FUTURE CLIMATE CHANGE IMPACTS ON THE BOREAL FOREST IN NORTHWESTERN ONTARIO

IMPLICATIONS FOR THE FORESTRY SECTOR AND THE LOCAL COMMUNITY

by

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AUTHOR'S DECLARATION FOR ELECTRONIC SUBMISSION OF A THESIS

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

A large body of research has documented evidence of climate change impact already occurring on different systems on earth, future impacts can be expected. Accordingly, research is urgently needed to analyze the potential impacts of climate change on forest ecosystems in order to contribute to better landscape planning and management. This thesis investigates how climate change affects landscape change, and how to use this understanding in the analysis of land-use and landscape planning and management to adapt to climate change impacts. In particular, this study examines how climate change may impact a managed forest in terms of timber availability, and the regional community that relies on it for its survival.

I hypothesized that the Boreal forest in north western Ontario will change in the short term (i.e. 60 years) in species composition and will produce less available timber as a result of human-induced climate change as modeled by different General Circulation Models plus harvesting, compared to a baseline climate. The study objectives were (a) to evaluate the degree of change in land cover (species composition) under forest harvesting and various climate change scenarios; (b) to analyze timber availability under different climate change scenarios, and harvesting; (c) to describe possible scenarios of land cover change as a result of climate change impact and harvesting to assist in policy-making related to land-use and landscape planning; and (d) to identify possible sources of both land-use conflicts and synergies as a result of changes in landscape composition caused by climate change.

The study area was the Dog-River Matawin forest in north western Ontario (≈ 8 x 104 ha). It is currently under harvesting. I used the Boreal Forest Landscape Dynamic Simulator (BFOLDS) fire model to simulate landscape change under different climate change scenarios (CCSRNIES A21, CGCM2 A22), which were then compared to simulations under a baseline climate scenario (1961-1990). I also developed an algorithm for the geographic information systems Arc View©, that selected useful stands, and simulated harvesting and regeneration rules after logging, processes not currently included in BFOLDS. The studied period covered 60 years to analyze impacts in the medium term in the landscape change.

Results obtained were the following. (1) There will be a shortage in timber availability under all scenarios including the baseline. The impacts of climate change will cause a deficit in timber availability much earlier under a warmer scenario with respect to the baseline. The combined impact of climate change and harvesting could diminish timber availability up to 35% compared to the baseline by year 2040 under the CCSRNIES A21 scenario mainly due to an increase in fires. Deficits will occur 10 years before in the same scenario compared to the baseline (by year 2035). (2) In both scenarios and the baseline, there will be a younger forest. In 60 years, there will not be mature forest to support ecological, social and economic processes, as the forest will only have young stands. (3) Results obtained indicated that species composition will not change importantly among the scenarios of climate change and the baseline every decade, but there will be a change in dominance along the 60 years of the simulation under each scenario including the baseline. Softwood increased in dominance and hardwood decreased in all scenarios.

The period length used in the simulation of 60 years appeared to be too short to reveal conspicuous changes in species composition. Increases observed in softwood over hardwood related to the increase in fires which promoted the establishment of species such as jack pine as well as the application of regeneration rules after logging. This finding did not agree with the hypothesis. Results of timber availability were consistent with what I expected. Warmest climate change scenarios (CCSRNIES A21) impacted both the amount of timber available (less availability every ten years) from the beginning of the simulation and the time when deficits occurred.

There are important economic, social and environmental implications of the results of this study, namely a future forest that would be young and would supply much less timber. For the forestry industry, production goals would be hindered in the medium term, falling short of industry demands. For a society that depends heavily upon the forest to survive, declining production can imply unemployment, thus affecting the welfare of the community. For the environment, such a young, fragmented forest could be unable to sustain important key species and ecological processes, leading to a loss of biodiversity, Land-use and landscape planning should be used to regulate how the land is used to minimize climate change impact.

They should be further used as adaptation tools, to help in ameliorate those climate change impacts that do occur.

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Dedication

I dedicate this work to God, who always has guided me for unexpected but always exciting experiences.

I also dedicate this work to my beloved wife Marisa. Thank you for being always with me during these the long years in this far away country.

To my little son Arturo Rafael, you are now only one year old and does not understand the transcendence of this stage in my life, but know that you are my inspiration and the meaning of everything I do now. I love you.

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Mom, I know you are taking care of me from whenever you are. I miss you.

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List of acronyms

BFOLDS. Boreal Forest Landscape Dynamic Simulator.

CC. Climate change.

CCIARN. Canadian Climate Impacts and Adaptation Research Network

CCPB. Canadian Climate Program Board.

CCME. Canadian Council of Ministers of the Environment.

CFS. Canadian Forest Service.

CICS. Canadian Institute for Climate Studies.

COSEWIC. Committee on the Status of Endangered Wildlife in Canada.

FSM. Fire Regime Simulation Module (in BFOLDS).

GCM. General Circulation Model.

GHG. Green house gases.

GIS. Geographic Information System.

GST. General systems theory.

IPCC. Intergovernmental panel on climate change.

LE. Landscape ecology.

LL. Lands for Life.

MF. Ministry of Forests.

MUM. Multiple use modules.

NAS. National Academy of Sciences.

NLM. Neutral landscape models

NRC. Natural Resources Canada.

OMNR. Ontario Ministry of Natural Resources.

OLL. The Ontario Living Legacy.

RCM. Regional Circulation Models.

SRES. Special Report on Emission Scenarios.

TAR. Third Assessment Report.

UNFCCC. United Nations Framework Convention on Climate Change.

VTM. Vegetation Transition Module (in BFOLDS).

1 Introduction

1.1 Human-induced climate change within the context of landscape and land-use planning and management

> There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities. (IPCC, 2001b:10)

The impacts of global temperature increases for 2004 and projections for the following 50 years have recently been summarized (MET, 2005). In Canada impacts are expected a variety of sectors (Canadian Council of Ministers of the Environment, 2003; IPCC, 1996; 2001a). As climate change impacts are expected to be more extreme at higher latitudes (IPCC, 2001b), ecosystems in Canada are at higher risk than other regions. This thesis relates to the forest ecosystems in Northern Ontario, Canada.

Canadian forests cover about 400 M ha and comprise 10 % of the world's forests (Natural Resources Canada, 2001) and 30% of the world's boreal forests (Natural Resources Canada, 2004c). Direct employment from Canada's forestry sector was 361,300 in 2002, or 2.3% of total employment not to mention indirect employment. Forestry related employment is spread all across Canada but is concentrated in Quebec (122,700), British Columbia (87,300) and Ontario (86,200) (Canadian Forest Service, 2004). Potential impacts of climate change in the 21^{st} century in the case of Ontario forests are indicated on Table 1.1. Negative effects from climate change on the forestry sector could be detrimental to Canada and hinder the objectives of sustainability that Canadian authorities and population are proud to support:

> As a recognized world leader in sustainable forest management, Canada must be able to demonstrate to the world that its forest sector is economically viable, environmentally responsible and socially accountable.(Natural Resources Canada, 2004c:4)

Given the important role of the boreal forest in global climate regulation as well as in global raw materials production, the negative effects on the Canadian boreal forest would also have global implications.

Ecosystems are permanently changing, and climate change can accelerate that change at unexpected rates. It is no longer valid to plan and manage forests (or any ecosystem) on the assumption of a static situation (Spittlehouse and Stewart, 2003). Acknowledgement of this constant change is relevant to practice better planning and management. The environmental and economic importance of forests in Canada points towards construction of scenarios revealing potential negative (or positive) impacts of climate change, which can aid in planning and management. Planning that takes into consideration potential climate change affects (negative or positive) will help in fulfilling that goal.

Table 1.1 Potential major impacts of climate change on Ontario forests (Colombo et al., 1998)

• In north western Ontario, fires and droughts will become more frequent and severe.
• Insect outbreaks and disease are expected to mirror fire and drought incidence.
• New plant associations are expected to occur as individual species are favored over others and as rates of migration differ between plant species.
• North eastern Ontario may experience enhanced forest growth and productivity, while drought, fire, insects, and disease in north western Ontario are expected to reduce growth rates and threaten wood supplies, perhaps within the next 30 years.
• Unique ecosystems and threatened and endangered species may be unsustainable if they have highly specific climate requirements.
• Biodiversity conservation may change meaning as a management objective if climate change allows species to migrate to new areas, there is strong genetic selection pressure, and the ability to reproduce is reduced in some species.

To address complex environmental issues related to climate change, research must include analyses of both past, and future, to identify driving forces in regional landscape dynamics. Thus this thesis aims to encourage discussion about change and process in an exploited boreal landscape typical of those found from Alaska, through Europe to Siberia, and to use that knowledge for better planning and management.

1.2 Purpose of the thesis

This thesis is concerned with understanding drivers of landscape change. Specifically, it aims to understanding the role of climate change in landscape dynamics and to use this understanding in land-use and landscape planning and management as well as to adapt to climate change. This thesis examines how climate change can impact a managed boreal forest in terms of timber availability for a whole regional community that relies on the forest and timber availability. It also analyses species composition change as a result of climate change impacts.

1.3 Hypothesis

Boreal forest in north western Ontario will change in the short term (i.e. 60 years) in species composition, and timber availability as a result of human-induced climate change, as modeled by various General Circulation and harvesting models, compared to a baseline climate.

1.4 Objectives

General objectives

a) To study the link between climate change and landscape change.

b) To analyze the role of landscape and land-use change in directing adaptation to climate change.

Specific objectives

a) To evaluate the degree of change in land cover (species composition) under forest harvesting and various climate change scenarios.
b) To analyze timber availability under different climate change scenarios, and harvesting according to present demand in the area.
c) To describe scenarios of land cover change resulting from climate change impact and harvesting, so as to assist policy-making related to land-use and landscape planning.
d) To identify possible sources of both conflicts and synergies among stakeholders in their relationship with the landscape as a result of changes in landscape composition caused by climate change.

1.5 Theoretical framework

This thesis is framed within the following theories and paradigms. Systems and hierarchy theory will be used to understand the transcendence of the research problem within a comprehensive framework. Landscape ecology provides tools to identify drivers of landscape change, as well as concepts and techniques of landscape analysis.

1.6 Conceptual framework

The conceptual framework of this thesis is shown in Figure 1.1. Causes and facts of climate change are reviewed on Section 3.2. Climate change scenarios were constructed. A modeling exercise was performed based on a landscape fire model (BFOLDS), over a 60 year period, stopping every 10 years to apply harvesting and regeneration. Statistics on available timber were employed to translate climate impacts to an understandable language for the forestry industry and local communities. The ultimate goal is to provide a tool to inform stakeholders and the community about potential climate change impacts and to raise awareness, so as to promote participative planning exercises. Thus this research may help in designing adaptation (and mitigation) measures.

1.7 Structure of the thesis

The thesis was divided into six chapters, including this introduction.

1. *Introduction.* This chapter establishes of the general framework, objectives and approaches taken in this work.

2. *Theoretical consideration in landscape ecology, management and design.* This chapter reviews the philosophical foundations of landscape ecology, like holism, systems and hierarchy theories, as well as its focus and methodological approaches. Some fundamentals of landscape planning and management are also outlined.

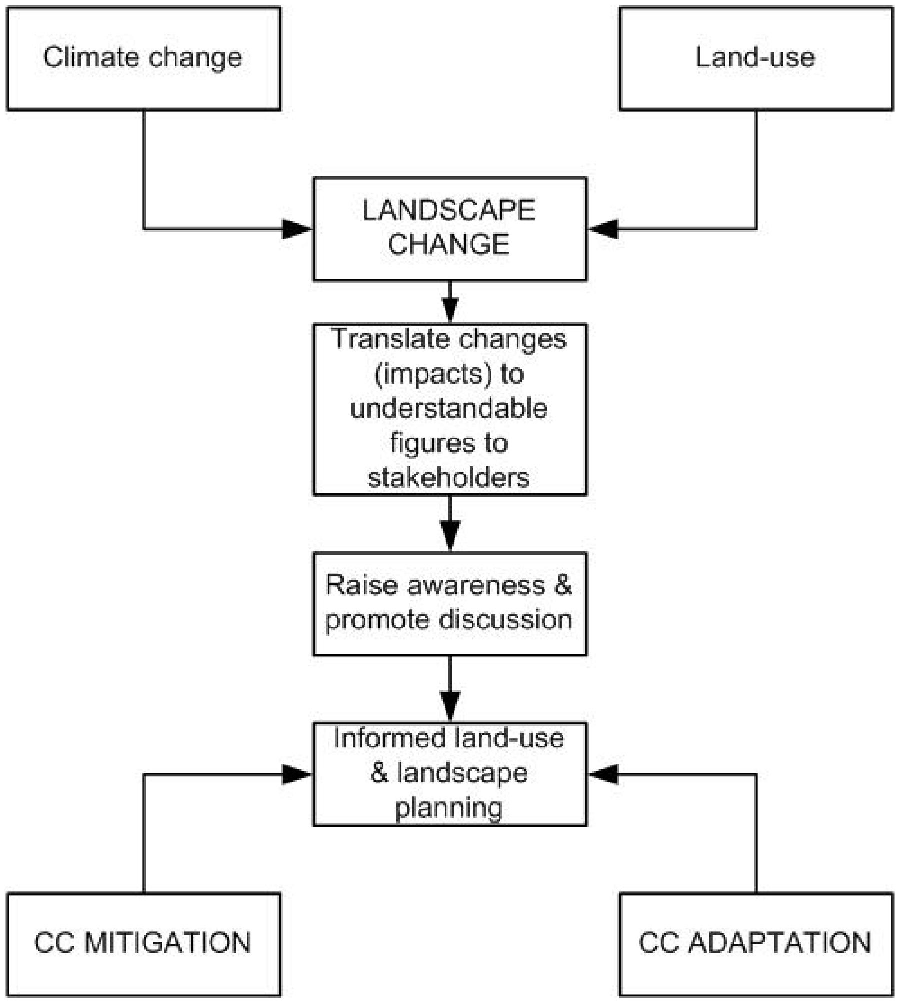

Figure 1.1 Conceptual framework.

3. *Recent climate change as a driver of landscape change and function.* Chapter 3 reviews the climate change as a driver of landscape change. Here the issue of climate change is defined and discussed in detail. Some known and potential impacts of the recent climate change phenomenon on ecosystems are also explained. The boreal forest in Canada is reviewed in the light of the potential impact of climate change. This chapter also explains some technical aspects of the study of climate change including general circulation models, scenario construction and some downscaling techniques. A summary of the concepts of adaptation and mitigation is included, as well as some relationships between land-use and climate change. Simulations of climate change and harvesting are also reviewed. The economic importance of

forestry is summarized here. Finally land-use planning in Ontario is discussed to contextualize discussion of the provincial planning framework, which is intended to result on sustainable land use.

4. *Identification of climate change impacts in north western Ontario Boreal forest and the impacts on the forestry sector.* This chapter explains the case study of climate change impacts on the Dog River-Matawin forest in north western Ontario. The modeling of the landscape uses the fire landscape model BFOLDS. This sector describes the methods devised to calculate yields, and to allocate useful timber, and to develop rules for to simulating harvesting decisions and regeneration after logging.

5. *Results.* In this chapter, results are presented in terms of species dominance changes during the time of the simulation (60 years), and figures are presented about timber available and logged under various scenarios.

6. *Discussion and conclusions.* The results are discussed first, and then the response to the objective of the whole thesis is covered. Environmental and economic implications from the results are discussed to reveal some potential conflicts and synergies. The chapter also identifies issues raised for future research. Some planning recommendations are made.

7. The final part presents several Appendixes. Here raw data, charts, and a glossary of the more used terms are included.

2 Theoretical considerations in landscape ecology, and landscape planning and management

2.1 Introduction

The concepts of landscape, environmental planning and land management are central in this thesis and constitute the conceptual framework dealing with the main thesis topic; analysis of climate change impacts on landscape change in northwestern Ontario.

This chapter explores theoretical foundations of the environmental movement in North America, and philosophical underpinnings of the work related to landscape analysis. First, the concepts of the land ethic, holism, general systems theory, hierarchy theory, and the implications of scale are analyzed. Second, the chapter discusses how landscape ecology is an appropriate framework for analyzing landscapes. Two approaches to landscape analysis are reviewed: Zonneveld's and Forman and Godron's. Third, landscape change as a part of landscape ecology is defined within the context of the impact of climate change on ecosystemsl. Definitions of landscape and management are discussed and related to landscape ecology. Finally, environmental planning is introduced and related to the issue of climate change.

