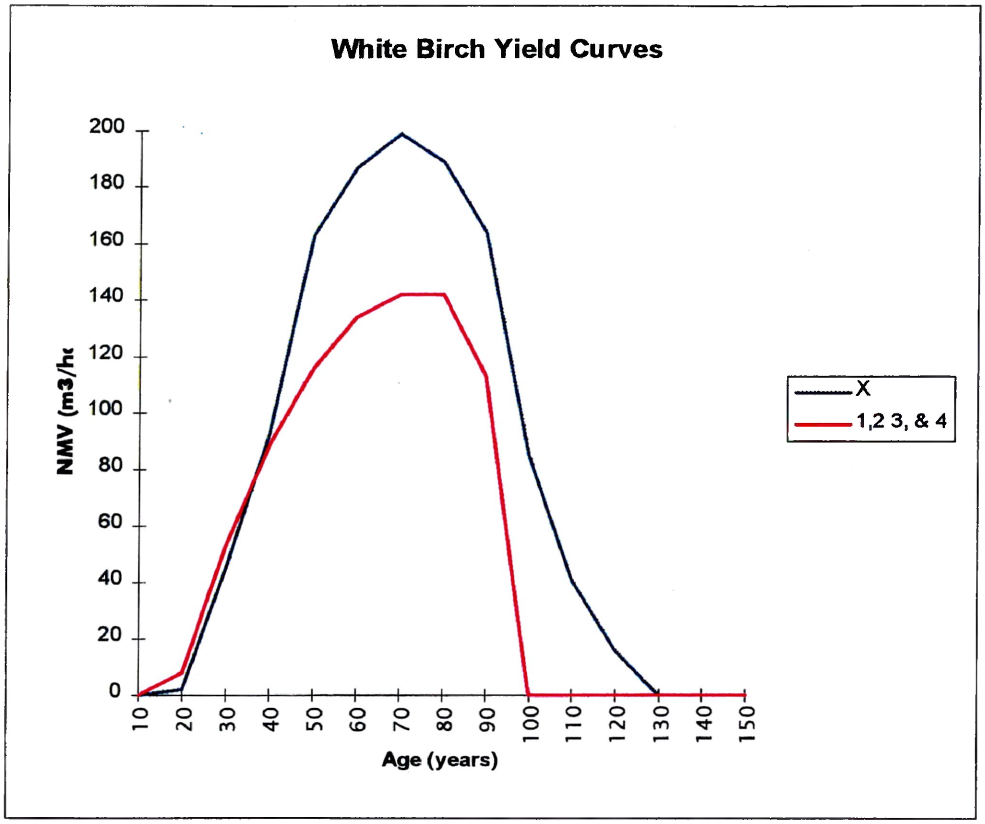
White Pine Yield Curves
600
500
400
300
200
100
0
m3/ha
10
30
50
70
90
110
130
150
170
190
Age (Years)
X, 1
1
2
3, 4



Jack Pine Yield Curves
300
250
200
150
100
50
0
NMV (m3/ha
10
20
30
40
50
60
70
80
90
100
110
120
130
140
stand age (years)
x
1
2
3
4


Balsam Fir Yield Curves
NMV (m3/ha
Age (years)
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
110
X
1
2
3
4


Poplar Yield Curves
NMV (m3/ha
Age (years)
400
350
300
250
200
150
100
50
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
X
1
2
3
4


White Birch Yield Curves
NMV (m3/hc
200
180
160
140
120
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Age (years)
X
1,2 3, & 4

APPENDIX IV

Benchmark Activity File

```
#   BENCHMARK ACTIVITY FILE
#
#   HSG run for 4 townships in the Timmins Forest.
#   Harvest 14000 m3/year spruce; 5000 m3/yr Pj; 4500 m3/yr Po.
#   No access constraints apply.
#   Obtain harvest by mimimize volume loss rule (Rule 2).
#   Project over a 100 year time in 10 10-year steps.
#
# Name the inventory dataset.
#
INVENTORY ../data/timmins.inv
#
#
# Name the category file to set up 10-year age class categories.
#
SOURCE ../data/category.dat
#
#
# Yield curves. Use the SOURCE command to read in these file names.
#
SOURCE ../data/yield.inc
#
#
# State table describing succession rules
#
STATES ../data/state.dat
#
#
# Treatment file describes the preferred silvicultural treatments by
# species and site class combinations.
#
TREATMENT ../data/basic1.trt
#
#
# Set the Operable Minimum statement..stands with less than this amount
# of volume have their merchantable volume set to 0 & are bypassed during
# harvest.
#
OPMIN 40
#
#
# Set the SILVA limit (maximum area of silvicultural treatments/yr/ha).
#
SILVA 200
#
#
# The begin statement specifies the year to update the inventory
# and begin the simulation.
#
BEGIN 1993
#
#
# Name the schedule file to contain the harvest and silvicultural treatment
# schedule information from this run of the model.
#
```

BENCHMARK ACTIVITY FILE

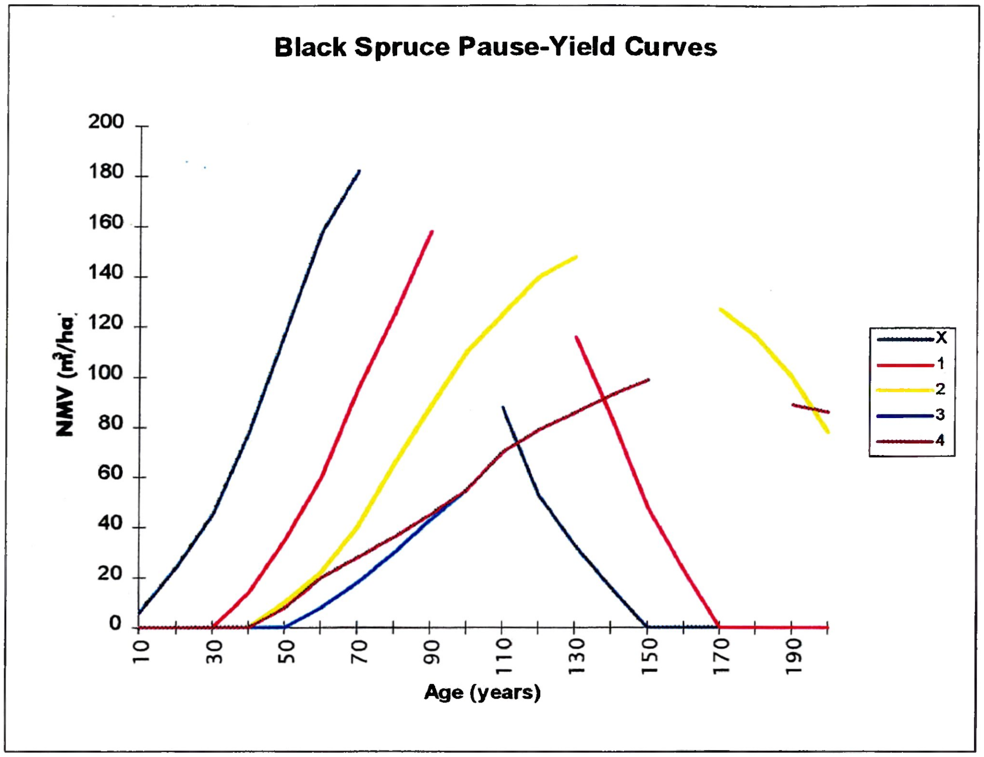
```
#
SCHEDULE basic.sch
#
#
# The SNAPSHOT command captures a version of the inventory file
# up to date as of the current time in the simulation model. This
# file will have the inventory brought up to date as of 1993.
#
SNAPSHOT bas1993.inv
#
#
# The STEP statement controls how far ahead the inventory is
# moved in each iteration, and how the harvest is to be implemented.
# In this case the model will step ahead by 10 years and will
# attempt to harvest 14000 m3/year spruce, 5000 m3/yr of jack pine
# and 4500 m3/yr of poplar (trembling aspen), according to a minimize
# volume loss rule.
#
STEP 10 : Sb/Sw=14000,Pj=5000,Po=4500 : Rule_2-Sb/Sw=14000(50),Rule_2-
Pj=5000(90),Rule_2-Po=4500(100)
#
#
# Take another snapshot of the inventory after the first 10 years of
# simulation.
#
SNAPSHOT bas2003.inv
#
#
# Step ahead another 40 years in 10 year steps. Use the same volume
# targets and harvest rules as before.
#
STEP 10 : Sb/Sw=14000,Pj=5000,Po=4500 : Rule_2-Sb/Sw=14000(50),Rule_2-
Pj=5000(90),Rule_2-Po=4500(100)
STEP 10 : Sb/Sw=14000,Pj=5000,Po=4500 : Rule_2-Sb/Sw=14000(50),Rule_2-
Pj=5000(90),Rule_2-Po=4500(100)
STEP 10 : Sb/Sw=14000,Pj=5000,Po=4500 : Rule_2-Sb/Sw=14000(50),Rule_2-
Pj=5000(90),Rule_2-Po=4500(100)
STEP 10 : Sb/Sw=14000,Pj=5000,Po=4500 : Rule_2-Sb/Sw=14000(50),Rule_2-
Pj=5000(90),Rule_2-Po=4500(100)
#
#
# Capture a snapshot of the situation 50 years in the future.
#
SNAPSHOT bas2043.inv
#
#
# Turn the schedule file record off. Spatial patterns beyond about
# fifty years in the future are too uncertain.
#
SCHEDULE
#
#
```