The thesis uses some concepts like environment, ecology, ecosystem, ecosystem health, and landscape that deserve precise definitions. First, ecology was defined by Haeckel as:

> The entire science of the relations of the organisms to the surrounding exterior world, to which relations we can count in the broader sense all the conditions of existence. These are partly or organic, partly of inorganic nature."

It has also been defined as the study of the relationship between organisms and their environment (Eggleton, 1939).

Ecosystem is defined as "the system composed of physical-chemical-biological processes active within a space-time unit of any magnitude, i.e. the biotic community plus its abiotic environment" (Lindeman, 1942:400). It is important to note that Tansley (1935) proposed that size and extend (i.e. scale) of ecosystems is determined according to the purposes and methods for particular studies. This definition is pertinent for this thesis as the landscape concept is repeatedly used. If an ecosystem can have different scale depending of the study focus, then landscape can be identified as an ecosystem as well.

Environment is the total surroundings of an organism, including other plants and animals and those of its own kind. Relationship includes interactions with the physical world and with members of the same species.(Smith and Smith, 1998).

Regarding ecosystem health, Haskell et al. (1992), noted that:.

> An ecological system is healthy and free from "distress syndrome" is it is stable and sustainable- that is, if it is active and maintains its organization and autonomy and is resilient to stress (p.9).

This definition sets a framework to define thresholds from which determine when an ecosystem can be considered "unhealthy".

This work relates to the analysis of the boreal landscape. Landscape has been defined differently. The definition by Zonneveld (1995) fulfills the objectives of this thesis.

> Landscape is a complex of relationship systems, together forming (also by virtue of its physiognomy) a recognizable part of the earth's surface, and is formed and maintained by the mutual action of abiotic and biotic forces as well as human action. (Zonneveld, 1995:4).

In this thesis the landscape is understood as an ecosystem that frames various processes expressed though change, function and structure. These definitions set the stage for analyzing the role of climate change on landscape change.

2.2 Conceptual framework

The landscape concept has different meanings for different people (Wiens, 1999). As a so that, working with it requires some conceptual and methodological boundaries. This thesis recognizes the landscape as a framework for planning for different stakeholders in the land use. Stakeholders can be envisaged to include organisms other than only humans. This thesis develops around the dynamics of the use of landscapes by humans (e.g. the forestry sector), and the relationship between changes in climate and landscape change at regional scale. In this section, some conceptual, philosophical and theoretical foundations are proposed for conservation and management of the land(scapes) (Zonneveld, 1995). Definitions of landscapes and the scale concept are indicated. Finally, the landscape concept is established as a framework for planning land use.

2.2.1 Philosophical roots in the study of the landscape

Why care about good landscape management? Does it matter? Is it not enough to take goods from the wild without further consideration? One cannot argue that careless for the environment (landscape) to less materially and technologically developed societies. Many ancient and traditional societies have a close relationship with their surrounding environment. No matter how developed a society is, a cultural trail is needed to transit from a solely resource-based vision of the environment to another that cares for the ”natural”.

The shift from a purely utilitarian view to a more comprehensive environmental vision (Mitchell, 2002) is rooted in various philosophical and theoretical propositions. Some of them are presented in this section. The land ethic philosophy forms a possible foundation for the North American environmental conservation movement. Second, holism, provides a conceptual framework to understand nature as a “whole”. Then the general systems theory (GST) and the theory of hierarchy (and the implications of scale) are presented as important supporting theories. Finally a relationship between these concepts and global issues is established.

2.2.1.1 Human attitudes towards nature in North America

Attitudes towards nature and the wild, can range from the very respectful to fear that can conduce to ecosystem destruction. Kellert (1996) has shown this and shown advanced the understanding of human values regarding nature in North America. Through a series of studies developed over two decades, he explained how humans react and think about the environment. He proposes the term “biophilia” to explain that humans always have the need relate with their natural environment. He proposes nine values that reveal how humans understand and relate to nature (Table 2.1). Those attitudes act as catalysts for the evolution of a values system in North America. It is true that the human society (at least a sector) seems to be advancing to a more respectful relation to the natural environment, but the fact that different views exist, obliges one to keep in mind that societal heterogeneity can help but also impede conservation actions.

Table 2.1. Typology of human values towards Nature (from Kellert, 1996).

Values	Definition
Utilitarian	Use and exploitation of nature.
Naturalistic	Experience nature.
Ecologic-Scientific	Systematic study of nature.
Aesthetic	Appreciate the physical appearance of nature.
Symbolic	Use of nature as language and thought.
Humanistic	Attachment and love for aspects of nature.
Moralistic	Reverence for nature.
Dominionistic	Dominance of nature and control of it
Negativistic	Aversion, fear from nature.

2.2.1.2 The Land Ethic

Although the human concern for protection of the land can be seen around the world (Primack, 1998), in North America the Land Ethic has been influential as an ethical reference in landscape and environmental studies. The land ethic was proposed by Aldo Leopold in *A Sand County Almanac* (Leopold, 1949). Leopold argued for an ethic that extends the boundaries of the biotic community, and including soils, water, plants, and animals or, collectively, the land. He regarded land as all things on, over, or in the earth.(Leopold, 1949). Leopold considered the following (Primack, 1998):

a) Nature, as landscape, organized as a system of interrelated processes. He concluded that the most important goal of conservation was to maintain the health of natural ecosystem and ecological processes, and as such, the conservation of the system, and;

b) Humans as a part of the ecological community, rather than standing apart from nature and exploiting it.

In these propositions, various concepts are relevant to landscape ecology studies covered later in this chapter. One is the notion that humans are a part of the environment, with the same importance as the other organisms and elements of the biota. The other is the concept of an entity with holistic character. Landscape is seen as a system, so a change in any component will be reflected in a change in the whole system. Although the system sometimes compensates for these changes, it may return to a different location of the "thermodynamic branch" (system's trajectory) (Kay, 1991), resulting in a change from the original state.

The advances in natural sciences in North America show the positive influence of the land ethic. This can be seen in the comprehensive frameworks for planning and studying landscapes, that not only consider the object or process under study, but also the "surroundings" that include other important processes beyond it. Examples of them are ecosystem management (Grumbine, 1994), landscape ecology (Forman and Godron, 1986), and the proposals for ecological land classification (Rowe, 1980). They show how the spirit of the land ethic has strong influence in North America.

2.2.1.3 Holism

Another important philosophy is holism. Smuts (1926) postulated the theory of holism, which establishes that reality can be understood as a whole without knowing each particular component of it. In Smuts' (1926:86) words:

> [In taking an organism as an example] as a type of a whole, we notice the fundamental holistic characters as a unity parts which is so close and intense as the to be more than the sum of its parts; which not only gives a particular conformation or structure to the parts but so relates and determines them in their synthesis that their functions are altered; the systems affects and determines the parts, so that they function towards the "whole"; and the whole and the parts therefore reciprocally influence and determine each other, and appear more or less to merge their individual characters: the whole is the parts and the parts are in the whole, and this synthesis of whole and parts is reflected in the holistic character of the functions of the parts as well as the whole.

Thus the most important concept of holism is that; *the whole is more than the sum of its parts*. Holism also indicates how each element is significant only because of its position and relationship with the surrounding elements (Antrop, 2000).

Some theories of analyzing of systems (living and non-living) have a strong basis on holism. Feibleman (1954), proposed the *theory of the integrative levels.* With this theory Feibleman sets a method of analysis of the whole through the understanding of its integrative levels. He formulated the *laws of the levels* (Table 2.2) that explain a system behaviour and function based on the analysis of the levels of integration of a whole. Feibleman also proposed rules of explanation

Table ***2.3***. These propositions enrich the discourse related to holism and ways to analyze the whole.

Table 2.2 Laws of the levels (Feibleman, 1954).

1.	Each level organizes the level of levels below.
2.	Complexity of the levels increases upwards.
3.	In any organisation the higher levels depends upon the lowers.
4.	In any organization, the lower level is directed by the higher.
5.	For an organization at a given level, its mechanism lies at the level below and its purpose at the level above.
6.	A disturbance introduced into an organization at any one level reverberates at all the levels it covers.
7.	The time required for a change in organization shortens as we ascend the levels.
8.	The higher the level, the smaller its population of instances.
9.	An organization at any level is a distortion of the level below.
10.	Events at any given level affect organizations al other levels.
11.	Whatever is affected as an organization has some effects as an organization.

Table 2.3 Rules of explanation (Feibleman, 1954).

1.	The reference of any organization must be at the lowest level which will provide sufficient explanation.
2.	The referent of any organization must be to the highest level which its explanation requires.
3.	An organization belongs to its highest level.
4.	Every organization must be explained finally on its own level.
5.	No organization can be explained entirely in terms of a lower or higher level.

Novicoff (1945) explained *the concept of integrative levels and biology*. This is another interpretation of holism focusing on systems. He explains the concept as follows:

> The concept of integrative levels describes the progress of the inanimate, animate and social worlds. It maintains that such progress is the result of forces which differ in each level and which can properly be described only by laws which are unique for each level. Since higher level phenomena always include phenomena at lower levels, one can not fully understand the higher levels without an understanding of the lower level phenomenon as well. But a knowledge of the lower levels does not enable us to predict, a priory, what will occur at a higher level (p. 214).

Rowe (1961) interpreted the understanding of the whole based on the analysis of the integrating levels in his paper "the level-of-integration and ecology". This author explains that the objects we perceive are volumes discriminated from their surrounding. A level corresponds to an object as defined. A level (an object) should contain volumetrically and structurally lower levels (smaller objects), which in turn are part of the levels above. He goes beyond in proposing that each object will constitute the immediate environment of the object at lower level. This approach is a spatial one that understands a whole as a volumetric "container" of smaller ones.

These theories show the importance of holism as a tool for explaining how a system behaves; they also contain many elements of the hierarchy theory as explained below.

As complex systems (Antrop, 2000; Boothby, 2000) landscapes benefit from the analysis of wholes, whereas a reductionist approach would be difficult to apply to broad scales[1] (Zonneveld, 1995).

Zonneveld (1990), noted that each whole (in this case, a landscape) is a system which is organized by relationships in a relatively steady state. That state may break up, however, and develop into a different level of state[2]. Climate change impacts on ecosystems can lead to those changes in ecosystems. The concept of holism constitutes an adequate framework to analyze those processes and monitoring those breaks or displacements (in our case changes) is important in landscape and resource management (Kay, 1991; Mitchell, 2002).

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[1] A real understanding gained by working from the basic elements upwards, as it is postulated by the reductionist paradigm, which has established a strong scientific debate (Bergandu and Blandin 1998) would be so difficult in the study of landscapes.
[2] This idea is so close to the views expressed by Kay (1991, 1993) related to *ecological integrity*, where an optimum operating point (e.g. climax in a succession) changes as a result of an attractor, which changes it to a different position of the same "thermodynamic branch". This would result in a small change in the system (where its integrity is not severely altered), or flip to another branch, which would result in a catastrophe, in which the system changes drastically.

2.2.1.4 General Systems Theory

General Systems Theory (GST) was first proposed by Ludwig von Bertalanffy in the 1950s (Bertalanffy, 1950). GST has been defined as a:

> "…logico-mathematical field, the subject matter of which is the formulation and deduction of those principles which is the formulation and deduction of those principles which are valid for "Systems" in general. There are principles which apply to systems in general whatever the nature of their component elements or the relation s or "forces" between them" (Bertalanffy, 1950:139).

Bertalanffy (1950) defined a *system* as .a complex of interacting elements. A system has its own characteristics in addition to the properties of its components and their relationships (Zonneveld, 1995). Within a system everything is connected and any change in one of its components affects the rest. This is an equally valuable concept in the analysis of cultural and natural landscapes[3], or in managing a pulp mill, an economy or a wilderness park. Thus one can postulate that GST is an intrinsic part of holism and a tool to conceptualize and organize programs, projects, analyses, etc. using a holistic perspective.

2.2.1.5 Hierarchy Theory

Hierarchy theory provides a framework for examining scale-dependent processes and their resulting patterns (O'Neill and Smith, 2002). Hierarchy theory (Allen and Starr, 1982; O'Neill et al., 1986) considers that any system is a component of a larger system, composed in turn of subsystems. Hierarchy theory considers that ecosystems are structured in discrete levels of organization (O'Neill and Smith, 2002). Moving from one level to another of the system, the characters of the phenomena change (Farina, 1998). A hierarchy is also defined as a system of interconnections wherein the higher levels constrain the lower levels to various degrees (that is, lower levels are nested in higher levels) (Turner et al., 2001). A hierarchy refers to ranked levels of organization, which may be defined by their physical, or spatial structure interaction rates, or other selected characteristics (Pulliam and Johnson, 2002). Each

[3] This concept helps in the analysis of situations like climate change. If climate changes, it has an effect on landscapes. In another situation, if the landscape changes, climate may vary a well, as I will discuss later.

level is itself considered a "whole"[4], so the hierarchy orders "wholes" in "wholes" and over "wholes". This hierarchical arrangement helps us to understand and explain different phenomena (Allen et al., 1987). For example, the answer to: *why?* (Why does something occur?), will ordinarily be found at the next lower level of organization. The answer to: *so what?* (What is the significance?), will ordinarily be found at the next higher level of organization (O'Neill and Smith, 2002).

There are two classification approaches used by agencies to help managers understand the composition, structure and function of the ecosystems in space and time: classification classification by agglomeration and classification by subdivision (regionalization) (Zonneveld, 1995). Whereas classification by agglomeration is a means of arranging entities into groups or sets on the basis of their similarities and relationships, and is from below (Rowe and Barnes, 1994), classification by subdivision (regionalization) partitions the land into more or less homogeneous units from the top (Rowe and Barnes, 1994). The two approaches are organized in a hierarchy of levels or ecological units that express relations among them.

Ecological Land Classification (ELC) addresses all the dimensions of ecosystems and as such incorporates the interactions among landforms, soil, water, climate, fauna and human activities (Natural Resources Canada, 2003a). The goal of such classification schemes is to identify recurring ecological patterns on the landscape in order to reduce complex natural variation to a reasonable number of meaningful ecosystem units (Bailey et al., 1978). The basis for delineation of ecological units is to capture the major ecological composition and the linkages between the various components (e.g., landforms, soils, water, and vegetation) rather than treating each component as a separate characteristic of the landscape (Marshall and Schut, 1999). It is used as spatial context in which to make decisions, and is based on a hierarchy of ecosystems.

There are several examples of ELC. In Canada as a whole, the National Ecological Framework uses four levels of generalization going from a more to less detailed one as indicated by the number of zones indicated in parentheses below. Currently the levels are: ecozones (15); ecoprovincies (53); ecoregions (194), and; ecodistricts (1021) (Marshall and

[4] A "wholon" according to Zonneveld (1995).

Schut, 1999). Other examples include the Canadian Forest Ecosystem Classification (CFEC) (Natural Resources Canada, 2004a) and the Canadian National Vegetation Classification (CNVC) (Natural Resources Canada, 2004b). These classifications attempt to standardize the several classifications existing in Canada. They also look at standardize the classification with the International Classification of Ecological Communities (ICEC) to have a common ground and terminology for land planning. Rubec (1992) reviewed literature related to ecological land surveys and classifications from 1960 to 1990 in Canada. He reviewed about 500 papers related to land survey and classification and presents several examples of classifications undertaken in Canada in the period indicated above. This shows an application of hierarchy theory in very practical examples in developing planning frameworks for the use of the land.

2.2.1.6 Scale

The concept of *scale*[5] (Levin, 1992) is closely related to that of hierarchy. Scale represents the spatial or temporal dimensions of an object or process, characterized by both grain (the finest level of resolution, or measurement made in an observation, e.g. a "pixel" in remote sensing) and extent (the size of the areal or temporal boundaries of the system or the total area sampled, e.g. the size of an aerial photography) (O'Neill and Smith, 2002; Pulliam and Johnson, 2002). One of the most important lessons from the hierarchy theory is how phenomena change when the scale at which the observation is made changes as well[6] (O'Neill and Smith, 2002). When trying to understand the particular phenomena properly (Turner et al., 2001), scale becomes of paramount importance. If its importance is dismissed, one risks in missing or overemphasizing, certain processes or elements due inappropriate scale selection. Hierarchy theory and scale provide a useful framework with which to analyze landscapes logically; this strengthens its research and practice.

[5] It is common to find the terms "landscape scale" and "landscape level" in the literature about landscape ecology. Allen (1998) has discussed it and suggests the use of the term "landscape criterion" instead, because landscape is not a "scalar" concept, it is dimensionless. This opens the door for landscape ecology to make studies in different levels and not only in landscapes of several kilometres wide (Forman and Godron 1986) as it is considered through the human point of view and scale.

[6] Phenomenon that is "visible" at certain level might not be apparent in another. Similarly, at certain scale, and organism can perceive landscape elements that other organisms at other scales do not.

2.3 The Science of Landscape Ecology

The science of landscape ecology has conceptual roots in holism and GST. This field allows for both the study of change phenomena, and for the conceptual framework to develop appropriate management actions regarding landscapes. This section analyzes the science of landscape ecology. It starts by defining landscape, so establishing the foundation from which to discuss this concept. Then it introduces concepts related to landscape dimensions and factors. They help in the analysis of landscape function.

This section describes the approaches of Zonneveld, and of Forman and Godron and suggests a revision of landscape change, which is central in the thesis theme of human-induced climate change. The implications of studying landscape at broad scales, and some of the approaches used are also explored. Landscape planning and management are introduced, and some relationships between them and landscape ecology are described. Finally the relationship between this science and climate change is discussed.

2.3.1 Definition and characteristics of landscapes

The concept of landscape is difficult because it means different things for different peoples (Wiens, 1999) those different meanings are an obstacle for communicating among people interested in the study of this element (Tress and Tress, 2001).

First of all, it is important to consider the relationship between the ecosystem and the landscape. Some have distinguished the landscape as a level above the ecosystem, nevertheless Rowe (1961) indicated that the only organizational reality that deserves study is the ecosystem, understood as a tangible whole of living and non-living components. If we recognize the ecosystem as a level in a hierarchy as indicated in Section 2.2.1.3, and we consider that the ecosystem concept has no fixed space-time dimension, so it can have any magnitude (Lindeman, 1942). Thus the landscape can be considered as a group of ecosystems. Rowe (1961:422) supported this idea stating that:

> …each ecosystem, encapsulating successively smaller ones down the level of the individual organism-habitat cell or "monocene" […] is also part of a increasingly larger series.

A landscape can be one of those larger series that contains other ecosystems.

With this brief exposition, the use of the landscape concept as a framework for planning is clarified As a result, this thesis uses the term *landscape* more than ecosystem.

Ndubisi defined landscape as "…the template for understanding the intricate interactions between life and land. It implies the totality of natural and cultural features on, over and in the land." (Ndubisi, 1997:9). Likewise all landscapes are multifunctional and multidimensional (Naveh, 2001; Tress et al., 2001). This definition is adequate because it includes all possible elements that a whole (landscape) contains, and does not separate cultural or natural views of it. Other definitions of landscape have been proposed (Table 2.4). This landscape is holistic, with an implicit systems perspective. GST, and scale theory allow one to link the study of the landscape to analysis of global change, viewed as the analysis of a "whole" (e.g. landscape → landscape change), within another "whole" (e.g. the global environment → climate change).

Table 2.4 Other definitions of landscape.

"A heterogeneous land composed of a cluster of interacting components that is repeated throughout" (Forman, 1986).
"An area that is spatially heterogeneous in at least one factor of interest" (Turner, 2001).

Landscapes are dynamic, and complex, evolve continuously and show change as a result (Antrop, 1998; Bastian and Roder, 1998). This change can result from natural and/or human causes (Bastian and Roder, 1998). In this system, any change in either its characteristics or relationships may shift it to another state.

2.3.2 Landscape dimensions

Landscapes are heterogeneous. To understand their multifunctionality and multidimensionalilty (Tress et al., 2001) several different dimensions have been identified (Neef 1967 in Zonneveld, 1995): the topological, the chorological, and the geospherical. They have the following characteristics:

a) The topological dimension shows a relatively low variation in horizontal space. In this dimension, a landscape feature is analyzed from the vertical relationships among strata, soil, water, vegetation, climate, and humans.
b) The chorological dimension (horizontal variation and relationship among elements). Here the study of the landscape-ecological relationships among the ecotopes[7] of a mosaic is located. The combination of topological and chorological studies is the most characteristic aspect of landscape ecology (although not all landscape ecologists combine them, and some concentrate on only one of chorology or topology) (Naveh and Lieberman, 1984).
c) In the geospherical dimension, the relationships on continental and global scales are important (a systemic characteristic). This is the level where phenomena like climate change disruption occur, but as a consequence of the systemic nature of the planet, any change affects the other dimensions. (Zonneveld, 1995). This dimension is not easily handled by landscape researchers, but it has strong effects at finer scales[8].

Time is implicit in all three former dimensions and profoundly affects them. Landscapes evolve with time resulting in evolution in their structure and function. The objective of landscape science is to capture the variability and resultant heterogeneity on landscapes as dynamic entities.

These dimensions can be used by scientists and managers to describe ecosystem's composition, structure, and function in-space-and-time. They help to identify relationships forming between elements of an ecosystem and the surrounding environment. Once identified, probable explanations of an observed phenomenon can be drawn. If for example we are

[7] *Ecotope* is the minimum area, which can be considered a landscape (Zonneveld, 1995). In North America it is called *landscape element* (Forman and Godron 1986).
[8] Landscape ecologists call "broad scale" to scales e.g. 1:1,000,000, and "fine scale" to scales e.g. 1:1. Geographers and other professionals would refer to the same scales inversely and as "small scales" (e.g. 1:1,000,000), and "big scales" (1:1).

dealing with understanding the impact of climate change in a landscape, say the boreal forest, then the geospherical dimension helps to frame the issue of global change as a potential driver of landscape function, structure and change. The topological dimension helps to visualize the vertical variation and relationships between for example: water table level, soil composition, vegetation, and climate. These relationships can be described and used in understanding fundamental processes that can be employed to describe and prescribe measures and help in planning and management. The chorological dimension helps to understand and describe landscape structure and function in the horizontal plane. This dimension is useful in the description of processes like migration of species, soil erosion, and land cover structure. And last, there is the temporal dimension. Landscapes are entities that change over time. Depending of the temporal scale used different processes in the landscape can be described and used in planning and management. With these examples the importance of the landscape dimension is established.

ELC described in Section 2.2.1.5 is one useful framework for planning the land considering as well the landscape factors explained above.

2.3.3 Landscape factors

Landscape dimensions facilitate the conceptual analysis of landscape function and change. Function is caused by different factors. Van Wirdum (1982 in Zonneveld 1995) has identified four types of factors, which influence landscape function:

a) *Operational factors* are the physical and chemical processes involved in the function of the system, including the fluxes of energy and information which infuse into the system and act upon those processes, causing observable effects.
b) *Conditional factors* are more clearly observable conditions and situations that direct or create the fluxes but are not themselves the agents. Designed or planned elements can condition how a landscape "behaves" (e.g. controlling erosion or planting a windscreen).
c) *Positional factors* are related to the concrete location of an element in the landscape, which has effects on the function of the system, thus. topography influences the amount of

rain and radiation that a landscape receives and controls on water input to lakes (Swanson et al., 1988). Positional factors are fixed and not modifiable.

d) *Hereditary factors*. These factors have effects in the landscape, that can only be discerned from the study of the past as in paleoecology used to determine the history of a place in response to past ecology (Hunter et al., 1988).

The above factors are significant in the light of planning and management because, through their analysis, one can monitor conditions and decide how to preserve and/or change them.

2.3.4 Overview of landscape ecology

Landscape ecology has been defined as:

> …the study of the entire complex cause-effect network between living communities (biocoenoses) and their environmental conditions, which prevails in specific sections of the landscape. This becomes apparent in a specific landscape pattern or in natural space classification of different orders of size. (Troll, 1939 in Schreiber, 1990:23)

Various seminal notions appear in this definition:

a) *Change*, which results from the diverse cause- and-effect relationships.
b) *Networks* (systems of relationships) occur between organisms and their environment (a clear reference to ecology).
c) *Heterogeneity* is implicit in "conditions which prevails in specific sections of the landscape", because a landscape has different sections with particular features and functions).
d) A natural *ordering*, (i.e. hierarchy).

Thus landscape ecology is concerned with the landscape as a system, in structure, in function, in change (Forman and Godron, 1986; Hobbs, 1997; Risser et al., 1984; Turner et al., 2001; Wiens, 1999). To understand the structure, function and change in the landscape, the central questions of landscape ecology are (Risser, 1999; Risser et al., 1984):

1. How are fluxes of organisms, material, and energy related to landscape heterogeneity?
2. What formative processes, both historical and present, are responsible for the existing pattern in a landscape?
3. How does landscape heterogeneity affect the spread of disturbances?
4. How can natural resources management be enhanced by a landscape ecology approach?

Table 2.5 presents some other characteristics of landscape ecology, and the same general aspects discussed above are reflected in those descriptions.

Table 2.5 Additional characteristics of landscape ecology

Landscape ecology…focuses on (1) the spatial relationships among landscape elements, or ecosystems, (2) the flows of energy, mineral nutrients, and species among the elements, and (3) the ecological dynamics of the landscape mosaic through time. (Forman, 1983).
Landscape ecology focuses explicitly upon spatial patterns. Specifically, landscape ecology considers the development and dynamics of spatial heterogeneity, spatial and temporal interactions and exchanges across heterogeneous landscapes, influences of spatial heterogeneity on biotic and abiotic processes, and management of spatial heterogeneity (Risser, et al., 1984).

Landscape ecology was first introduced in Europe, and it has been credited to Carl Troll, who was impressed with possibilities in the use of aerial photography to understand the environment. He wrote:

> …from completely different sides, from the science of forest vegetation and biological aerial photo interpretation and from geography as “land science” and “ecology”, all the methods of natural science meet here. (Troll, 1939 in Schreiber 1990:23)

Landscape ecology was conceived as a human-related science (Naveh and Lieberman, 1984), but in North America there is a more natural-systems orientation to the discipline (Forman, 1995a; Forman and Godron, 1986; Risser et al., 1984; Turner et al., 1989).

Studying whole landscapes is sometimes not possible for a single discipline. Thus landscape ecology has been studied by geographers, biologist, ecologist, to landscape architects, and planners and as basic and applied endeavour. . Because of this diversity in approaches, it has been suggested that:

> ..it is better to call [landscape ecology] a transdisciplinary science because it is not just a combination of the methods of various sciences but is an integration on a higher level

> that influences -even embraces - other disciplines in basic philosophy and application. (Naveh and Lieberman, 1984:8)

In this way, landscape ecology is an umbrella over different disciplines, but shares similar concerns about the causes and consequences of spatial heterogeneity, and the effects of changes in scale in these relationships within the landscape (Wiens, 1999).

These different ways of studying landscapes have been grouped in two general lines of action (Moss and Milne, 1999): the bio-ecological and the geo-ecological (Rowe and Barnes, 1994). The first has been called as the "ecology in the landscape", in which ecology and biology have an important role. The later has had a more geographical orientation, and a more applied focus. It has an interest in building integrated social-economic landscape systems (Farina, 1993).

2.3.5 Two approaches within the science of landscape ecology

In this section two influential approaches in landscape ecology are presented: Zonneveld's and the Forman's (and Godron). This serves as a foundation for exploring where and how landscape planning and management contribute to landscape ecology.

2.3.5.1 The Zonneveld approach

This discussion is based on works by Zonneveld (1969; 1990; 1995). Zonneveld's approach is clearly based on the ideas of Carl Troll and was developed mainly in The Netherlands. Here, the analysis of the structure, function and change of landscapes is proposed through the division of landscape ecology into five subdivisions: morphology, typology (classification), chronology, chorology[9], and function (ecology). This taxonomy is based in the "common subdivisions of natural sciences" (Zonneveld, 1995), in which the analysis of an object (e.g. and organism) is undertaken:

1. An organism or system is described according its characteristics (morphology).

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[9] Chorology is at the same time a landscape dimension and a reference of activity or research with emphasis in the horizontal plane.

2. Once described, it is classified, and located in context among similar or different organisms or systems (classification).
3. Morphology and classification help in describing how the organism changes in time (chronology).
4. It is possible to be interested in how the organism changes its distribution and characteristics (chorology).
5. It is important to describe how the organism works as a system, and how it relates internally and externally (function).

These five subdivisions correspond to where specific disciplines make particular contributions. Nevertheless, a specific discipline can participate in more than one subdivision (i.e. landscape planning participates in classification [land classification and suitability analysis], chronology [developing future scenarios], and chorology [trying to allocate appropriate land uses in the horizontal plane]). In Section 2.3.2 it was emphasized topology and chorology as landscape dimensions, important for analyzing landscapes holistically. Thus each subdivision (and its component disciplines) has always to study landscapes considering the chorological and topological dimensions. It was stressed the importance of topology and chorology as landscape dimensions, important for analyzing landscapes holistically.

Zonneveld pointed out that the subdivision called “function” is landscape ecology “sensu strictu”, in which ecological aspects of the system are analyzed (e.g, patch dynamics, corridors, edge effects, etc.) and this corresponds largely to the North American approach. The other subdivisions contribute to this understanding. Their positions establish a feedback process among all subdivisions, with an emphasis on landscape ecology. These various contributions generate knowledge that becomes the theoretical and methodological foundation for landscape ecology.

Most important for this thesis, the diverse disciplines are part of and contribute to landscape ecology. For instance, landscape planning and management, and regional planning, or geography, use the knowledge, methods, and technologies from other subdivisions (i.e. landscape classification and evaluation). The other subdivisions take the results of the planning and implementation process as important experiences. In that sense landscape ecology becomes the tool for other subdivision and its disciplines, while each subdivision provides more knowledge to landscape ecology as a whole, and as a trandisciplinary science.

2.3.5.2 The Forman and Godron Approach

Another important approach is the Patch-Corridor-Matrix paradigm, proposed by Forman and Godron (1981; 1986), and Forman (1983a; 1983b; 1991; 1995a; 1995b; 1995c). This approach concentrates mainly on the chorological dimension (horizontal).

Forman considers that landscapes are composed as land mosaics (Forman, 1991), and these mosaics in turn are composed of landscape elements[10], identified as a patch (wide), a corridor (narrow), or the background (matrix). Those elements, in turn, are characterized by area, shape, width, and connectivity attributes (Forman and Godron, 1986; Turner et al., 2001).

The landscape structure concept elaborates on the notion that patterns and elements of landscapes have characteristics that are independent of climatic region, vegetation type, and human activity that allows for landscape classification (Forman, 1991), and this allows researchers to make generalize to any landscape, thus analysis of structure, function and change of landscapes employs landscape elements and their dynamics. This is relevant for planning purposes, as shown in the works of Dramstad et al. (1996), Collinge (1996), and Forman and Collinge (1997): several landscape elements (patches, edges and boundaries, corridors, and mosaics) are applied in landscape planning and design. These elements can be used to characterize different land uses, and to understand how fluxes (e.g. transportation of goods or species movements) influence landscape function and change.

This rationale has a strong basis in the theories of (a) island biogeography (MacArthur and Wilson, 1967) and from which landscape ecology has been considered an extension (Risser et al., 1984:2); (b) source-sink concept (Pulliam, 1988; Pulliam and Danielson, 1991);

[10] Forman (1986) has defined landscape elements as “the basic, relatively homogeneous, ecological unit, whether of natural or human origin, on the land at the scale of landscape” (p.595). Landscape element is equivalent to the “ecotope” proposed by Zonneveld (1995).

and (c) theory of metapopulation (Hanski, 1999; Hanski and Gilpin, 1997; Hanski and Gilpin, 1991; Levins, 1969; 1970). (Table 2.6). These examples clearly illustrate how in many concepts, landscape ecology is allied to the science of conservation biology (Diamond, 1976; May, 1975; Primack, 1998; Soulé, 1986; Soulé, 1994). Based on those theories, research has developed on landscape structure and function involving patch dynamics and disturbance (Pickett, 1978; Pickett and Cadenasso, 1995), habitat fragmentation (Harris, 1988), edge effects (Harris, 1984), study of ecotones (Hansen and DiCastri, 1992), the role of corridors as linkages between patches (Merriam, 1991; Saunders and Hobbs, 1991), and diversity in landscapes (Thompson et al., 1998).

Table 2.6 Important theories for landscape ecology

Theory of Island biogeography
Immigration and extinction are in equilibrium determined by island size and isolation. Immigration is a function of distance from the mainland. Extinctions are function of island size (MacArthur and Wilson, 1967).
Metapopulation Theory
Clusters of populations may interact over time through the exchange of individuals of genetic material, and that individual populations frequently may go extinct only to be re-colonized at a later time by immigrants from extant populations (Levins, 1969, 1970; Hanski and Gilpin, 1991, 1997; Hanski, 1999).
Source-Sink theory
Source habitat is defined as that habitat where local reproductive success is greater than local mortality, resulting in the production of surplus individuals that emigrate from the source area. Sink area consists of areas where local mortality is greater than local reproductive deficit (Pulliam, 1988, 199).