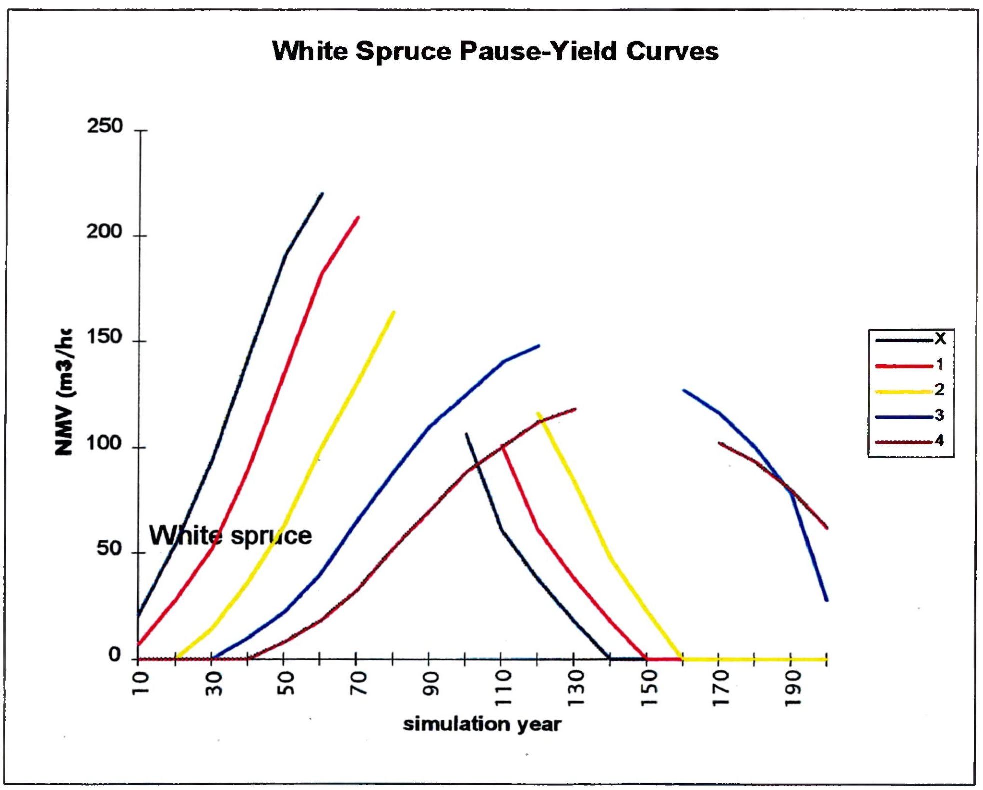
BENCHMARK ACTIVITY FILE

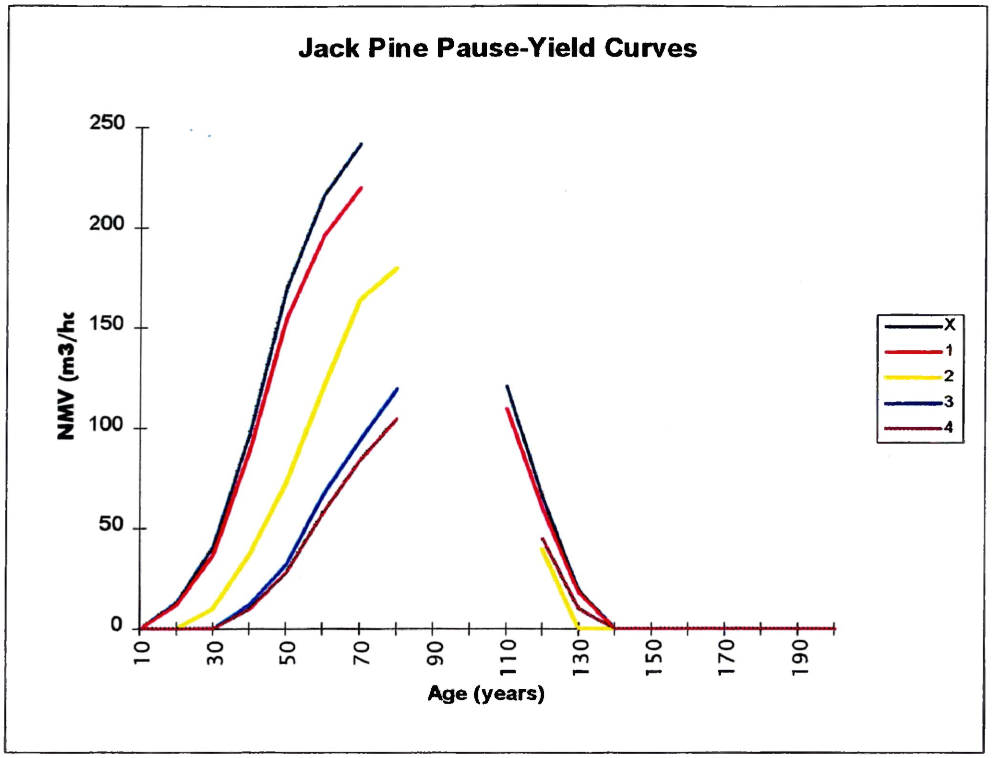
```
#
# Step ahead another 50 years to make sure that the harvest pattern
# is sustainable.
#
STEP 10 : Sb/Sw=14000,Pj=5000,Po=4500 : Rule_2-Sb/Sw=14000(50),Rule_2-
Pj=5000(90),Rule_2-Po=4500(100)
STEP 10 : Sb/Sw=14000,Pj=5000,Po=4500 : Rule_2-Sb/Sw=14000(50),Rule_2-
Pj=5000(90),Rule_2-Po=4500(100)
STEP 10 : Sb/Sw=14000,Pj=5000,Po=4500 : Rule_2-Sb/Sw=14000(50),Rule_2-
Pj=5000(90),Rule_2-Po=4500(100)
STEP 10 : Sb/Sw=14000,Pj=5000,Po=4500 : Rule_2-Sb/Sw=14000(50),Rule_2-
Pj=5000(90),Rule_2-Po=4500(100)
STEP 10 : Sb/Sw=14000,Pj=5000,Po=4500 : Rule_2-Sb/Sw=14000(50),Rule_2-
Pj=5000(90),Rule_2-Po=4500(100)
#
#
# Check for errors that occurred this run.
#
ERRORS
#
#
# Finished.
#
#
QUIT
```

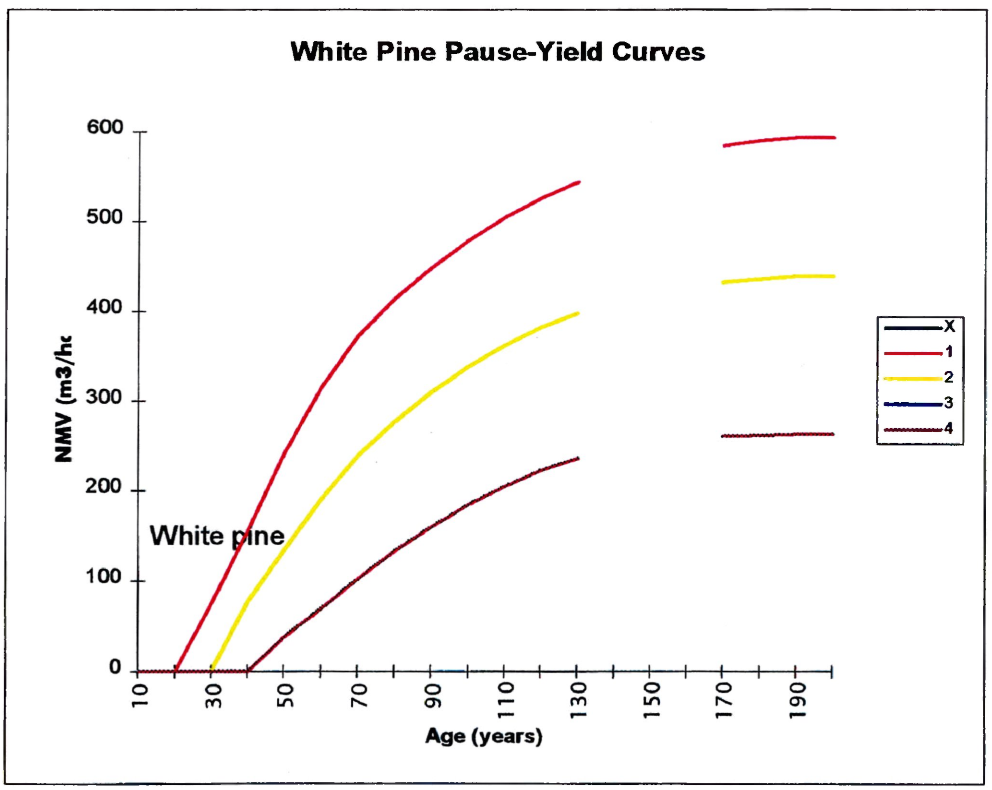
APPENDIX V

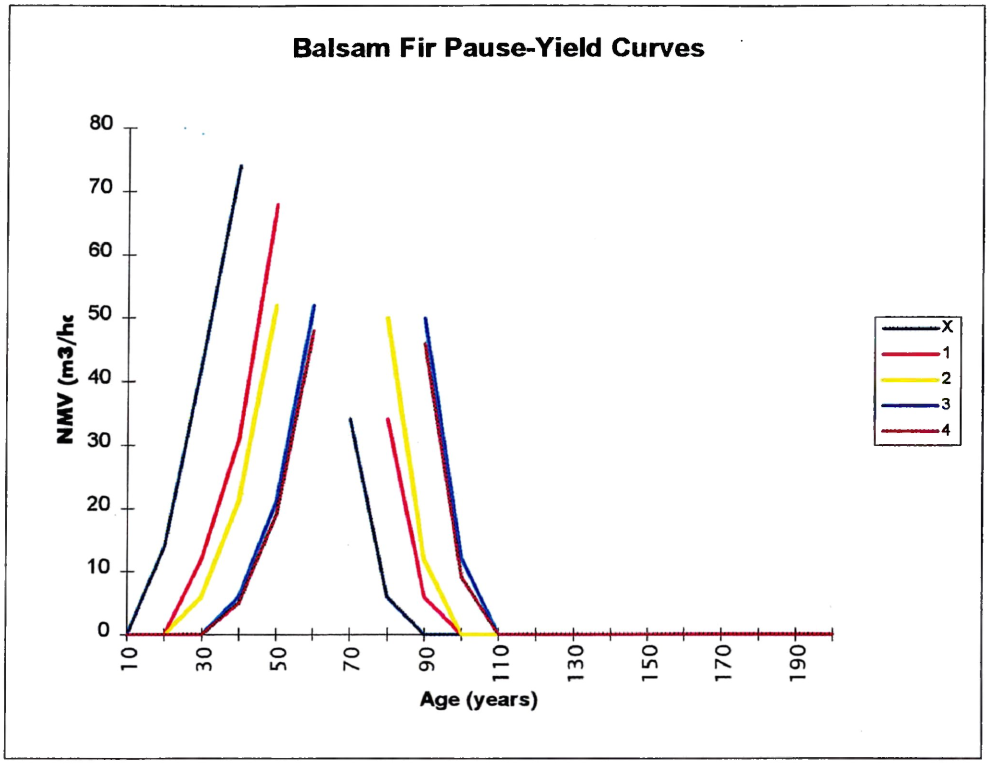
Pause-Yield Curves

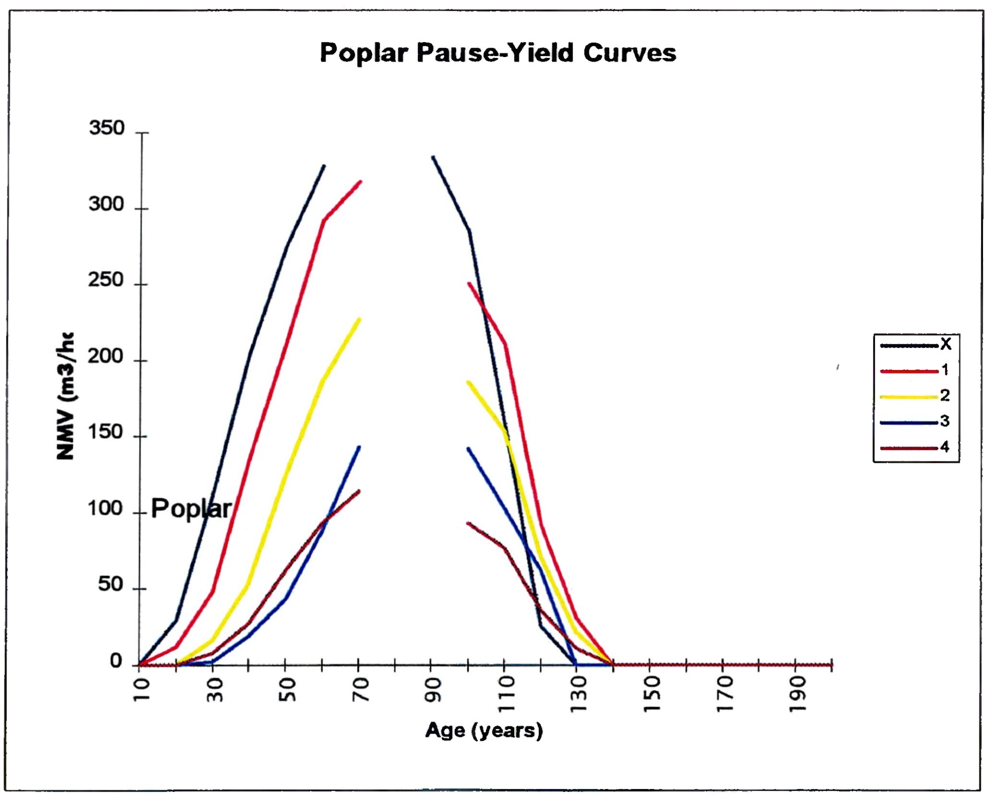

Black Spruce Pause-Yield Curves
NMV (m3/ha)
Age (years)
X
1
2
3
4
200
180
160
140
120
100
80
60
40
20
0
10
30
50
70
90
110
130
150
170
190

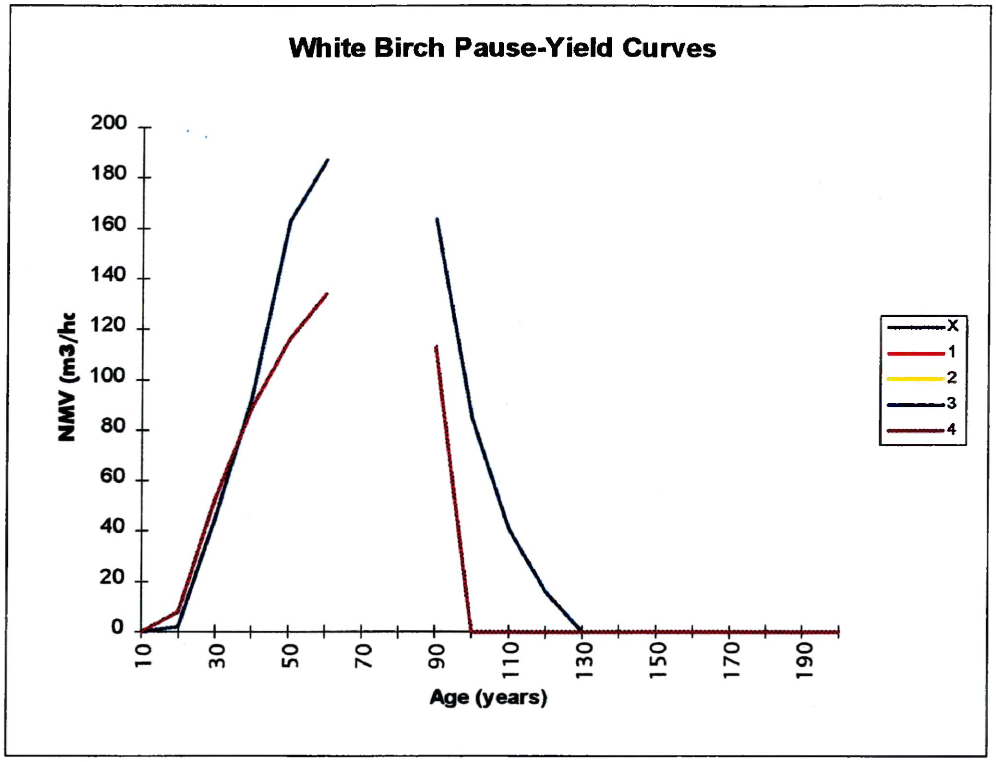

White Spruce Pause-Yield Curves
NMV (m3/ha
simulation year
White spruce
X
1
2
3
4
250
200
150
100
50
0
10
30
50
70
90
110
130
150
170
190


Jack Pine Pause-Yield Curves
NMV (m3/ha
250
200
150
100
50
0
10
30
50
70
90
110
130
150
170
190
Age (years)
X
1
2
3
4


White Pine Pause-Yield Curves
NMV (m3/ha
600
500
400
300
200
100
0
White pine
10
30
50
70
90
110
130
150
170
190
Age (years)
X
1
2
3
4

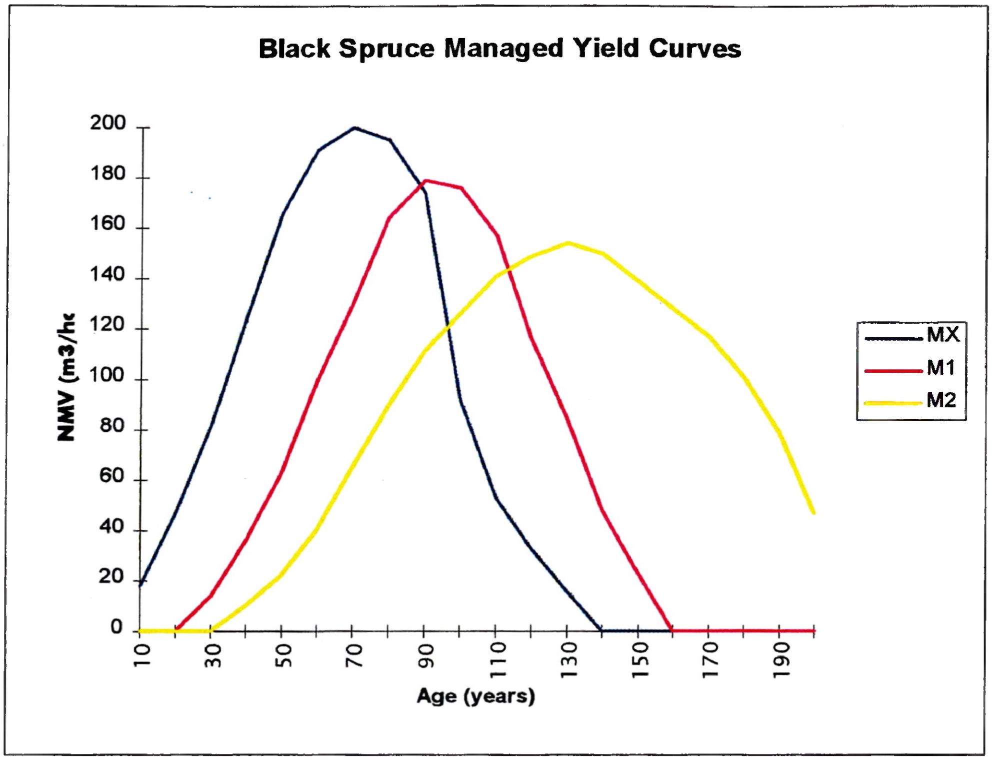

Balsam Fir Pause-Yield Curves
NMV (m3/ha
Age (years)
0
10
20
30
40
50
60
70
80
10
30
50
70
90
110
130
150
170
190
X
1
2
3
4