Planning and design of protected areas has received particular attention, based in these theories. Examples include: the biosphere approach (Batisse, 1997), multiple use modules (MUM) (Noss and Harris, 1986), and the Wildlands Project (Noss and Cooperrider, 1994) (see Figure 2.1), in which there are many concepts like the use of corridors and connectivity, the importance of core areas, and buffer zones (e.g. edge effects).

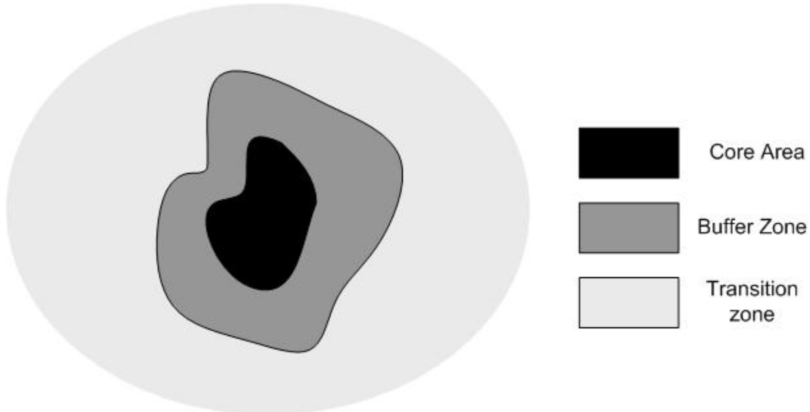


Figure 2.1 Zoning in a biosphere reserve (Batisse, 1997). Note the presence of edges and interior area. Landscape ecology works with those elements

Forman (1995) suggested a regional planning model based on the patch-corridor-matrix paradigm, that he called "Aggregate-with-Outliers" (Forman, 1995a; Forman and Collinge, 1996; Forman and Collinge, 1997) to be applied in regional planning. One should "aggregate land uses, yet maintain corridors and small patches of nature throughout developed areas, as well as outliers of human activity specially arranged along major boundaries" (Forman, 1995a : 437). This model has not been tested in real planning situations (Forman, 1995a), but it is proposed to be applied through: 1) the use of large patches of natural vegetation; 2) consider grain size; 3) risk spreading; 4) analysis of boundary zones; 5) use of small patches of natural vegetation; and, 5) use of corridors. Note how elements of the patch-corridor-matrix approach are present. It is also a good example of how the conditional factors concept reviewed in Section 2.3.3 is applied for desirable effects in the landscape. This model is focused mainly on the chorological dimension of landscape, but does not pay attention to topology. Nevertheless it bridges theory and application.

This section has brief described of landscape ecology and its application. It emphasized epistemological aspects to illustrate how it is related to landscape planning and management.

2.3.6 The Zonneveld and the Forman and Godron's approaches and ELC

The theoretical concepts inherent in Zonneveld and the Forman and Godron's approaches are complemented with ELC. Zonneveld based much of the understanding of the landscape on classification of the land (e.g. Zonneveld, 1969; 1989; 1995). He points to the importance of classifying the land to have a framework to plan and manage the landscape. He proposes criteria to develop such classifications. Forman and Godron also pointed out the importance of land classification in landscape studies as indicated in their seminal book *Landscape Ecology* (Forman and Godron, 1986). Throughout this thesis I have emphaised the importance of holism and hierarchy theories. Landscape ecology has been described as a discipline with roots in holism and hierarchy theories besides scale. Having a landscape focus implies to consider the context (chorology and topology) and the understanding of relationships that result in certain function and change. ELC offers the possibility of having a framework that allows for that landscape analysis, so the Zonneveld and the Forman and Godron's approaches should be complemented with ELC to make proposals that fit logically within the landscape system.

2.3.7 Landscape change

As noted, landscape ecology is the study of landscape structure, function, and change (Hobbs, 1997). This thesis analyses change in the landscape as a planning tool. One should not to forget that, under the concepts of holism and systems, no process is isolated from the other system components, so landscape studies, although interested with structure, function, or change (as it is the case here), should consider their place in the global system.

To analyze changes in the landscape, Golley (2000) identifies three dimensions in it:

1) The first describes the degree to which the system is controlled by internal or external processes.
2) The capacity of the system to resist disturbance that originates within or without the system, due to physical, chemical, biological, or socio-economic factors.
3) The position of the landscape in relation to attractors that influence direction of change.

This author also suggests the following questions for analyzing landscape change according to the above dimensions:

a) Is change due mainly to the internal dynamics of the landscape or to external influences originating from the landscape hierarchy?
b) Is change within or outside of natural variation?
c) Does change have a direction, due to the presence of attractors in the landscape, or is change random?
d) Can we explain the causes of change or are we able only to describe what we see?
e) Does change function within the system limits, or does it open the system to new configurations? That is, is change creative?
f) How do we value new forms of landscape and the processes that lead to them?

Antrop (1998) adds four more important questions: Change to what? How frequent are changes? What is the magnitude of change? And what is the reference time used? Another important element in the analysis of change is the need to describe the initial system to know if change has happened or not. These questions are relevant because they are so similar to those related to the analysis of adaptation to climate change, showing the appropriateness of landscape ecology as a framework to analyze changes in landscape and changes in climate.

2.3.8 Studying the landscape

Studying the landscape entails addressing in the issue of scale (see Section 2.2.1.6). Wiens (1999) and Turner (2001) argue for a landscape ecology that is most concerned with a general landscape model that can be applied at any scale according to the specific observed phenomenon, and not only with landscapes that are kilometres wide (as in Forman and Godron, 1986). In other words, a non-scalar dependent conceptualization of the landscape (Allen, 1998) can be more useful in landscape ecology.

2.3.8.1 About studying landscapes at coarse scale

When studying landscapes at fine scales (e.g. Collinge 1998) one can manipulate variables of interest in a laboratory fashion. In contrast, at coarse scale, the size of the unit of study becomes an issue, and controlling variables becomes difficult, and expensive. Sometimes "experiments" are impossible. One response is to take the opportunity of analyzing landscape dynamics after disturbance and monitor change (Baker, 1995)(e.g. fire, wind, earthquakes, volcanoes). Another approach is the use of models in the study of landscape dynamics. This approach is used in this thesis.

A model is "an abstract representation of a system or process"(Turner et al., 2001 : 47), which helps in make "manageable" processes that would be difficult to tackle in the real world. Models help to understand how certain variables impact a process. As models are simplifications of complex processes, they help to understand a part of the whole dynamic. As a result sometimes models have to be complemented with other methods to help understanding the whole landscape dynamic. Although they do not deliver final responses, they help in understanding the role of certain factors in the analysis of structure, function, and change in landscapes.

Various kinds of models have been used in landscape ecology (Turner et al., 2001): The following is a description of those models.

b) *Deterministic versus Stochastic.* : A model is deterministic if the outcome is always the same with specific inputs. If the model contains an element of uncertainty (chance), and repeated simulations produce different results, then the model is stochastic. The heart of this kind of model is the selection of random numbers from a suitable generator.
c) *Analytical versus Simulation.* These models have a closed-form mathematical solution (analytical model) or lack a closed-form solution. These models are dynamic.
d) *Dynamic versus Static*: dynamic models represent phenomena that change through time, whereas static models describe relationships that are constant (or at equilibrium) and often lack a temporal dimension.

e) *Continuous versus Discrete* Time. If the model is dynamic, then change with time may be represented in many different ways. If differential equations are used, then change with time can be estimated at arbitrarily small time steps. Sometimes models are written with discrete time steps or intervals. Models with discrete time steps evaluate current conditions and then jump forward to the next time, while assuming that conditions remain static between time steps.

f) *Mechanistic, Process-Based, and Empirical model.* These models represent dynamics in a manner consistent with real-world phenomena (e.g. mass and energy conservation laws). The term, "mechanistic", is applied to distinguish these models from black-box models. "Process-Based" implies that model components were developed to represent specific ecological processes, such as for example births, deaths, growth, photosynthesis, and respiration are used to estimate biomass yields, rather that simpler, more direct estimates of yields from the driving variables of temperature, precipitation, and sunlight. "Empirical" refers to a model formulated on simple or correlative relationships. This term also implies that model parameters may have been derived from data, as in regression models.

g) *Spatial models.* When the variables, inputs or processes have explicit spatial location, a model is spatial. A spatial model is only needed when explicit space is an important determinant or outcome of the process studied.

h) Decision support systems (DSS). DSS are a specific class of computerized information system that support decision-making activities (Power, 2004). These systems have been applied to a number of situations. In natural resource management there are some examples of DSS, for example DESERT (IIASA, 1998) developed a DDS to be used in water quality at basin scale and the IPM (Integrated Plant Protection Center, 2004) used in pest management.

Some models pertain to different categories. For example BFOLDS (Perera et al., 2003) is both stochastic and spatial. In Section 3.6, a more specific explanation of different landscape models that pertain to the objectives of this work is done.

2.3.8.2 The role of Null Models in landscape ecology

Discussion of neutral landscape models (NLM) in this thesis is pertinent. Climate change impacts deal with areas that normally correspond to coarse scales. The issue of manipulating landscapes at this scale is present here as well. The concept of NLM is useful in climate change research: a landscape under a scenario of no change (baseline) in climate can be conceptualized as the "null". The other scenarios are compared against it. In terms of experimental design, it corresponds to the control.

The NLM has been proposed as a way to address part of the issue of studying landscapes at a coarse scale within the limitations of landscape manipulation at that scale. In landscape ecology these models are also known as null models (Gardner and Walters, 2002), and have been used as referents to analyze the role of factors responsible of landscape pattern and other characteristics.

NLMs have a referent in null models in ecology. Gotelly and Graves (1996:3-4), have defined a null model as:

> …a pattern-generating model that is based on randomization of ecological data or random sampling from a known or imagined distribution. The null model is designed with respect to some ecological or evolutionary process of interest. Certain elements of the data are held constant, and others are allowed to vary stochastically to create new assemblage patterns. The randomization is designed to produce a pattern that would be expected in the absence of a particular ecological mechanism.

Within landscape ecology and in terms of landscape pattern, a NLM shows a characteristic spatial pattern in the absence of processes that may affect pattern in real landscapes (Gardner and Walters, 2002). NLM are generated with analytical algorithms and thus are "neutral" to the biological and physical processes that shape actual landscape patterns (e.g. they are "neutral" to topography, contagion, disturbance history, and related ecological processes, and their configuration is not a function of those natural processes) (Gardner et al., 1987; With, 1997). NLMs address how a landscape would look like if no processes affected the distribution of a particular habitat type of land (Donovan and Strong, 2003). An application can be the analysis of landscape fragmentation to determine when local animal species have difficulties to disperse (With, 1994; With et al., 1999).

NLMs have been used to understand statistical properties and connectivity of heterogeneous systems. Those models were developed based on percolation theory (Stauffer, 1985), which in turn was developed from the study of the flow of liquids through lattices of material aggregates (Orbach, 1986). "Percolate" can be defined as "to trickle or filter through a permeable substance" and so if a hypothetical organism can navigate a heterogeneous landscape by moving to adjacent suitable places, it is said that the landscape percolates (Donovan and Strong, 2003).

NLMs are the conceptual origin of neutral maps. Three of them are the most important (With, 1997): (a) simple random, (b) hierarchical random, and (c) fractal landscapes.

Simple random are the first generation of neutral landscapes, created by randomly assigning habitat to a proportion *h*, of the grid map (Gardner et al., 1987). The number of available habitat cells in a particular landscape is thus hm^2, where *m* is the number of cells along one side of the landscape grid (number of rows or columns (With, 1997)). Aggregation of landscape cells emerges from the use of different neighbourhood rules (Figure 2.2). The use of neighbourhood rules provides a species-centered definition of landscape structure, permitting patch structure to be identified at a scale appropriate to the organism in question, so rule 1 (nearest-neighbour rule) works for species with less dispersal abilities, whereas rule 3 (third-nearest neighbour) applies for more vagile species as it considers cells to be part of the same patch.(O'Neill and Smith, 2002).

Hierarchical random landscapes are based on the idea that natural landscapes exhibit scale-dependent changes in pattern. Species may respond to resource distribution at different levels within the hierarchical patch structure of the landscape as determined by their perceptual grain[11] and their spatial extent[12] (O'Neill and Smith, 2002), which us the broader scale at which the species interact with heterogeneity, usually determined by dispersal distances. According to O'Neill et al. (O'Neill et al., 1992), hierarchically structured landscape models reflect the inherent path structure of natural landscapes. These landscapes are generated setting hierarchical levels in a map *L*. The proportion of habitat that occurs within

[11] Grain is determined by the finest level of resolution or measurement, made in an observation. (O'Neill and Smith, 2002). In a satellite image the pixel is the grain.

[12] Extent of an observation set is established by the total area sampled (O'Neill and Smith, 2002). In a satellite image, the size of the image is the extent.

each level is set independently as *hi…hL*. The availability of habitat at one level constrains the availability of habitat at finer scales (With, 1997).

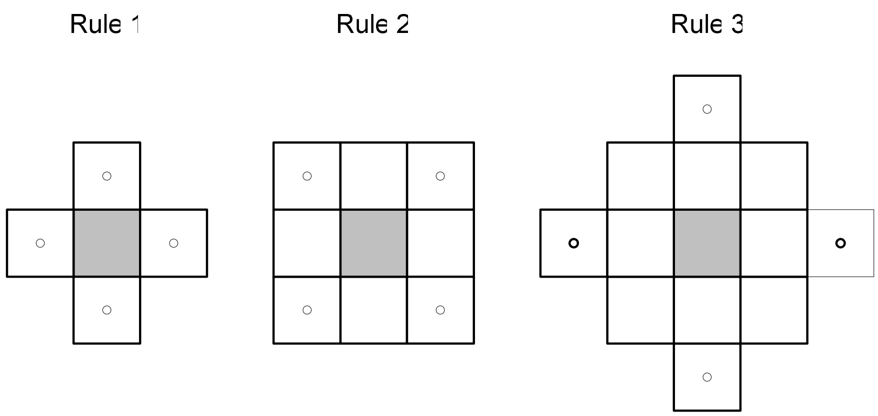


Figure 2.2 Three important neighbourhood rules: (1) nearest neighbour, (2) next-nearest neighbour, and (3) third-nearest neighbour (after With, 1997).

As most landscapes have multiple land-cover types, a more complex neutral model is needed to represent that diversity. One method for dealing with continuous and auto-correlated variation is the use of *fractal landscapes* (Turner et al., 2001). Fractal maps are produced in three steps: (1) generation of a topographic map with roughness controlled by *h*, (2) slicing the topography into contours with the area of each contour equal to the proportion of the map occupied by that habitat type, and (3) assigning ordinal habitat (land cover) to sites within each contour (Turner et al., 2001).

Null models and their rationale have been used to answer questions such as: *what happens when a landscape becomes fragmented?* (With, 1997), and also to find when an organism can move to adjacent suitable patches. This point has been termed in various ways: "critical probability" (Gardner et al., 1987), "critical thresholds" (Turner et al., 2001; With, 1997), and "percolation thresholds" (Donovan and Strong, 2003). In simple random landscapes this threshold depends on various aspects such as the dimension of the map, the neighbourhood rule used to define how a landscape is clustered, and the organism under study. Different threshold values have been reported, and some are shown in Table 2.7.

In practical terms the probability *Pc* that a land cover *n* is present in a landscape reaches a value at which a landscape can be considered fragmented if $n \leq Pc$. In other words, if we translate *Pc* and *n* into percentage (%), we could say that a landscape is fragmented when land cover *n* (%) is less than *Pc* (%). To give a hypothetical example, if *Pc=60%,* thus indicates that if $n<Pc$ a fragmented landscape results, with less connectivity, whereas if $n>Pc$ indicates a non fragmented landscape.

Figure **2.3**When the proportion of available habitat (shaded cells) is reduced, connectivity – the occurrence of percolation cluster-is disrupted (Figure 2.3), producing small isolated clusters of habitat across the landscape (With, 1997).