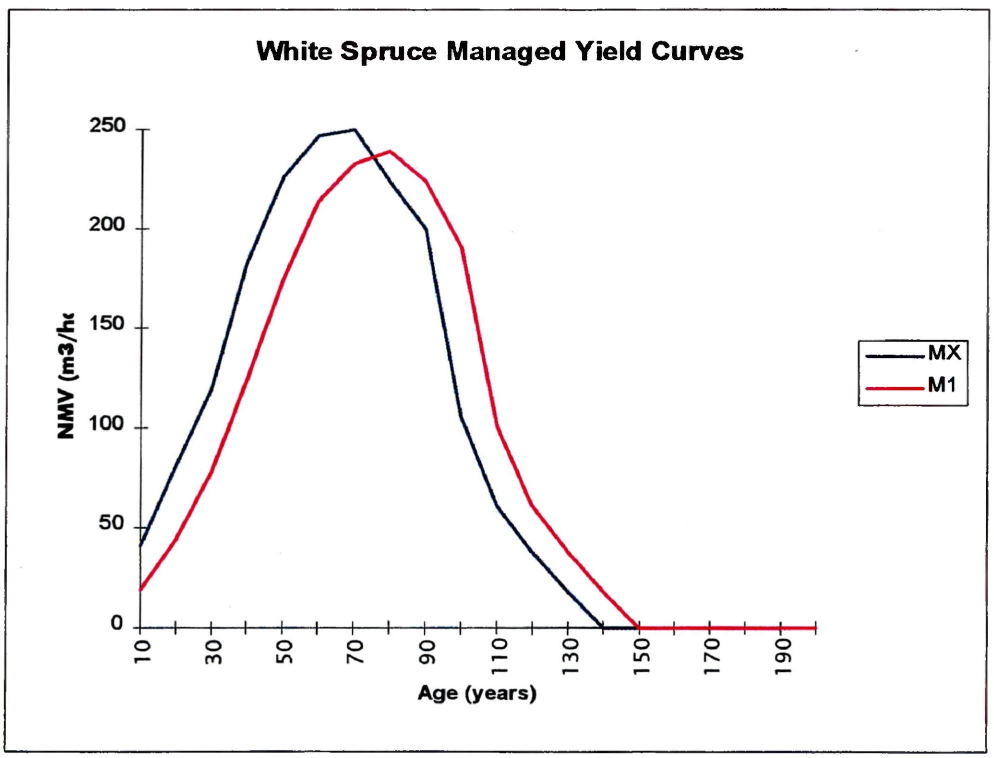

Poplar Pause-Yield Curves
NMV (m3/ha
Age (years)
Poplar
0
50
100
150
200
250
300
350
10
30
50
70
90
110
130
150
170
190
X
1
2
3
4

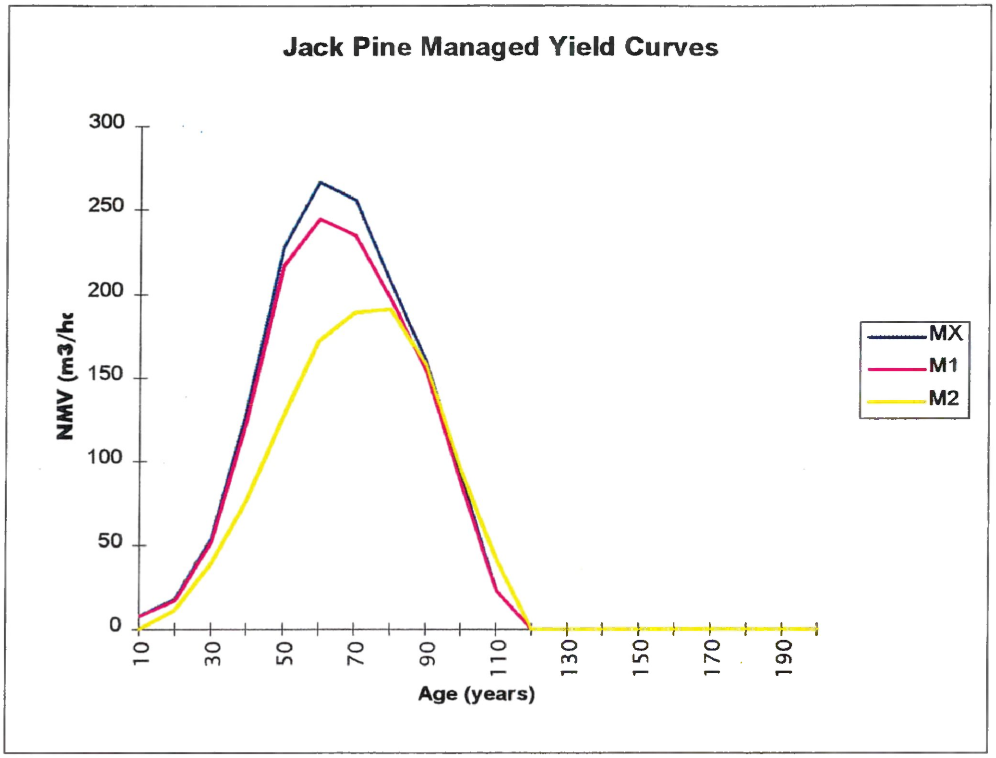

White Birch Pause-Yield Curves
200
180
160
140
120
100
80
60
40
20
0
NMV (m3/ha
10
30
50
70
90
110
130
150
170
190
Age (years)
X
1
2
3
4

APPENDIX VI

Managed Yield Curves

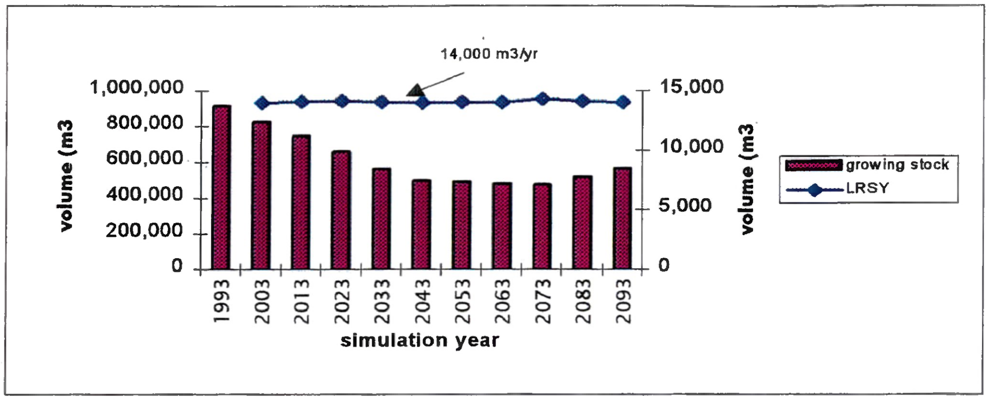

Black Spruce Managed Yield Curves
NMV (m3/ha)
Age (years)
MX
M1
M2
0
20
40
60
80
100
120
140
160
180
200
10
30
50
70
90
110
130
150
170
190


White Spruce Managed Yield Curves
NMV (m3/ha)
Age (years)
MX
M1
0
50
100
150
200
250
10
30
50
70
90
110
130
150
170
190

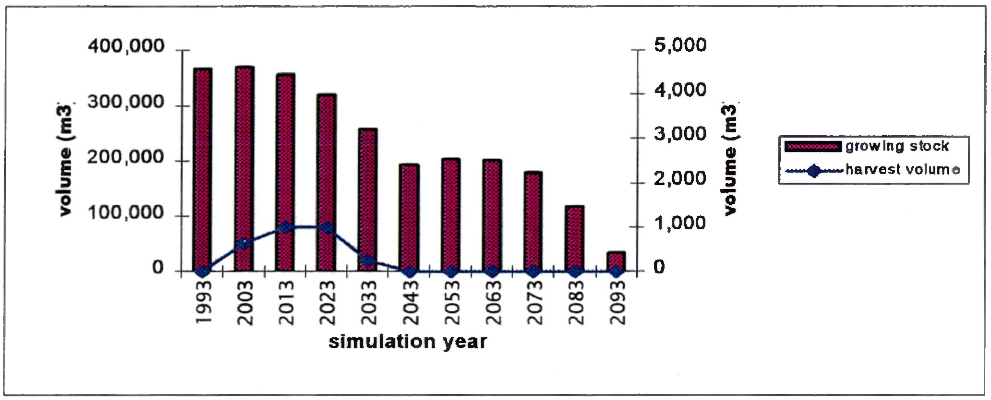

Jack Pine Managed Yield Curves
300
250
200
150
100
50
0
NMV (m3/ha
10
30
50
70
90
110
130
150
170
190
Age (years)
MX
M1
M2

APPENDIX VII

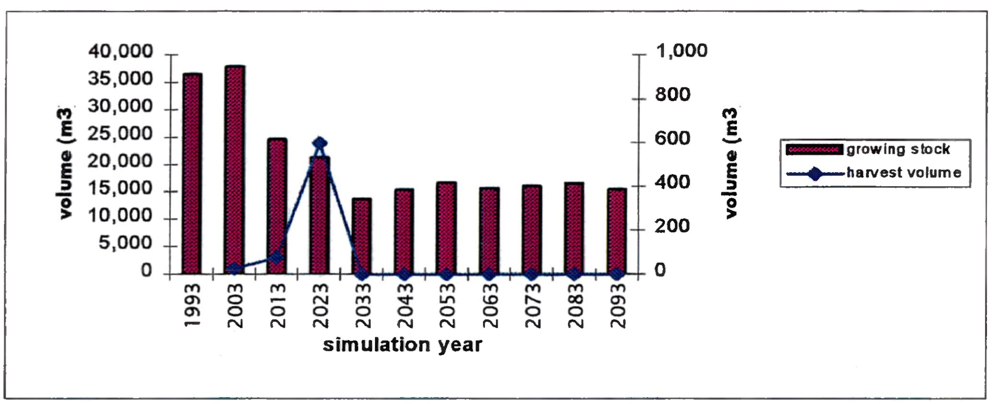
Growing stock curves and LRSY's and/or harvest volumes for
black and white spruce, jack pine, and white pine
(No-Regeneration Silviculture Scenario)



Black and white spruce

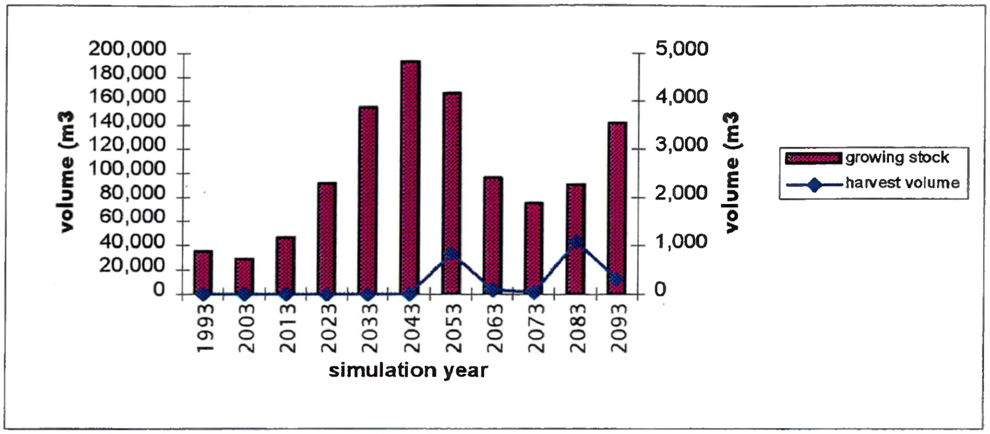


Jack pine

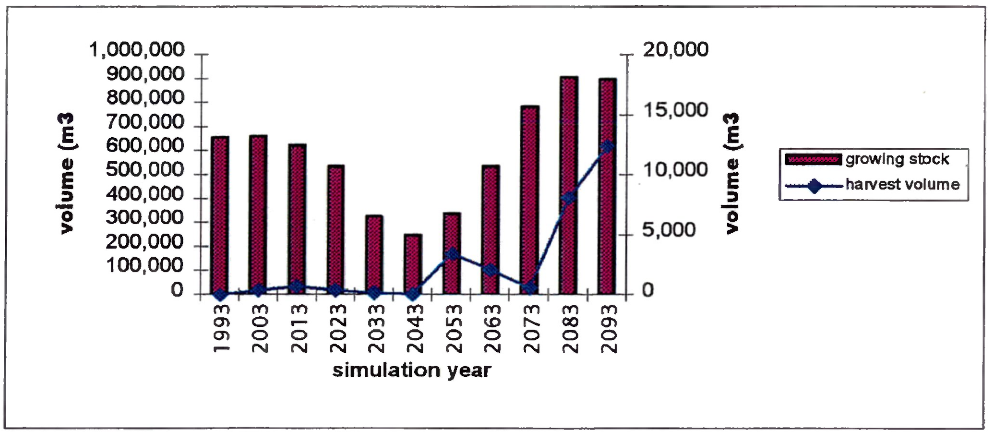


White pine

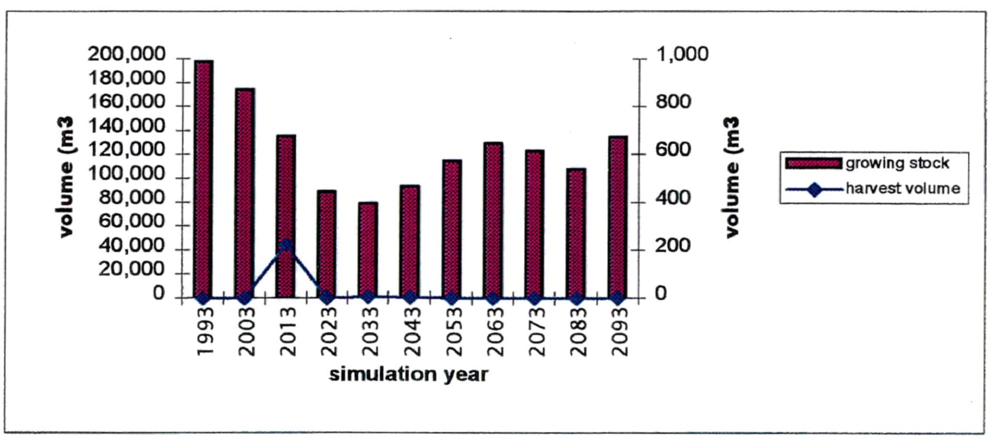
Growing stock curves and LRSYs and/or harvest volumes for black and white spruce, jack pine, and white pine (No-Regeneration Silviculture Scenario).



Balsam fir



Poplar

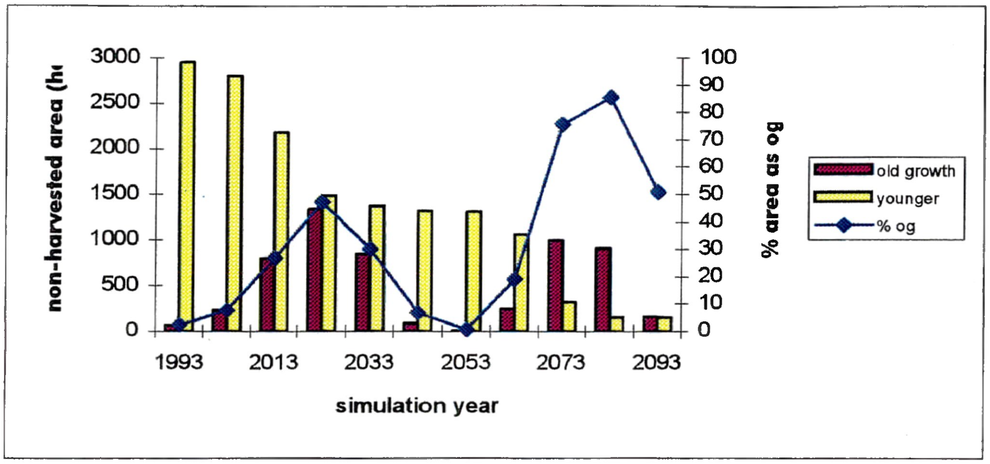


White birch

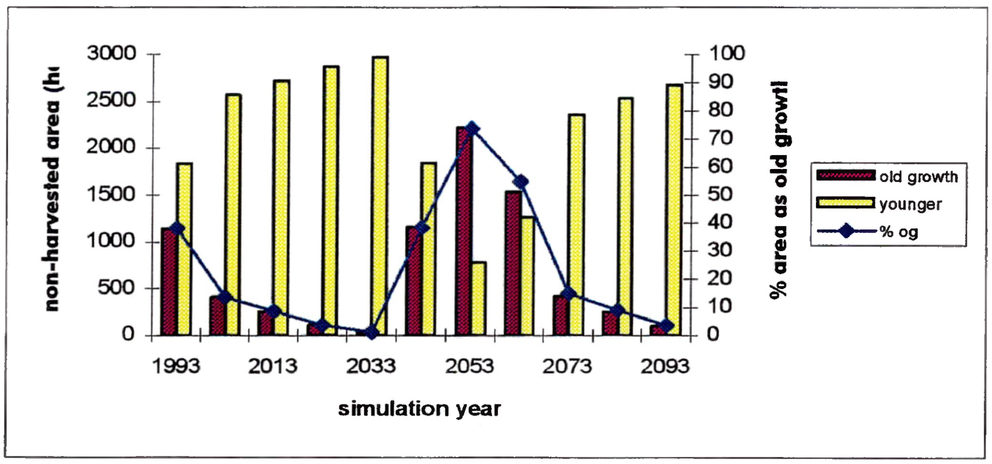
Growing stock curves and harvest volumes for balsam fir, poplar and white birch (No-Regeneration Silviculture Scenario).