Table 2.7 Different threshold values reported

Reference	Threshold reported (%)	Comments
Boswell et al. (1998).	45	Research done with army ant (*Eciton burchell*) in neotropical rainforest.
Hobbs (2002); Hobbs and Norton (1996); Macintyre and Hobbs (1999) (2002; 1996; 1999).	60	Proposed a classification for modification as follows: intact (> 90% of the original landscape remains), variegated (between 60-90 %), fragmented (10-60%), and relictual (<10%). They presented a chart with these landscapes and some additional characteristics.
Gardner et al. (1987).	59.28	Predictions from percolation theory and use of neutral landscape models.
With and Crist (1995).	35-40	Value proposed for species with good dispersal possibilities.
Lande (1987)	25-50 (species with high demographic potential, it is with more dispersing possibilities) 80%(species for low demographic potential)	Cited by with and Crist (1995)

Thresholds points vary with the species and scale under study, so to obtain an exact threshold point value is difficult. Vos et al. (2001) proposed the concept of Ecologically Scaled Landscape Indices to bridge the gap between empirical data, single species models, and indices of landscape configuration so that a critical value can be obtained and applied in management issues. Despite this interesting approach, there appear to have been no further similar studies

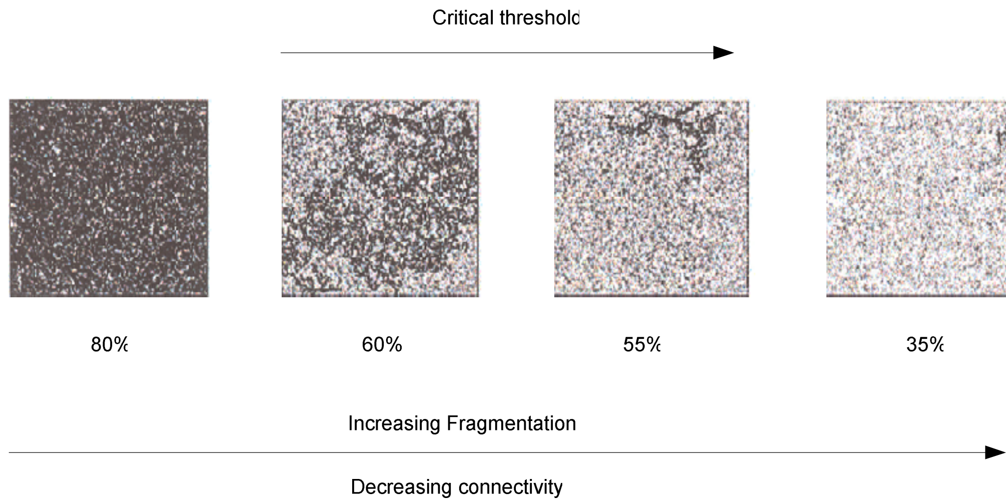


Figure 2.3 Critical threshold in landscape connectivity. The largest patches are the dense black areas in each landscape (after With, 1997).

2.4 Landscape planning and management and landscape ecology

Concepts of particular interest to landscape ecology, such as holism, systems, hierarchy, and transdisciplinarity have been stressed in this work. Another important aspect in this discussion has been the Zonneveld approach, in which landscape ecology is divided in five subdivisions, each of which has a particular focus on certain aspect of the landscape. These subdivisions corresponded as well to different disciplines specialized in those particular foci of the landscape. As a result, disciplines within each subdivision, simultaneously become tools for landscape ecology, as well as tools for each of those disciplines. Within this network, there has been a common concern among all disciplines to study the structure, function and change of landscapes, under the paradigm of landscape ecology (Hobbs, 1997). Thus, in summary the most important component of landscape ecology is the holistic framework that it offers to analyze and solve diverse situations in the landscape, its inhabitants, and components.

It has not been the intention to highlight specific concepts developed by scientists (e.g. patch, corridor, disturbance), but rather to describe the framework of landscape ecology. This framework is concerned, not only with ecological function in natural systems, but also with the social, political and economic aspects of landscapes. It is useful not only to find excellent models of how the landscape works, but also understand the real context in they will be located.

Practitioners and scientists in landscape ecology have failed in the establishment of a real transdisciplinarity application (Moss, 2000), even though this was a central founding tenet (Zonneveld, 1995). For this reason, some suggest that the field is experiencing an "identity crisis" (Hobbs and Norton, 1996; Risser, 1999), and so they ask, "what is landscape ecology really?" (Wiens, 1992). To reinforce the contribution of landscape ecology, landscape ecologists must improve, facilitate, and develop a system of communication and dialogue among its fields in all its subdivisions. In particular, it is important that an exchange take place between basic and applied science in the field (Forman, 2002; Hobbs and Norton, 1996; Seddon, 1986).

Landscape planning, design and management, as applied disciplines, can offer landscape ecology, a means to assay theoretical findings "on the ground" (Opdam et al., 2002; Zonneveld, 1995). It is now evident that landscape ecology can serve as a tool for landscape planning and management.

2.4.1 Overview of landscape planning and management

Any landscape planning initiative is based on a suite of societal values, where the allocation of natural resources is in large part based on this suite of values.

Landscape planning has been focused in diverse ways, ranging from the aesthetic to the physical study of land (Turner, 1983). This thesis focuses on physical landscape planning (Steiner, 1991b). Landscape planning has been defined as the "process of choice based on knowledge about people and land" (Steiner, 1991b:520), and as the practice of planning for the sustainable use of physical, biological, and cultural resources. It seeks the protection of unique scarce, and rare resources, avoidance of hazards, protection of limited resources for controlled use and accommodating development in appropriate locations (Fabos, 1985). Marsh (1998) identifies the following areas of activity of landscape planning: (a) environmental inventory; (b) opportunities and constrains; (c) site assessment, land capability, carrying capacity, and sustainability planning; and, (d) hazard assessment and risk management.

Landscape planning is inherently interdisciplinary, with biological, physical, and social science components, as well as the creative traditions of landscape architecture (Ahern, 1999). The term “landscape planning”, refers also to what is often called “landscape ecological planning” (e.g. Hersperger, 1994; Makhzoumi, 1999; Makhzoumi, 2000; Ndubisi, 1997; Steiner, 2000). Landscape ecological planning has a more ecological orientation. Here the integration of the topological and chorological (see Section 2.3.2.) perspectives in landscape planning is evident (Ahern, 1999). Early works like McHarg (1969) were developed mainly in the topological dimension, whereas in more recent models, the chorological one complements the former, and as a result, a more complete vision of the landscape is created (Ahern, 1999).

Management related to natural resource has been defined as the “capacity to control, handle or direct” (Mitchell, 2002:6). The same author has pointed out that all management is in fact biodiversity management, whether intended or not, through any decision about land use. It is important to consider that in deciding not to do something in the landscape and leaving it to evolve by itself is also a management decision. Management has the responsibility for making things work, after putting plans and knowledge into action. It reports results, which will help to identify what has been useful, what needs to be modified, and what has to be avoided. In visualizing the landscape within a systemic view, management decisions can also (and should) include people and their behaviour and their influence in the environment.

In dealing with landscapes, landscape planning tries to manage complex systems, under conditions of uncertainty and chaos[13]. There are various planning approaches that address

[13] Chaos has been defines as ”order without predictability”. Applied to the study of physical and social systems some of them might be capable of being understood, in the sense that they can be described relative to a set of conditions or rules, but they remain fundamentally unpredictable (Mitchell, 2002).

chaos and uncertainty differently. The rational comprehensive model has been one of the most prevalent (Mitchell, 2002). This model has a set of well defined steps: (1) defining the problem, (2) establishing goals and objectives, (3) identifying alternative means to achieve the goals and objectives, (4) assessing the options against explicit criteria, (5) choosing a preferred solution and implementing it, and (6) monitoring and evaluation (Mitchell, 2002). As this model is completely "top-down" in approach it does not accept the concept of chaos. "Experts"[14] make decisions without participation of stakeholders and look for the optimum solution, which is not always achievable in managing natural and social systems.

Incremental planning is based upon the idea that people are "boundedly rational" and that they "satisfy" rather than maximize. The world is bounded because not all detail and complexity is considered. This approach concentrates attention upon familiar and better-known experiences, limits the number of alternatives to be explored, and reduces the number and complexity of variables to be considered. Here a solution that is "good enough" or satisfactory is searched instead of the optimum. Incrementalism is often characterized as being reactive to existing conditions, rather that being proactive in trying to move towards an improved state of affairs (Mitchell, 2002). This model is more apt to deal with chaotic situations.

An alternative model that combines the strengths of the former two approaches is mixed scanning (Mitchell, 2002). Here the decision maker relies upon a continuous series of incremental decisions, but that also readily scans a limited range of other alternatives, each of which represents a major departure from present practice. Here the decision maker looks for and considers options which are significantly different from the status quo.

Last, the transactive planning model follows the belief that one should consider the experience of people who will be affected by the planning or decisions (Friedmann, 1973) Here inter-personal dialogue and mutual learning are important.

There is no perfect way to plan in a situation of uncertainty and chaos. Planning related to climate change impacts and adaptation lies in this realm. No final responses can be proposed when the phenomenon under study involves non-linear processes, and when it is

[14] Often called "economic person" (*op cit.*).

related to natural and social systems. This thesis looks to provide information to stimulate debate and not to give a final answer when dealing with complex issues as climate change impacts.

2.4.2 Landscape ecology as a tool for landscape planning and management

Landscape design offers insights in how to implement theoretical knowledge of landscape ecology in practical situations. In this vein, Ahern (1999) proposed that landscape ecology can assist in the design and evaluation of spatial concepts and that implementation of these concepts through landscape plans is a basis for field experiments, which can, in turn, generate new knowledge.

The landscape plan, final product of the landscape planning activity, offers specific recommendations regarding land-use allocation, the designation of levels of protection, and strategy development to "undo" past negative impacts. Thus, landscape plans are hypotheses of how proposed plans (i.e. proposed landscape structure) will influence landscape processes (Ahern, 1999). If the planning recommendations are implemented, landscape ecologists may gain new knowledge (Golley and Bellot, 1991) as their research may be corroborated.

Spatial concepts have been proposed as referent for landscape planners (Ahern, 1999). They express, through words and images, an understanding of a planning issue and the actions considered necessary to address it. They are related to the proactive, or anticipatory, nature of landscape planning, in that they express solutions to bridge the gap between present and the desired future situations (Golley and Bellot, 1991). Landscape ecology assists in the conception and evaluation of these spatial concepts, through identification of patterns indispensable of ecological functions; informing about issues like connectivity, and disturbance regimes, among other aspects (Ahern, 1999). In works of Bell, 1999, 2001; and Lucas, 1991, pattern is a good example of the use of landscape ecological knowledge in landscape planning and design,. Other studies about the effects of landscape pattern in landscape function include Baskent (1999), Cullinan and Thomas (1992); Cushman and Wallin (2000); Hansen and Urban (1992).

Two landscape planning approaches are analyzed here: Steiner's (2000) and the Ahern's (1999) (Table 2.8, Figure 2.4, and Figure 2.5). These approaches will be used as an example of where landscape ecology can be a useful as a tool for landscape planning and management. They are presented as a sequence and relationships of steps or activities, from the establishment of goals, the elaboration of the landscape plan, to the administration/management.

Table 2.8 Steiner and Ahern's models. Summary of steps/activities included in each case.

Steiner's Model (2000)	Ahern's Model (1999)
a) Problem and / or opportunity identification b) Goal establishment c) Regional level inventory and analysis d) Local level inventory and analysis e) Detailed studies f) Planning concept g) Landscape plan h) Education and citizen involvement i) Design explorations j) Plan and design Administration	a) Determination of goals b) Synthesis of assessment of abiotic, biotic, and cultural aspects, which defines areas for potential spatial conflict and compatibility. This is used to develop spatial concepts c) Selection of planning strategies d) Scenarios construction to verify implementation feasibility e) Evaluation of scenarios f) Landscape plan g) Adaptive management

Differences are evident between the models, such as Steiner's is more explicit goal establishment versus Ahern's is greater detailed in terms of spatial concepts and scenario construction. To be used as tools to applied landscape ecology, both models present the following characteristics:

1) There are opportunities to analyze the problem from the chorological and topological dimension, and the possibility for a more holistic vision (because they are concerned not only with the biotic or abiotic, but also the cultural aspects). This is shown in steps (c), and (d) in Steiner's model, and (b) in Ahern's (Table 2.8). These activities require land classification and/or evaluation (called suitability analysis[15]) (McHarg, 1969; Steiner, 2000). Note also that there is a notion of hierarchy in visualizing problems at different levels (e.g. local, regional).

[15] Usually this kind of evaluation is made according to relative values against which landscape characteristic are rated, then their suitability for certain uses is determined. The particularity here is that those values are totally based on the priorities of the study, which corresponds to human criteria and values (Zonneveld 1995). That can be seen as a weakness of landscape ecology for landscape classification and evaluation.

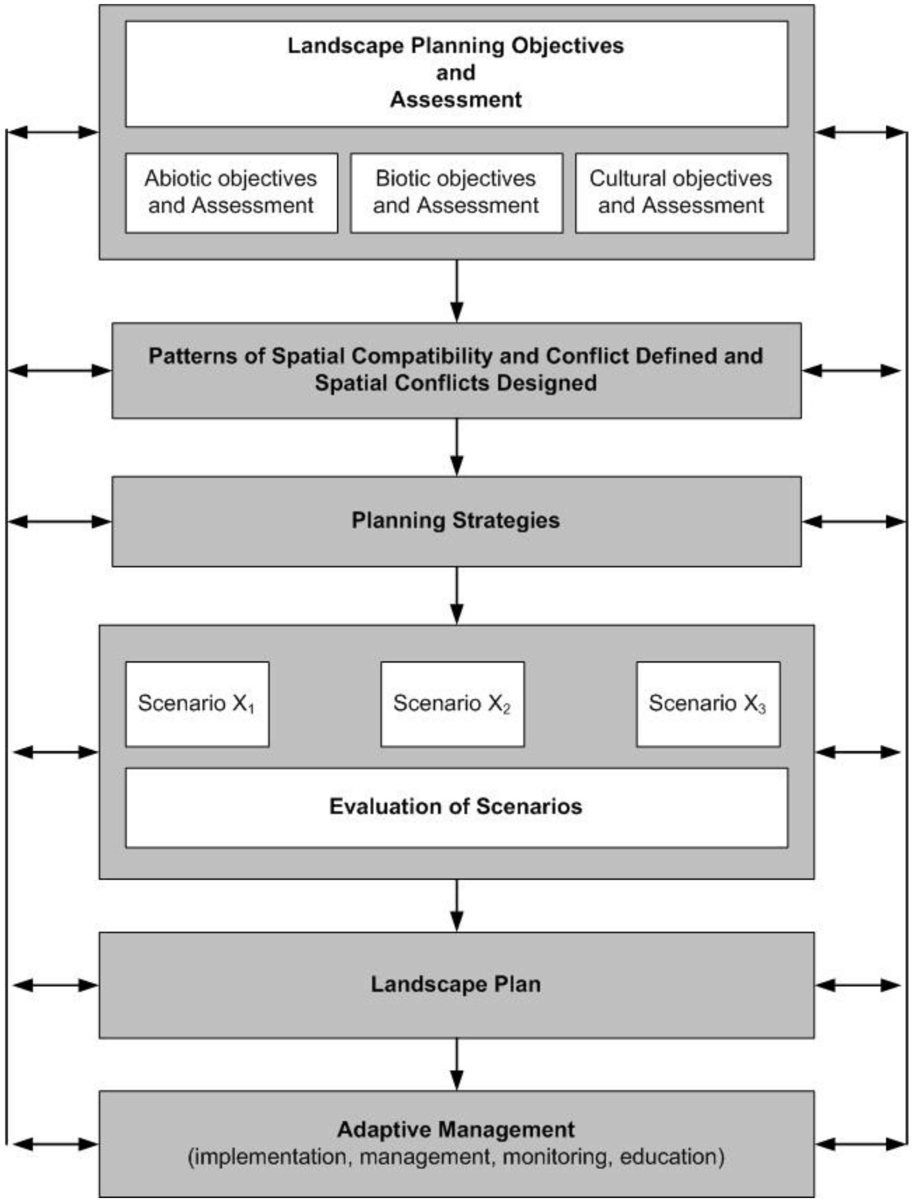


Figure 2.4 Ahern's model for landscape planning (after Ahern 1999).

2) Spatial concepts are less explicit in Steiner's model but still present (Table 2.8).

3) They produce scenarios of the probable situations, (*g* in Steiner's, and *d* in Ahern's), (Table 2.8). This aspect is relevant to analysis of landscape change, and enables consider use of scenarios of climate change disruption in the planning process; and,

4) The landscape plan in both models is considered, in this context, as a landscape ecology hypothesis.

They recognize that the process ends in implementation, and administration of the plan (and use possibility of monitoring). As landscapes are complex the approach has to be adaptive (Holling, 1978), The Steiner's model nevertheless, resembles more a rational comprehensive model approach (see Section 2.4.1) so it is not so flexible in an adaptive management framework. These two models demonstrate possibilities for collaboration between landscape ecology, and planning and management. Therefore the main strength of landscape ecology in landscape planning is the holistic framework that it offers for analyzing and understands structure, function and change of landscapes. Deficiencies in communication among different practitioners and scientists, which has resulted in a lack of validation of landscape ecological principles in landscape ecology, need to be addressed.

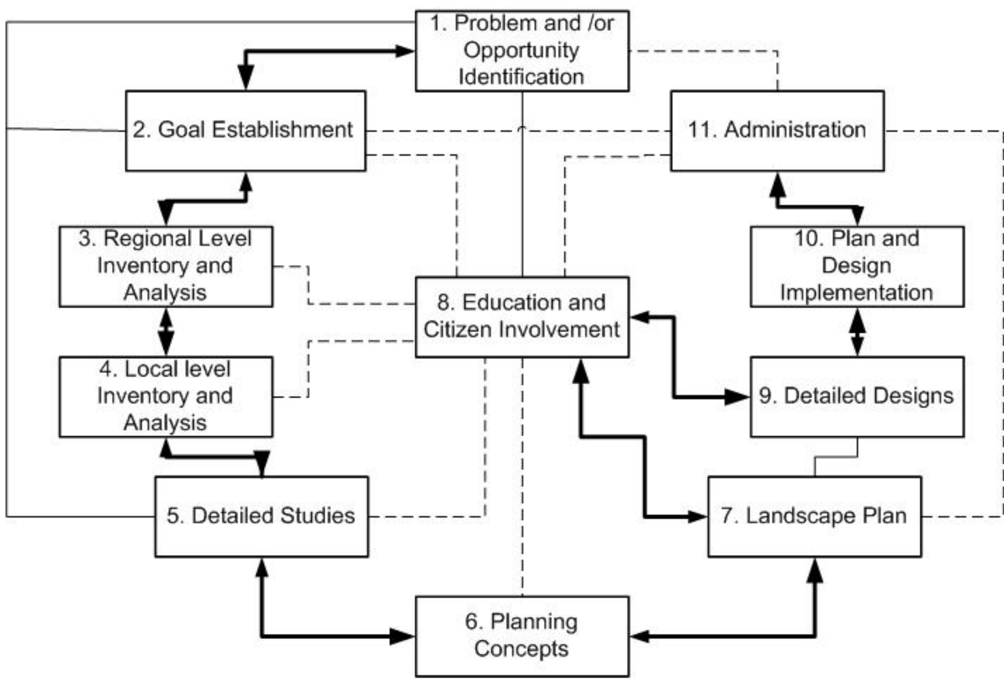


Figure 2.5 Steiner's model for landscape planning (after Steiner, 2000).

2.4.3 Environmental Planning

So far, important aspects of landscape ecology have been described, and how they can be used in landscape planning and management has been summarized. In this section other important conceptual considerations related to environmental planning, including landscape planning, are stressed. This discussion explores the several implications for "managing the environment", and how this should be done using a broad and integrated approach. Although this issue could be a whole Ph.D. thesis, just a few aspects in planning for the environment and its resources are highlighted.

The following meanings emerge when the concepts of resource[16], environment, planning and management are combined (Mitchell, 2002):

- *Resource and environmental planning* concerns resources and/or environment, identification of possible desirable future end states, and development of courses of action to reach such end states.
- *Resource and environmental management* relates to decisions and action (policy and practice) regarding how resources and the environment are appraised, protected, allocated, developed, used, rehabilitated, remediated and restored, monitored and evaluated.

Our incomplete knowledge entails many difficulties in working with the environment. Planning better use and management of the environment obliges planners to deal with *change, complexity, uncertainty,* and *conflict management*, (Mitchell, 2002). Planning in such a situation has leads one to focus on the precautionary principle as well as on adaptive management, and both are important in the study of this thesis.

The precautionary principle was first proposed in Germany in the 1950s as a result of discussions focused on the need for foresight. It resulted from recognition of the need for caution, and represented a move away from reactive planning and management (Mitchell, 2002). It was included in the Principle 15 of the Rio Declaration:

> In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irresistible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

The precautionary principle reflects the adage that "an ounce of prevention is worth a pound of cure" (Mitchell, 2002). It also stipulates that, rather than waiting for complete

[16] The concept of "resource" has had a utilitarian meaning, so those elements of the environment that have an utilitarian value are the only important to protect over the other elements present (Mitchell, 2002), that is why the concept of "environment" is more adequate to embrace the whole environment without having that utilitarian value.

understanding, managers and decision makers should anticipate potential harmful environmental impacts from actions, and take decisions to avoid such harm. Furthermore recognizes that uncertainty is a reality, due to the incomplete knowledge about ecosystem behaviour, faulty assumptions about ecosystem function, and difficulty in forecasting future technical innovations. This principle should be considered when making resource decisions in which (1) the range of possible impacts from one or more uses cannot be predicted, (2) one or more of the outputs or outcomes could have extremely undesirable impacts for future people, and (3) substitutes are not available for the resource to be used (Mitchell, 2002). Actions to adapt to and to mitigate climate change can be developed through this approach as all those of the above elements are present when working in the climate context.

The precautionary principle has had a major impact on law and policy in the last years (Cooney, 2004), Implementing the principle has presented some issues. In trying to overcome implementation issues, Cooney (2004:25) points that:

> …due to the knowledge of uncertainty there have been problems in its implementation. It appears that the precautionary principle will often have little systematic impact on practice unless formulated as an obligation, and linked to specified process or outcome standards developed on a sectoral basis, with respect to, for instance, specific species, fisheries, or protected areas.

In order to implement the precautionary principle, Table 2.9 presents some policy and management approaches that can help agencies and organizations to implement it.

Table 2.9 Options to implement the precautionary principle by organizations and agencies (from Cooney, 2004)

Specific policy tools:	**Management and Policy Approaches**
▪ Reversal of evidentiary burden. ▪ Placing the evidentiary burden on proponents. ▪ High standard of proof. ▪ Complete prohibition of particular activities. ▪ Leaving "margin of error". ▪ Information and monitoring requirements.	▪ The Ecosystem Approach, or ecosystem-based management ▪ Adaptive management ▪ Environmental impact assessment and risk assessment

Some other examples besides the Rio Declaration, of the application of the precautionary principle are: the Canada Fisheries Act, the Convention on Biological Diversity, the Stockholm Convention on Persistent Organic Pollutants, and the Cartagena Protocol on Biosafety. Those documents adhere with the Principle 15 of the Rio Declaration.

Holling (Holling, 1978) proposes adaptive management as another approach (and a tool for the precautionary principle as shown in Table 2.9). "…to cope with the uncertain and the unexpected. How in short, to plan in the face of the unknown…" (Holling, 1978: 7) was needed. The rationale is that people have always lived in an unknown world, and yet have generally prospered. The traditional way of dealing with the unknown has been through trial-and-error. What is known becomes the point of departure for a trial. Errors both provide new information and understanding, are necessary to gain understanding about previously unknown conditions, and improve our capability to deal with them (Mitchell, 2002:134). To apply an adaptive approach, three minimum conditions should be met (*op cit.*):

1. The experiment cannot destroy the experimenter, or at least someone has to be able to learn from the experience;
2. The experimenter should not create irreversible changes in the environment. If that did occur, then it would be difficult, perhaps impossible, for the experimenter to benefit from the new knowledge, and;
3. Having learning from failures the experimenter must be willing to start again.

There are different ways to manage through adaptive management (Allan and Curtis, 2003; Walters and Holling, 1990);

a) Evolutionary or trial and error, in which early choices are essentially not planned, while later choices are can deliver better results.

b) Passive adaptive, where lessons from the past are used to design a single best policy to apply currently.

c) Active adaptive management, where policy and its implementation are used as tools for accelerated learning.

Knowing those different forms of adaptive management, help in apply it in practice.

2.5 Summary and Conclusions

In this section, some important conceptual foundations to environmental preservation have been reviewed. General aspects of the land ethic; holism, GST, hierarchy theory, scale theory were reviewed. Finally the use of these conceptual elements in analysis of landscape change, driven by a number of elements in the whole system is contextualized. The main finding from this brief review is that the theories analyzed are bonded by conceptualization of a whole, hierarchically organized system. Another important element is the consideration of scale: a focus on an inappropriate scale can lead to wrong conclusions.

After revising the philosophical underpinnings of the environmental thinking in North America, landscape ecology was reviewed. This transdisciplinary uses diverse disciplines ranging from biology to landscape architecture that have particular foci, which enriches the whole body of knowledge. Thus landscape ecology has various dimensions that give it a holistic focus. The North American focus in landscape ecology is more concerned with ecology in natural places, whereas the European counterparts developed more human-centered landscape ecology. Landscape ecology studies landscape structure, function and change. Its strengths lie in its spatial concepts and in theoretical findings that have emerged. However, the failure of practitioners to communicate with scientists is a weakness in common practice of landscape ecology.

This chapter also discussed difficulties in experimenting with landscapes at coarse scales. Null models were described as a possible methodology for analyzing landscape structure, function and change. Finally, this chapter analyzed the meaning and significance of environmental management for planners. There is no guarantee that planning has full knowledge to do a perfect job. Uncertainty and potential conflict are always present. The precautionary principle and the adaptive management are frameworks for planning under conditions of high uncertainty.

In the light of the above, analysis of climate change and its impact on landscapes must be framed within a holistic, systems approach. The issue of scale over space and time is applicable to climate change, and selection of the right scales is important in planning land use There is limited point in planning for the short term when impacts can appear in the long term, and there is no point in planning for a phenomenon at a given scale which is irrelevant for certain organism which relate closely to another scale.

All these considerations help to conceptualize analysis of climate change impacts on landscapes. This is, in fact, the analysis of landscape change through analysis of landscape structure as a result of energy fluxes.

3 Human-induced climate change as a driver of landscape change and function.

3.1 Introduction

This chapter reviews the characteristics of recent climate change to establish links between climate change and land-use planning as adaptation tools. First, the concept of human-induced climate change is introduced, and then examples of actual or potential biophysical impacts of this phenomenon are given. Finally the context the case of the Boreal forest in Canada, especially in Ontario is reviewed.

Climate modeling techniques are introduced. The characteristics, advantages and limitations of General Circulation Models are reviewed. Greenhouse Gases (GHG) Emission Scenarios from the Special Report on Emission Scenarios (SRES) are also described. Downscaling techniques are introduced, and the use of stochastic weather generators as downscaling tools is examined.

Climate Change adaptation and mitigation are described. The possibility of land-use planning as an adaptation and mitigation strategy is also explored. Lastly the use of LANDIS and BFOLDS for modeling landscape change under climate change scenarios is studied.

3.2 Recent human-induced climate change

To understand the general causes of climate change it is necessary to address the balance between the energy that the earth receives from the sun, as light and ultraviolet radiation and the energy reflected back to the space as infrared energy (IPCC, 2001b). Any factor, natural and/or human-induced, that changes this balance affects the climate system. The atmosphere traps a fraction of this energy so it returns to the earth and thus regulates the climate system. This is called the *greenhouse effect*. Atmosphere composition contains gases that impede infrared radiation from returning to space. This raises the temperature of the lower atmosphere, and thus the Earth's surface temperature. These gases are called greenhouse gases (GHG) and are indentifies in Table 3.1. Their presence in the atmosphere is normal at varying historical conce ntrations. A change has been observed in that composition since the 19^{th} Century. Since the industrial revolution, the normal climatic pattern has been altered by human influence (IPCC, 2001c) as carbon dioxide (CO_2) and other GHG have increased 30 to 45% over pre-industrial levels. Air pollution has contributed to that increase. On the other hand, processes like land-use change (e.g. extensive deforestation that has an effect in the balance of sinks and sources of CO_2) also contribute to the GHG enrichment in the atmosphere.

Table 3.1 Greenhouse gases in the Kyoto Protocol and in the Montreal Protocol and its Amendments (IPCC, 2001b).

Carbon dioxide (CO2)
Methane (CH4)
Nitrous oxide (N2O)
Hydrofluorocarbons (HFCs)
Perfluorocarbons (PFCs)
Sulphur hexafluoride (SF6)
Chlorofluorocarbons (CFCs)
Hydrochlorofluorocarbons (HCFCs)
The halons.
Tropospheric ozone (O3)
Stratospheric water vapour (H2O)
Tropo-spheric H2O
Carbon monoxide (CO)
Volatile organic compounds (VOC)
Nitrogen oxides (NOx = NO+NO2)
Aerosols

It is believed that the increase in GCG is the primary cause of observed increases in global temperature in the 20th century (IPCC, 2001c). If the Kyoto Protocol is fully implemented, model predictions suggest that there would be a reduction of global warming by about 0.05°C from 1.4 to 5.8 °C by 2100 (IPCC, 2001b). Yet with radical targets, such as 20 percent reduction in greenhouse gas emissions from annex 1 countries[17] warming would be reduced by only a further 0.1°C by 2050 (Canadian Climate Program Board, 1998; Parry et al., 1998; United Nations, 1997). The international community realizes that even with mitigation some climate change is inevitable, and adaptation will be required.

[17] Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Czechoslovakia, Denmark, European Economic Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great, Britain and Northern Ireland, and United States of America (United Nations, 1992).

Signs of the impact of recent climate change over different ecological and physical systems have been indicated (Hughes, 2000). Some of them are summarized in Table 3.2.

3.2.1 Impact of climate change on the biota

Regarding climate change impacts on the biota, the IPCC (2001b) has reported that the anomalous climate of the 20th Century has an impact on the physiology, distribution and phenology of some species. These changes are consistent with some theoretical predictions.

Species can show three mechanisms to adapt to climate change (Noss, 2001): phenotypic plasticity (acclimatization); adaptive evolution; and migration to suitable sites (Bawa and Dayanandan, 1998). Of these three, there is evidence that migration has been the main mechanism of adaptation, manifested in former changes in climate (Noss, 2001). There are two additional possibilities: the decline and/or extinction of species. In any case, there is a great chance in loss of biodiversity (Noss, 2001).

Walter, et al. (2002) found ample evidence of impacts of the 30 years of warming at the end of the 20th Century on: (1) the phenology and physiology of organisms, (2) the range and distribution of species, (3) the composition of and interactions within communities, and (4) the structure and dynamics of ecosystems. Root et al. (2003) also found evidence of impacts based in an analysis of 143 studies. They found that 80% of the species studied are shifting ranges in the direction expected on the basis of their known physiological constraints and relationships with climate. They concluded that the balance of evidence suggests that climate change impact on species is already evident.

The possibility of migration has problems. Assuming that 1ºC of annual mean temperature is equivalent to a latitudinal shift of 150 km, or an elevation shift of 250 m (MacArthur, 1972), an increase in mean annual global temperature of 1ºC in 20 years would necessitate migration rates of 7.5 km / yr. The fastest tree migration rates recorded in North America during the last interglacial were 10 to 40 Km per century (Gates, 1993; Primack, 1998).

Table 3.2 Examples of recent changes to physical features of the earth (Canadian Council of Ministers of the Environment, 2003; Hughes, 2000)

Sea levels
• The global sea level has risen by 10-25 cm over the past 100 years.
Sea Ice
• Reductions in the coverage of summer ice since 1990, with an accelerated decline over the period of 1987-1994.
Glaciers
▪ Glaciers in European Alps have lost 30 – 40% of their surface area and approximately half of their volume since the mid-1800s.
▪ The area of the Canadian Arctic that is permanently covered by sea ice has decreased by about a quarter since the late 1960s. Hudson Bay is now ice free a week longer, on average, than it was 30 years ago.
Climate
▪ Most of Canada has become wetter, with increases in precipitation ranging from 5% to 35%.
Insects
▪ Warmer temperatures may be contributing to recent increases in the population of the mountain pine beetle, an insect pest responsible for the destruction of valuable timber in B.C.
People
▪ The traditional knowledge that aboriginal people relied on in the past to live off the land is becoming harder to apply as a result of more variable weather and changes in the timing of seasonal phenomena. A shorter, less reliable ice season has also made winter travel, hunting, and fishing in the North more difficult and dangerous.

In recent work that support these interpretations, Malcolm et al.(2002b; 2002a) verified that global warming situations may require migration rates faster than those observed during postglacial times. To find out how that would happen they used fourteen different combinations of coupled GCMs and Global Vegetation Models (GVM) to determine the migrations distances species would need to migrate in a climate change scenario situation. They found that high migration rates ($\geq$1000 m year^{-1}) were relatively common in all the models used, and that the boreal and temperate biomes would require higher migration rates than the tropical biomes.