APPENDIX VIII

Supply of old growth over time for jack pine and balsam fir
(No-Regeneration Silviculture Scenario)

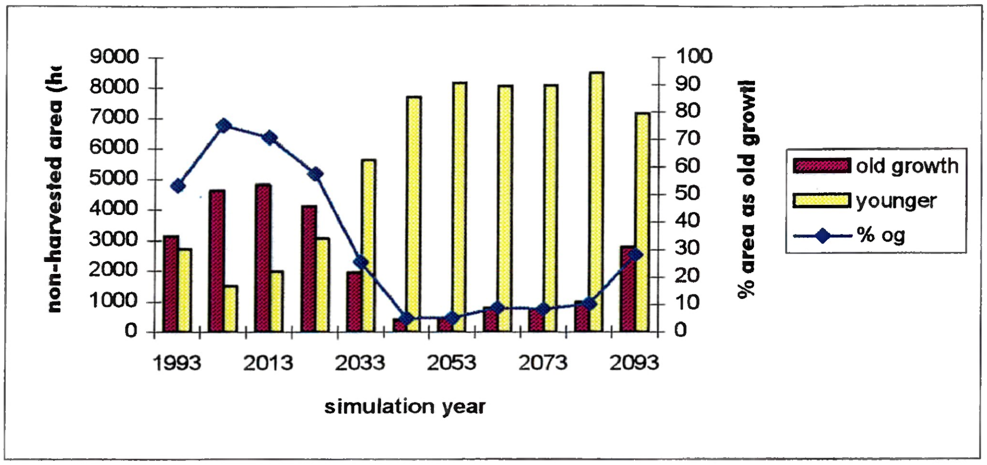


Jack pine

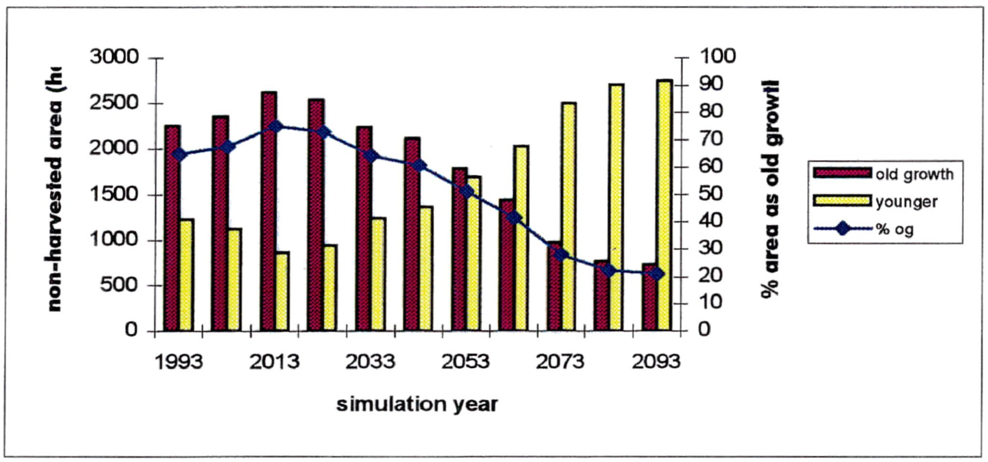


Balsam fir

Supply of old growth over time for jack pine and balsam fir
(No-Regeneration Silviculture Scenario)



Poplar

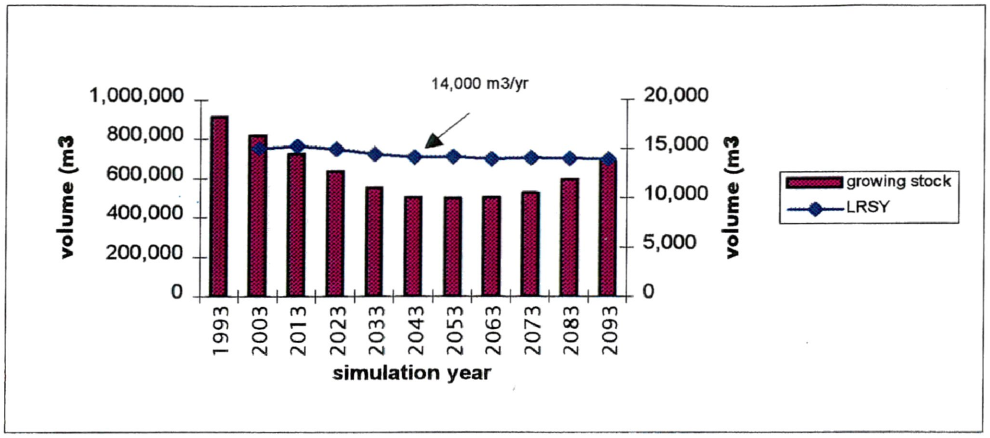


White birch

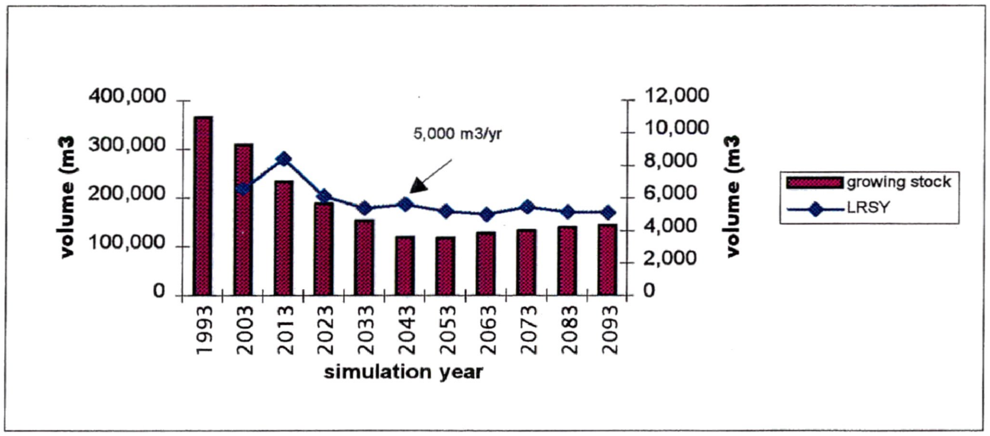
Supply of old growth over time for poplar and white birch
(No-Regeneration Silviculture Scenario)

APPENDIX VIX

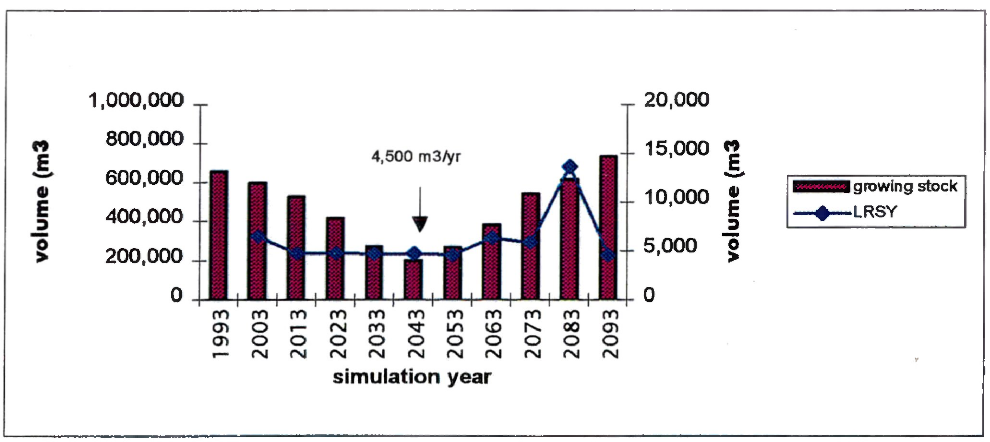
Growing Stock Curves and LRSY's for black and white spruce,
jack pine, and poplar
(Benchmark Scenario)



Black and white spruce



Jack pine

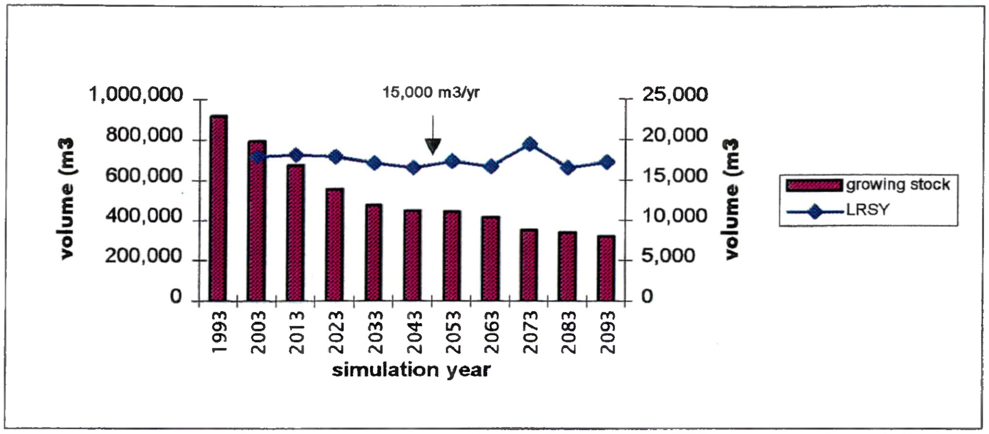


Poplar

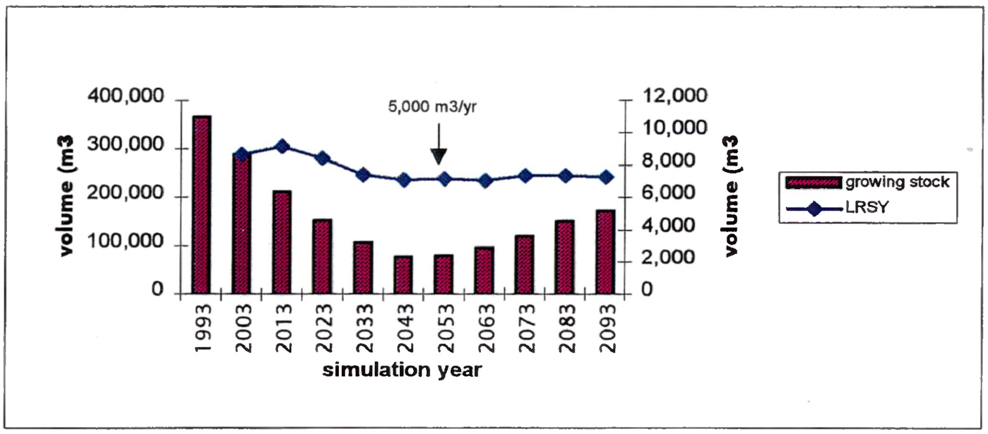
Growing stock curves and LRSYs for black and white spruce, jack pine, and poplar (Benchmark Scenario).