In the context of a fragmented landscape, it would be even more difficult for species to migrate (Bawa and Dayanandan, 1998; Malcolm, 2002b; Shafer, 1999). This suggests the need for alternative forms of management and preservation for those species considered important[18.] For example, translocation of species (plants and animals) has been proposed as one possibility to help species in that migration (Bawa and Dayanandan, 1998; Griffith et al., 1989).

3.2.1.1 The case of Boreal forests in Canada

Climate change is projected to be most extreme at higher latitudes (IPCC, 2001b). The northern location of the boreal forest in Canada implies that the potential climate change impacts should be studied there. The importance of the boreal forest for the Canadian economy is a further reason for such studies (Lenihan and Neilson, 1995). The boreal forest in Canada comprises 82% of Canadian productive forests. Boreal forest has relatively few tree species. They are adapted to cold climate and fires (Thompson, 2000).

In Ontario, three major forests are present: the Carolinian, the Great Lakes-St. Lawrence, and the Boreal (Thompson, 2000). The Boreal Forest occupies the largest area in Ontario (Figure 3.1). It is dominated by coniferous and mixed wood forests. Soils are shallow humo-ferric podzols, or brunisols with some luvisols (Thompson, 2000) The main tree associations present in the boreal forest are shown in Table 3.3. The most abundant, is the black spruce and jack pine, about 70% of the boreal area (Ontario Ministry of Natural Resources, 1996b).

[18] Again, preservation in this context would be more directed by human preferences. Nature will evolve anyways, so the decision if the natural response is "desirable" or not, reflects anthropogenic desires and values more than natural function.

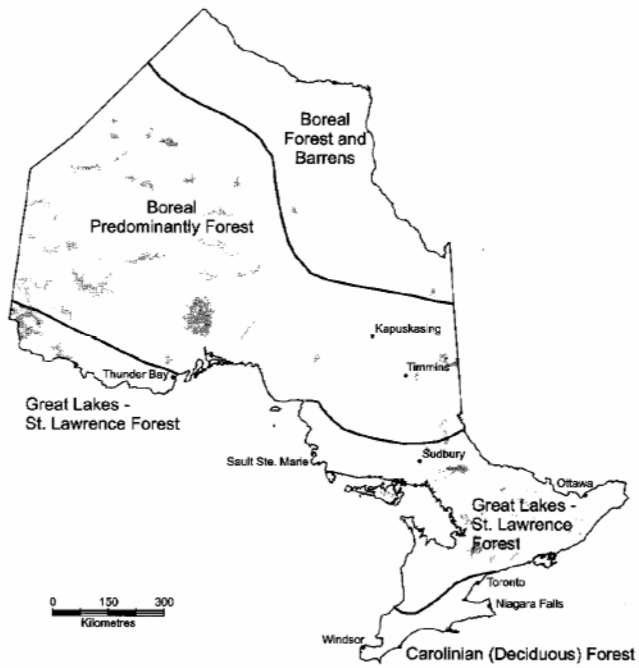


Figure 3.1 Boreal forest in Ontario (from Thompson 2000*).*

Table 3.3 Main tree associations in the Boreal Forest (Thompson, 2000).

▪ Jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*).
▪ Jack pine and black spruce mixed with white birch (*Betula papyrifera*) and trembling aspen (*P*opulus *tremuloides*).
▪ Trembling aspen, white spruce (*Picea glauca*) and black spruce.
▪ Trembling aspen and balsam fir (*Abies balsamifera*)
▪ Black spruce and balsam fir

3.2.1.1.1 Main drivers in Boreal Forest Dynamics

The distribution of the associations in Table 3.3, relates closely to the disturbance regime (Suffling, 1995). The most important disturbance is fire, although insect outbreaks and blow-down events are also present (Thompson, 2000). Harvesting is another driving force in the Boreal forest. Climate has a direct role in the boreal forest dynamics. A change on climate can affect the way that ecosystem works so that planning and management of the boreal forest should include potential impacts of harvesting and climate change in the short and medium term.

3.3 Climate change modeling and impact analysis

This section explores some technical and conceptual aspects of climate modeling and how impact analyses are undertaken.

3.3.1 Climate change scenarios

A climate change scenario refers to a plausible future climate constructed explicitly for use in investigating the potential consequences of anthropogenic climate (IPCC, 2001b), and is useful for evaluating impacts.

Scenarios of climate change can be classified as:

a) *Arbitrary (synthetic) scenarios* - These consider incremental changes in mean temperature and/or precipitation amount, usually combined with a baseline climate database. They can be used in preliminary studies of system sensitivity (Canadian Institute for Climate Studies, 2000a).
b) *Analogue scenarios* – They involve the use of past climates as scenarios of future climate (temporal analogue scenario), or the use of current climate in another location (usually warmer) as a scenario of future climate in a study area (spatial analogue scenario) (Canadian Institute for Climate Studies, 2000a).
c) *Climate Models* – Climate models, and particularly global circulation models (GCMs) are the major source of information for constructing scenarios of climate change, albeit at very coarse scale. Regional climate models (RCMs) provide climate information at higher spatial resolution than GCMs but are not widely available (Canadian Institute for Climate Studies, 2000a). GCMs are considered to be the only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations, although there are limitations on the usefulness of GCM outputs because of the high cost of conducting simulation experiments and their coarse spatial resolution (Canadian Institute for Climate Studies, 2000a). In transient GCMs, historical (since the nineteenth century) and future forcing due to greenhouse gases and sulphate aerosols have

been included, thus enabling comparisons to be made between modeled and observed climate over the historical period (Canadian Institute for Climate Studies, 2000a).

3.3.1.1 Limitations of GCMs

Some of the limitations of GCMs are the following:

a) As indicated, their coarse spatial resolution, makes difficult to identify regional or local changes in climate (Table 3.4) (Canadian Institute for Climate Studies, 2002b).
b) Some physical processes are not well understood and others may not been included in the model (Etkin and Bush, 1998).
c) Not all scenarios have the same climate variables available (Canadian Institute for Climate Studies, 2003).

Despite those limitations, GCMs are valuable tools for understanding possible future situations and help in the decision-making processes, which includes landscape and land-use planning as well.

Table 3.4 GCM resolution (Canadian Institute for Climate Studies, 2003)

GCM	Resolution °lat×°long / km x km†	GCM	Resolution °lat×°long / km x km
CGCM1	3.75 × 3.75 / 412 × 416	CCSR98	5.6 × 5.6 / 616 × 621
CGCM2	3.75 × 3.75 / 412 × 416	CSIROMk2b	3.2 × 5.6 / 352 × 621
HadCM2	2.5 × 3.75 / 275 × 416	GFDL-R15	4.5 × 7.5 / 495 × 832
ECHAM4	2.8 × 2.8 / 308 × 310		

† Distance is approximate considering a degree of latitude equals aprox. 110 km, and a degree of longitude at the equator equals aprox. 111 km

3.3.2 Scenario construction

Impact studies construct scenarios, using climate models by calculating the difference (for temperature) or ratio (for precipitation) between a particular time period in the future and the simulated baseline for the same period (Canadian Institute for Climate Studies, 2000a). The change is the difference between the climate change experiment (T1) and the experiment (T2) (Canadian Institute for Climate Studies, 2000a) (Figure 3.2). This method assumes that both the control and climate change experiments exhibit similar drift and long-term variability (Canadian Institute for Climate Studies, 2000a).

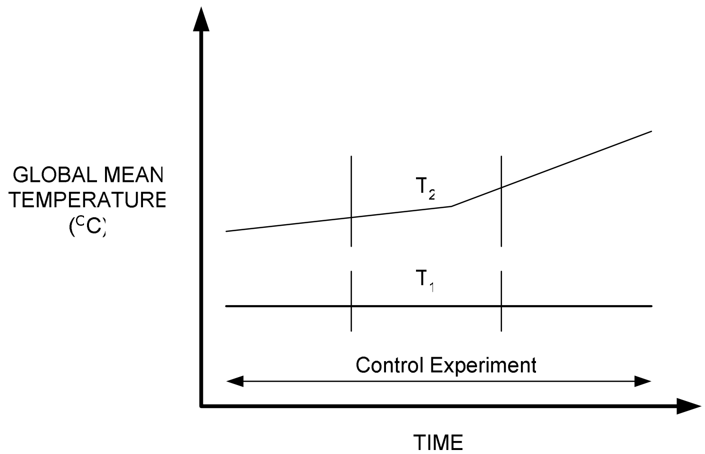


Figure 3.2. Scenario construction (after Canadian Institute for Climate Studies, 2000a).

3.3.2.1 Emissions scenarios

In analyzing of a potential climate situation, one should consider emission scenarios that depict possible future emission situations. Emission scenarios are alternative images of the future. Emissions scenarios are based on different assumptions about human behaviour over the next 100 years. They are also tools to analyze how driving forces may influence future emission outcomes for assessing the associated uncertainties (Nakicenovic et al., 2000). Scenarios are used as input into a climate model to compute climate projections.

The IPCC Special Report on Emissions Scenarios (SRES) (Nakicenovic et al., 2000) proposes four storylines[19,20] or narratives of qualitative emissions drivers (e.g. political, social,

[19] Each family of SRES scenarios includes a descriptive part (called a "storyline") and a number of alternative interpretations and quantifications of each storyline developed by six different modeling approaches. Each storyline describes a demographic, social, economic, technological, and policy future for each of the scenario families. Within each family, different scenarios explore variations of global and regional developments and their implications for GHG, ozone precursors, and sulphur emissions. Each of these scenarios is consistent with the broad framework specified by the storyline of the scenario family (Nakicenovic et al., 2000).
[20] Globally Harmonized Scenarios share common major input assumptions that describe a particular scenario family at the global level (i. e., global population and GDP within agreed bounds of 5% and 10%, respectively) compared to the marker scenarios over the entire time horizon 1990 to 2100 (deviation in one time period being

cultural and educational conditions). The approach involved developing four alternative scenario "families", comprising 40 SRES and subdivided into seven scenario groups. SRES are quantitative interpretations of these qualitative storylines. Table 3.5 summarizes the storylines.

Table 3.5 Summary of storylines (from Nakicenovic et al.2000).

SRES Storylines
The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system.
The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.
The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

3.3.3 Downscaling

The coarse scale of GCMs has led to efforts to "downscale" global results to finer spatial resolutions (Canadian Institute for Climate Studies, 2000b). Downscaling refers to the techniques to derive finer resolution climate information from coarser resolution GCM output.

The following are empirical/statistical transfer methods and statistical/dynamical methods to downscale GCM's output (Canadian Institute for Climate Studies, 2002b):

tolerated). To further scenario comparability more stringent harmonization criteria were applied where population, GDP, and final energy trajectories were harmonized at the level of the four SRES regions (Nakicenovic et al., 2000).

a) *Transfer functions* - statistical relationships are calculated between large-area and site-specific surface climate, or between large-scale upper air data and local surface climate.
b) *Weather typing* - statistical relationships are determined between particular atmospheric circulation types (e.g., anticyclonic or cyclonic conditions) and local weather.
c) *Stochastic weather generators* - these statistical models may be conditioned on the large-scale state in order to derive site-specific weather (e.g. SDSM (Wilby et al., 2002) , LARS-WG (Semenov et al., 1998), and ClimGen (Stockle et al., 1999)).

Regional climate models (RCM) have been developed to enhance our understanding of climate processes at lower spatial scales; nevertheless, they are not as widely available as GCMs. The use of GCMs and of statistical downscaling has been more common in research related to the impact of human-induced climate change.

Another approach is to downscale monthly GCM to daily data. The differences between the GCM and the control scenario are applied to daily data observed in the study area. Figure 3.3 shows this rationale in an example in Poza Rica Veracruz, Mexico.

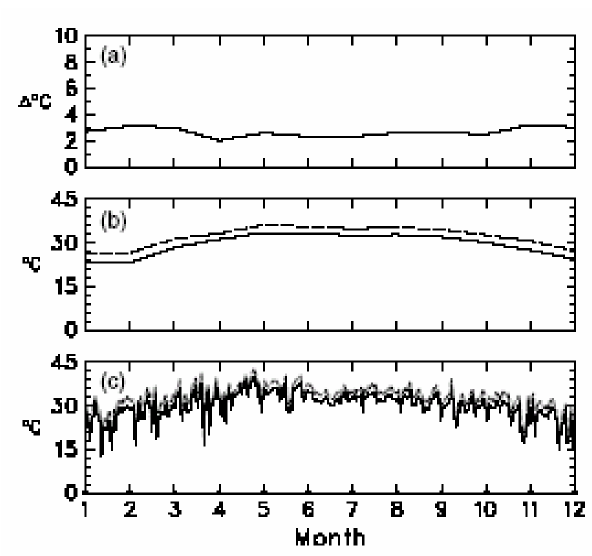


Figure 3.3 An example from Poza Rica (20.3° N, 97.3° W). (a) Mean monthly differences (Δ) (2 X CO_2 minus control) of average temperature. (b) The average 17 years (1973 to 1989) and the 2 X CO_2 mean monthly temperature. It was obtained by adding the differences indicated in (a) to the baseline (solid line). (c) It is the example of year 1975 where the monthly differences in (a) were applied to the daily data (dashed line) (Reproduced with permission from the IPCC, 2001).

3.3.4 Stochastic weather generators

Some projects require daily time series of climate data (e.g. hydraulic structures, agriculture yield models, etc.). In many cases data are not available for all parameters and periods needed, or only monthly values are accessible (Wilks and Wilby, 1999). For developing countries, the problem becomes yet worse as less climate information is available in many cases. The approaches to generate needed data at a particular location include geostatistics, from which techniques of interpolation have been used to find information of sites that do not have data (e.g. Inverse Distance Weighted, Natural Neighbours, Spline, Kriging and Trend) (Burrough and McDonnell, 1998). With advances in Geographic Information Systems (GIS), application of these techniques to spatial datasets has become feasible (e.g. (Booth, 2000)). The second approach is the use of stochastic weather generators. For research related to climate change, weather generators have been used as downscaling tools from GCM output.

Wilks and Wilby (1999) Have analyzed the use and characteristics of weather generators. Here, only some important characteristics of these tools are highlighted. A stochastic weather generator produces artificial time series of synthetic weather data of unlimited length for a location, based on the statistical characteristics of observed weather data a specific location. (Canadian Institute for Climate Studies, 2002a; Semenov et al., 1998). It can be used to in-fill missing climate data (Wilks and Wilby, 1999). Weather generators are also considered as complex random number generators (Von Storch et al., 2004) that can produce daily weather data at a particular location, based on existing climate information (Wilks and Wilby, 1999). Although weather generators' outputs behave statistically like observed weather data, it is not expected that any particular simulated weather sequence duplicate weather observations at a given time on either the past or future (Wilks and Wilby, 1999). As such, a weather generator is not an averaging tool. Model verification has to be based on analysis of the statistical characteristics of observed and generated data (Canadian Institute for Climate Studies, 2002a). As precipitation is the most critical meteorological variable in many processes, and its absence or presence affects the statistics on many non-precipitation variables to be simulated, the development of weather generators has been commonly emphasizing precipitation processes. In many weather generators the initial process is based in the analysis of precipitation, and then other parameters are analyzed and generated in turn.

For each month, different model parameters are used in order to reflect seasonal variations in both the values of the variables themselves and in their cross-correlations, i.e., in the relationships between the individual variables over time (Canadian Institute for Climate Studies, 2002a).

As GCM outputs cannot be used directly at a site because of their very coarse spatial resolution, weather generators can serve as a computationally inexpensive tool to produce site-specific climate change scenarios with daily time-steps. Thus changes in both climate means and climate variability predicted by GCM experiments can be applied to the parameters derived by the weather generator for the site. Daily scenario data can then be obtained by running the weather generator, and by comparing the statistical characteristics of the observed versus the generated data (Semenov and Barrow, 1997; Semenov et al., 1998; Wilks, 1992).

Weather generators have been classified as “Richardson” (Richardson, 1981; 1982; Richardson and Wright, 1984) which have a Markov Chain approach, and “Serial” (Canadian Institute for Climate Studies, 2002a) or spell length (Racsko et al., 1991). Markov models construct a random process which determines a day at a station as “wet” or “dry”, depending on the presence or absence of precipitation on a previous day (Von Storch et al., 2004).