APPENDIX X

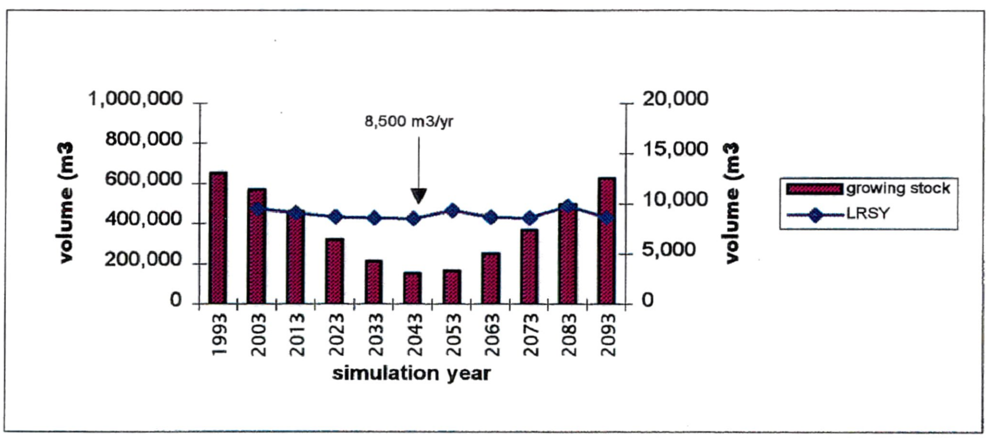
Growing stock curves and LRSYs for black and white spruce, jack pine, and poplar (Maximum-Regeneration Silviculture Scenario)



Black and white spruce



Jack pine

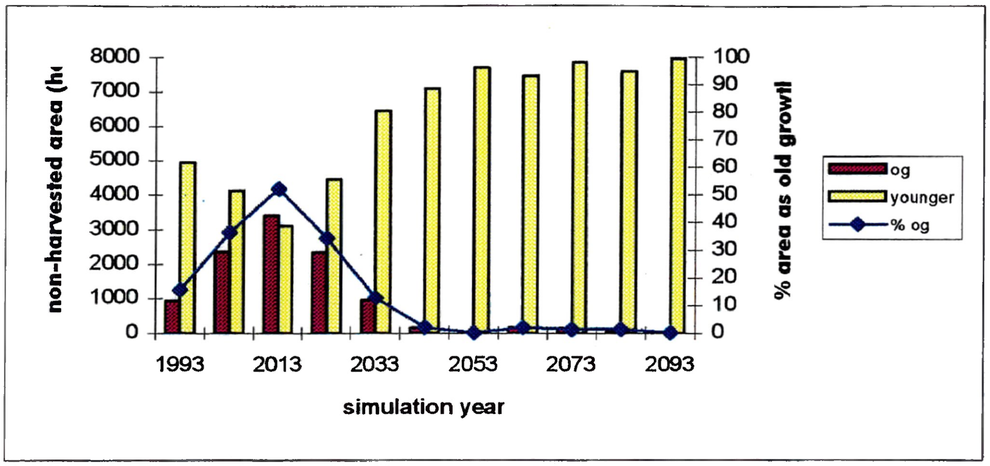


Poplar

Growing stock curves and LRSYs for black and white spruce, jack pine, and poplar (Maximum-Regeneration Silviculture Scenario).

APPENDIX XI

Supply of old growth over time for poplar (Maximum-Regeneration Silviculture Scenario)

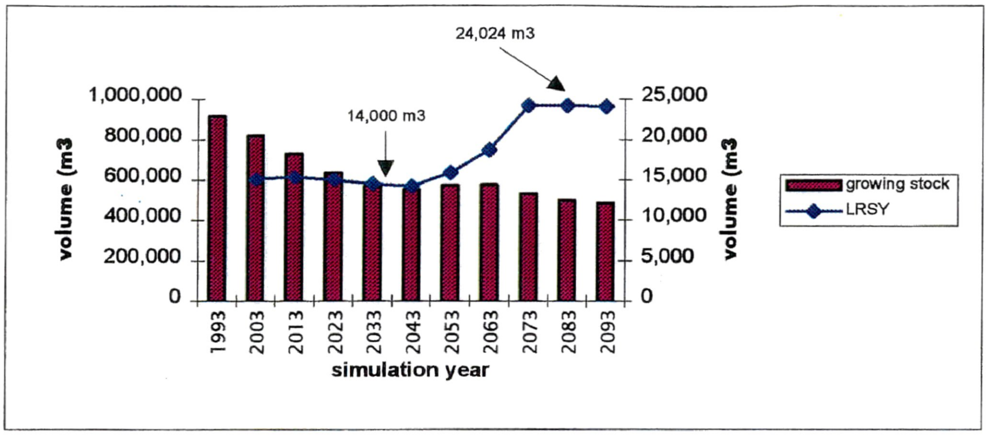


Poplar

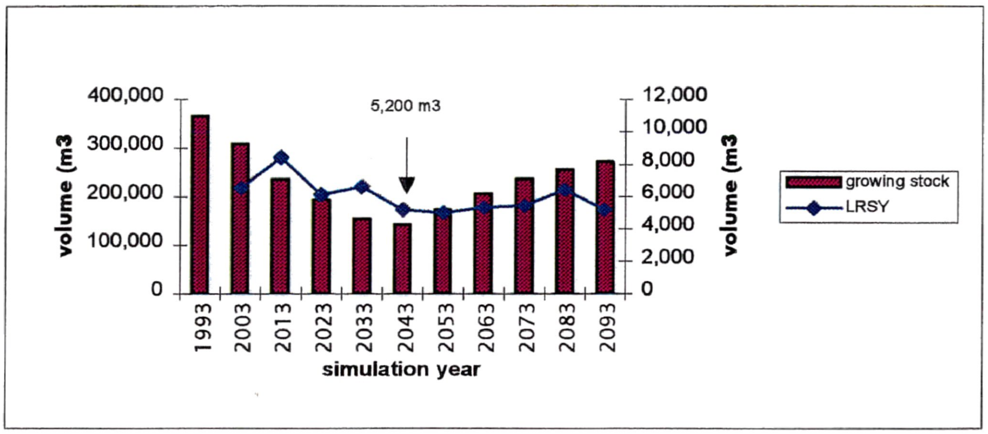
Supply of old growth over time for poplar (Maximum-Regeneration Silviculture Scenario).

APPENDIX XII

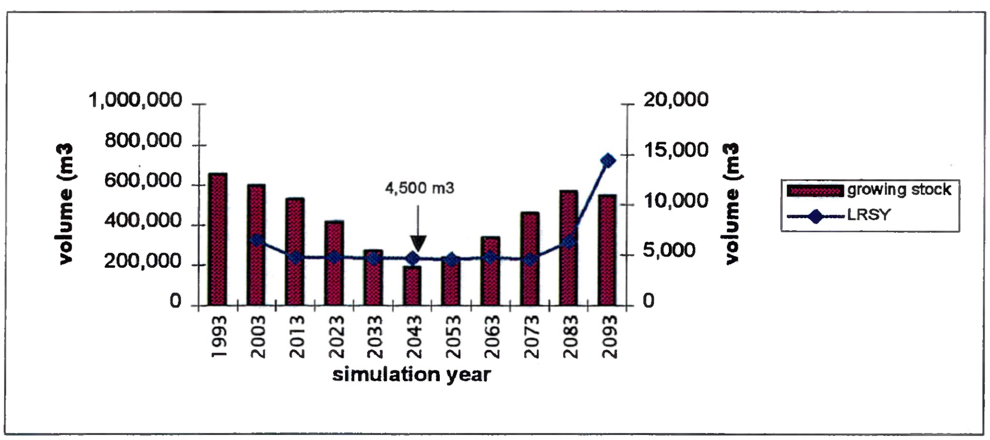
Growing stock curves and LRSYs for black and white spruce, jack pine and poplar (Concentrated-Silviculture Scenario)



Black and white spruce



Jack pine



Poplar

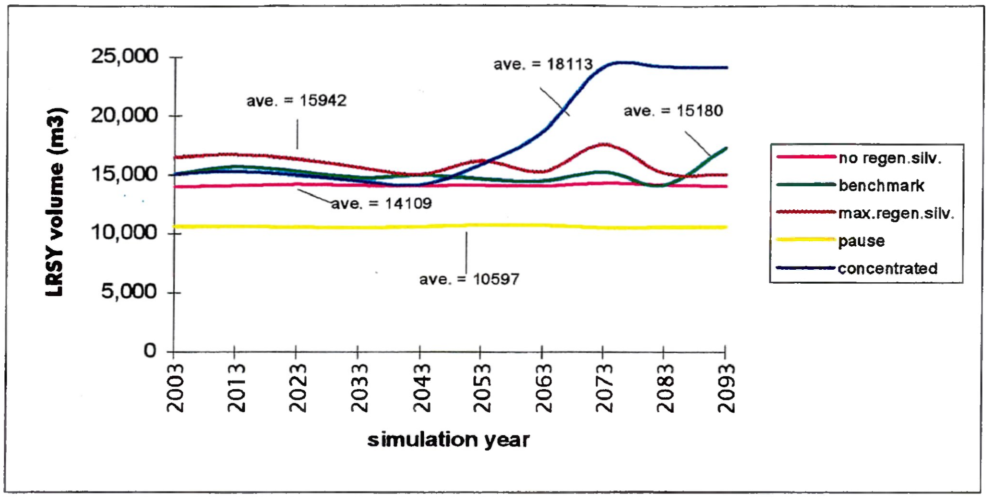
Growing stock curves and LRSYs for black and white spruce, jack pine and poplar (Concentrated-Silviculture Scenario)

APPENDIX XIII

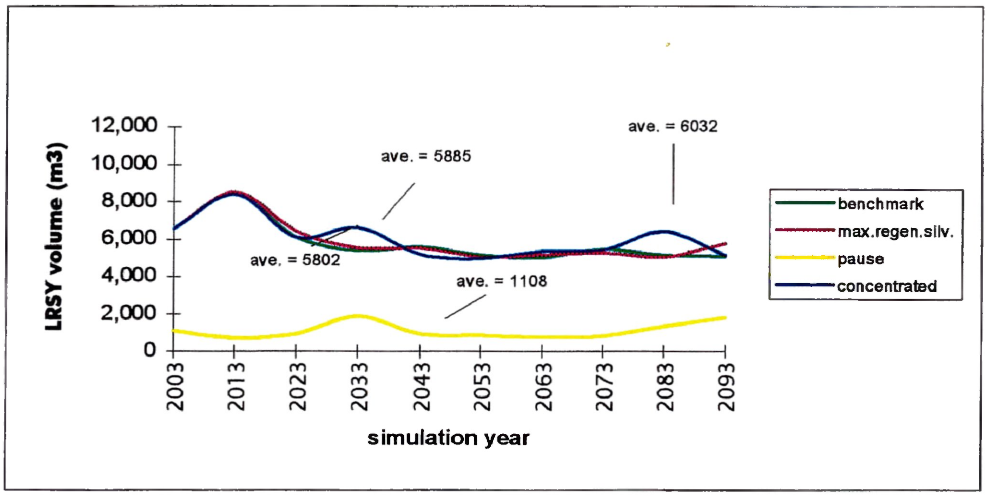
Long-run sustained yield levels: a comparison between simulation scenarios for black and white spruce, jack pine, and poplar.

and

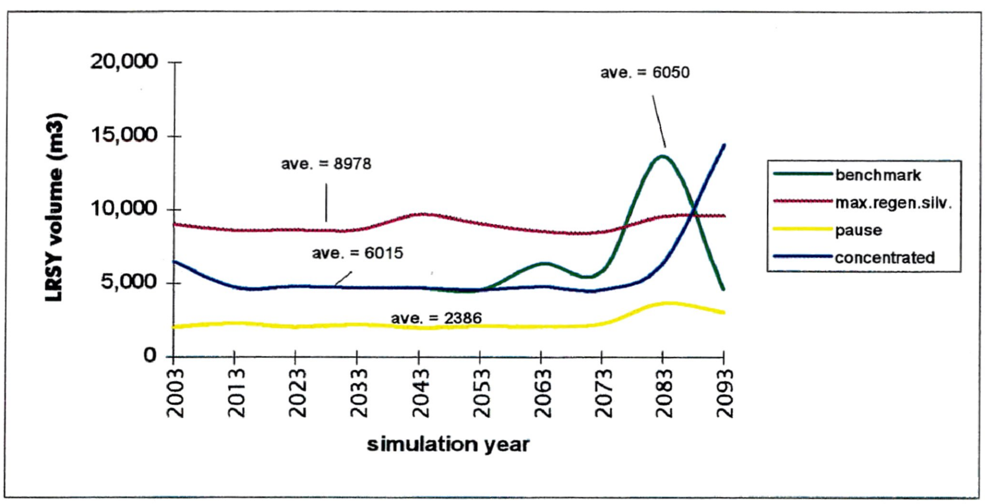
Growing stock curves: a comparison between simulation scenarios for white pine, balsam fir, and white birch.



black and white spruce

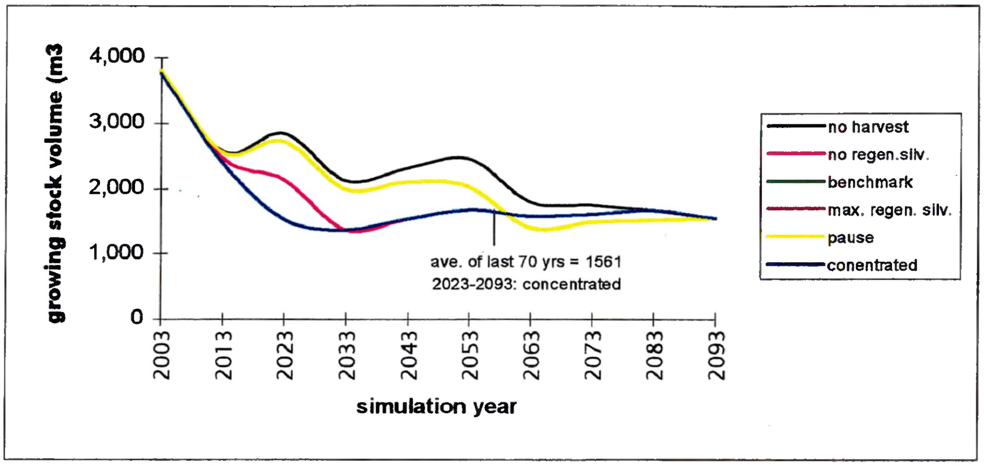


jack pine

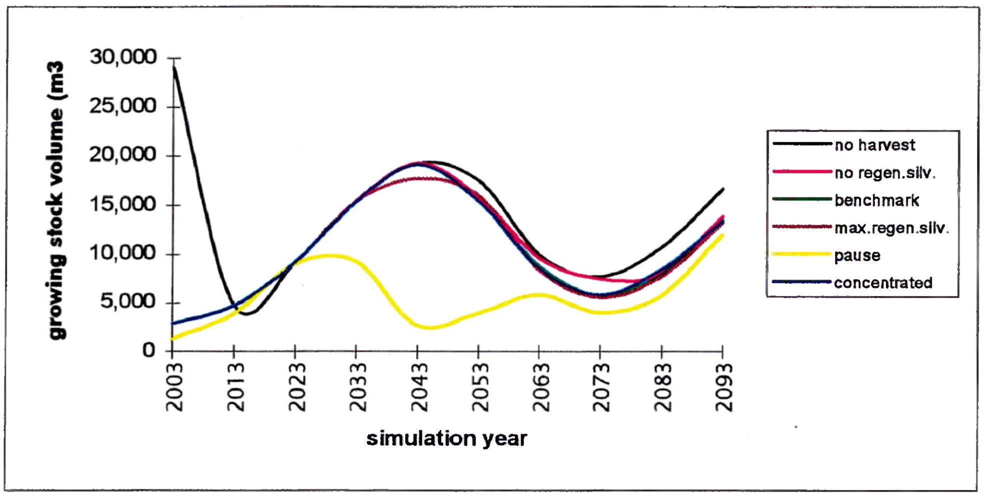


poplar

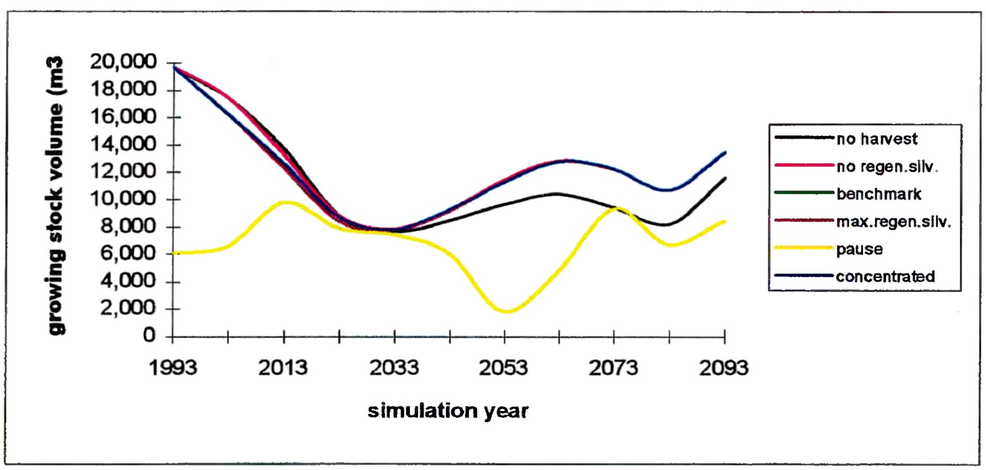
Long-run sustained yield levels: a comparison between simulation scenarios for black and white spruce, jack pine and poplar.



white pine



balsam fir



white birch

Growing stock curves: a comparison between simulation scenarios for white pine, balsam fir, and white birch.