In the United States the WGEN developed by Richardson and Wright (1984) is widely used. It estimates daily precipitation, maximum and minimum temperatures, and solar radiation, and it is designed to preserve interdependence between variables, as well as persistence and seasonal characteristics of each variable. In this model monthly statistics, which in many cases are the ones available, cannot be used to generate daily data. This model was developed to be used mainly in continental United States (Ndlovu, 2003).

To counteract some limitations of WGEN, a modified version called CLIMGEN was developed by Gayton and Campbell at Washington State University. This model generates daily maximum and minimum temperature, and precipitation from either daily weather data, if available, or from monthly summaries.(Ndlovu, 2003). CLIMGEN follows a similar approach to Richardson models, but can generate daily data from monthly records. Another advantage of CLIMGEN is the possibility to generate climate variables needed for landscape models like BFOLDS (see Section 3.6.2). The daily parameters generated in CLIMGEN are temperature, evapotranspiration, wind speed, precipitation, dew point, and solar radiation.

CLIMGEN has been used in research related to agricultural cropping systems modeling (e.g. Acutis et al., 2000, Annandale et al., 1999), and mainly as part of the CropSyst[21] model (Bellocchi et al., 2002; Turbiello et al., 2000) .

Other models (Serial Models) like Lars-WG (Racsko et al., 1991; Semenov and Brooks, 1999) which were developed specifically for climate change impact applications. Lars-WG has been compared to WGEN (Semenov et al., 1998), and performed better in generating weather data with the input from GCMs . For a model like BFOLDS, which needs daily data, Lars-WG seems not to be appropriate as it does not produce the whole set of data BFOLDS needs like temperature, relative humidity precipitation and wind.

3.4 Uncertainty

Uncertainty in models can result of the following (Moss and Schneider, 2000): (a) known processes but unknown functional relationships or errors in the structure of the model; (b) known structure but unknown or erroneous values of some important parameters; (c) known historical data and model structure, but reasons to believe parameters or model structure will change over time; (d) uncertainty regarding the predictability (e.g., chaotic or stochastic behaviour) of the system or effect; and (e) uncertainties introduced by approximation techniques used to solve a set of equations that characterize the model. Other sources of uncertainty relates to the quality of data gathered, inappropriateness of/lack of confidence in underlying assumptions; and uncertainty due to projections of human behaviour (e.g., future consumption patterns, or technological change), which is distinct from uncertainty due to “natural” sources (Moss and Schneider, 2000). All those sources of uncertainties contribute to the uncertainty in the final assessment. This chain of uncertainties for a cascade

[21] It is intended to serve as an analytic tool to study the effect of cropping systems management on productivity and the environment.

extends to the following aspects (Mearns et al., 2003) (a) specifying alternative emissions futures, (b) converting emissions to concentrations; (c) converting concentrations to climate forcing; (d) modelling the climate response into inputs for impact studies; (e) converting the model response into inputs for impact studies; and (f) converting impacts. Figure 3.4 shows the sources of uncertainty that form a cascade of uncertainties in impact studies. Going from socio-economic assumptions and emissions scenarios, down to impact models and impacts, there is an accumulation of uncertainties that is expressed as "cascading" assumptions. From Impacts there are two possibilities: to develop policy responses either through mitigation or adaptation based on the impacts found, or, as interactions and feedbacks in land use change. The issue of accumulative uncertainty should be identified and measured if possible to have a better approximation of impacts and to responses to those impacts (IPCC, 2001b).

3.5 Adaptation and Mitigation

The vast majority of scientist and managers accept the significance of human-induced climate change. Two main policies have been devised to deal with climate change impacts: adaptation and mitigation (Carter et al., 1994; Smit, 1992). Mitigation is the prevention of dangerous interference with the climate system through the stabilization of atmpspheric greenhouse gas concentrations (Burton et al., 2002).

Mitigation is a response to the broad issue of climate change (Smit et al., 1999). Mitigation is implanted at international government level through agreements like the Kyoto Protocol (United Nations, 1997). Mitigation has not only been proposed for industry emissions, but also in land-use and management and afforestation is one example of this (as in Dale, 1997).

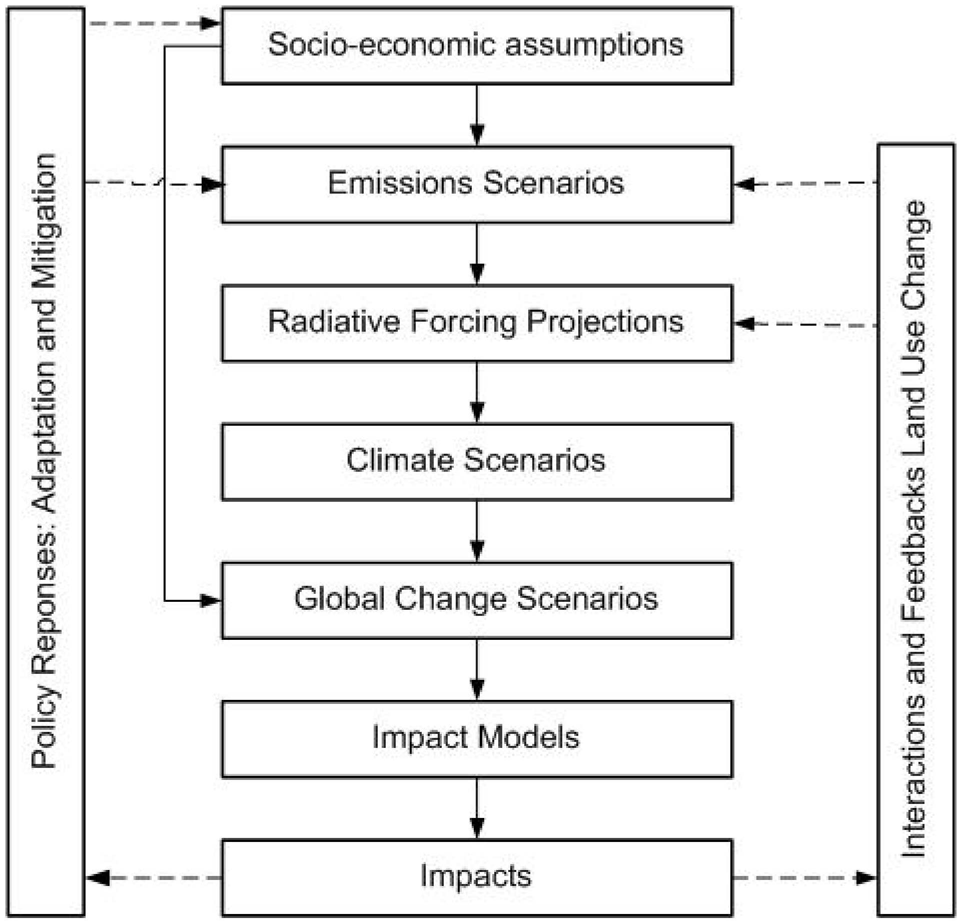


Figure 3.4 Cascading Uncertainties (adapted from IPCC [2001]; and Mearns et al. [2003]).

Once it is accepted that some human-induced change in climate is likely, the need for adaptation emerges. Climate change adaptation has been defined as an

> Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities […] climate adaptation policy refers to actions taken by governments including legislation, regulation, and incentives to mandate or facilitate changes in socio-economic systems aimed at reducing vulnerability to climate change, including climate variability and extremes. (IPCC, 2001d:72)

Changes in socio-economic systems can be done in practices, processes, or structures (Watson et al., 1996). As indicated in Section 3.3.2.1 SRES scenarios are produced with assumptions about how society can be like in the following 100 years.

Mitigation has received more attention than adaptation. One reason is that it is widely understood that, in the long term adaptation will not suffice (Burton et al., 2002), and so, it is necessary to keep working in mitigation.

Monastersky (1999) has pointed out that, no matter what happens with international agreements (e.g. the Kyoto Protocol) we are experiencing climate change now, and we shall still be experiencing it for many years so we have to think in adaptation..

It is not possible to predict exactly what or how changes will occur in the future, because climate system responses are non-linear (Scheraga and Grambsch, 1998). Nevertheless the need for planned action remains if society wants to be prepared for potential threats.

3.5.1 Some characteristics of adaptation

Adaptation has two main roles (Smit et al., 1999).First, adaptation is a part of impact assessment, where the central question is "what adaptation are likely?". Second, adaptation is a part of policy response, where the central question is "what adaptations are recommended?" The main interest for impact assessment is the understanding of adaptations, predicting circumstances under which they can be expressed, and estimating their implications for the systems or regions of interests. As a policy response (e.g. with decision models), adaptation is a prescriptive or normative exercise, which requires information of possible adaptation strategies or measures, as well as on principles for evaluating the merits of adaptation options. A complete adaptation approach has to deal both roles at once. Table 3.6 shows those two roles, and relates them to specific articles of the United Nations Framework Convention on Climate Change (UNFCCC)(1992).

Carter et al. (1994) have proposed six general strategies for adapting climate change impacts (Table 3.7). Scheraga and Grambsch (1998) proposed nine fundamental principles for designing adaptation policy. They help to contextualize the issue of adaptation and to discriminate possible sources of misunderstanding about what to adapt and how to adapt (Table 3.10).

Table 3.6 Roles of adaptation (after Smit et al. 1999).

	Adaptation as a part of IMPACT ASSESSMENT	**Adaptation as part of POLICY EVALUATION**
Analytical function	Positive	Normative
Purpose	Predict, estimate, likelihood	Evaluate, prescribe
Central Question	What adaptations are likely?	What adaptations are recommended?
UNFCCC Article	Art 2. Are the impacts likely to be dangerous for ecosystems, food production and sustainable development?	Art 4. Which measures should be formulated and implemented to facilitate adequate adaptation?

So far all concepts reviewed help to contextualize and to understand mitigation and adaptation to climate change. However society's willingness to expend resources to avoid the effects of climate change will depend on its perceptions of the risks poses by climate change, the perceived costs of the effort, and how much it is willing to risk possible negative consequences of climate change (National Academy of Sciences, 1992; Office of Technology Assessment, 1993). In this context educating society about the risks and potential impacts of climate change is important to garner support for adaptation science and application.

The policy-making process has to be informed as well as possible about potential situations, in order to establish better policies.

Table 3.7 Six strategies for adapting to climate change (Carter et al., 1994)

Strategies for adapting to climate change
1. Prevention of loss, involving anticipatory actions to reduce the susceptibility of an exposure unit to the impacts of climate. 2. Tolerating loss, where adverse impacts are accepted in the short term because they can be absorbed by the exposure unit without long term damage. 3. Spreading or sharing loss, where actions distribute the burden of impact over a larger region or population beyond those directly affected by the climatic event. 4. Changing use or activity, involving a switch of activity or resource use to adjust to the adverse as well as the positive consequences of climate change. 5. Changing location, where preservation of an activity is considered more important than its location and migration occurs to areas that are more suitable under the changed climate. 6. Restoration, which aims to restore a system to its original condition following damage or modification due to climate.

3.5.2 Landscape and land-use planning as adaptation tools to climate change

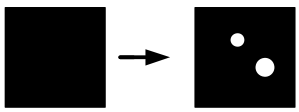
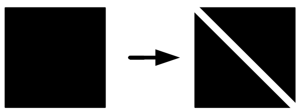
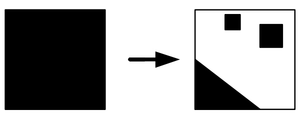
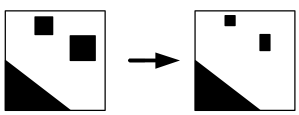
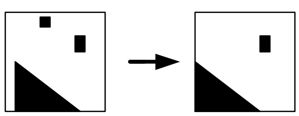
Land-use has been defined as "the management regime humans impose on a site" (Dale, 1997); it has also been defined as a human purpose or intent applied to biophysical attributes of the earth's surface (Lambin et al., 2002). Land-use also refers to the way and the purposes for which humans employ the land and its resources (Meyer, 1995).

Forman (1995a) deals with this issue from a landscape ecology perspective, and has defined it as "land transformation", and described it through five different processes: perforation, dissection, fragmentation, shrinkage, and attrition (Figure 3.5).

Various land-uses have implications at different temporal and spatial scales. Hodge (1998) identified four spatial scales concerning land-uses: individual parcel of land, districts, community, and regional. ***Table 3.8*** shows these four scales with examples, description level, and issues. Hodge's approach to land-use planning has a strong urban focus, and stops at regional scale. In terms of an ecosystem approach, it can be referred as a hierarchy of small to large ecosystems. In Ontario the Oak Ridges Moraine is classified as an ecodistrict (Marshall and Schut, 1999). It provides the boundary for land-use planning at lower scales.

For Barrow (1997), land-use planning is done at three scales: the local, the regional, and the national, showing a more comprehensive approach. Thus one should consider different tools that feed the process of land-use planning, and that establish a conceptual link between land-use, landscape planning, and climate change. Among those tools, Barrow (1997) suggested that land capability assessment, appraisal land evaluation, land suitability assessment, and terrain evaluation, are all useful in planning land-use. He described those processes within the framework of environmental assessment.

Landscape planning has been defined as the use of a given site or the optimum site for a given use, both considered on an extensive scale (Seddon, 1986), and it covers macro-environmental on land-use and planning activity dealing with landscape features, processes and systems (Marsh, 1998). The landscape encompasses the use of land-housing, transportation, agriculture, recreation, and natural areas (Steiner, 1991a), as well as the physical expression of those in land-use.

Spatial processes	Patch number	Average Patch Size[1]	Total interior habitat[2]	Connectiv-ity across area[3]	Total boundary length[4]	Habitat	
						Loss	Isola-tion
 Perforation	0	-	-	0	+	+	+
 Dissection	+	-	-	-	+	+	+
 Fragmentation	+	-	-	-	+	+	+
 Shrinkage	0	-	-	0	-	+	+
 Attrition	-	+	-	0	-	+	+

Footnotes. [1]Perforation = "0" if size is measured as diameter rather than area; Attrition = "0" or "-" if patch loss is ≥ average patch size. [2]Shrinkage or Attrition = "0" if patch change had no interior habitat. [3]Perforation = "-" if random straight routes are measured; Shrinkage or Attrition = "-" if measured as probability of object crossing using patches as stepping stones. [4]Shrinkage = "0" or "+" if portion lost makes no change or increases boundary of the patch

Figure 3.5 Major spatial processes in land transformation and their effects on spatial attributes. + = increase; - = decrease; 0 = no change. Effects are measured for the block land type or habitat. (from Forman 1995).

The major drivers of land-use and landscape change are human population, affluence, technology, political economics, political structure, attitudes, and values (Turner et al. 1993 cited by Dale 1997) (Table 3.9).

At a global scale, change in landscape results from different drivers (Sala et al. 2000): land-use, climate, nitrogen deposition, biotic exchange and atmospheric CO_2. Thus land-use is one of the major drivers of global environmental change (Slamaker, 2001).. All those processes are expressed in change in landscapes. Planning should regulate landscape change, and thus the effects of that change. Adaptation to climate change through landscape and land-use change is a well established principle.

Table 3.8 Land-use at different scales (From Hodge, *1998).*

Scale	Examples	Description level
Individual parcel of land	House, lot devoted to a shopping centre, apartment complex or public building.	Detailed description of land-use in particular.
District	Similar sets of land uses occur as residential neighborhood, central business district, industrial park	Dominant land-uses usually the basis of the description.
Community		Grouping of districts (e.g. residential areas) of grouping of uses (e.g. commercial areas, regional shopping centers)
Regional level		Distinction between urban areas, agricultural areas, open spaces, etc.

The central question here in this these is “What is the role of land-use and landscape planning as adaptation tools to human-induced climate change?”. Although land-use change and its influence on global change have been studied by different researchers, but the study of the role of landscape and land-use planning as adaptation tools as a response to those changes is yet to be done. Most existing has been developed within the mitigation sector (e.g., the role of afforestation), and planning for the rise in ocean levels. This section reviews various concepts related to an adaptive response through land-use and landscape planning.

Table 3.9 Human causes and consequences of land-cover change (from Dale [1997] based on Turner et al. [1993]).

Causes	**Consequences**		
	Typical land-cover changes	**Typical activities that modify land cover**	**Ecological characteristics affected**
Population growth	Forest harvesting	Irrigation	Biodiversity
Affluence	Agricultural expansion	Fertilization	Habitat
Technology	Urbanization	Forest degradation (thinning, coppicing, gathering wood)	Soil quality Productivity
Political economy	Second home development	Introduction of exotics	Extractable resources
Political structure	Flooding	Landscape fragmentation	Water quality
Attitudes and values			Regional and global climate

If changes in land-use can affect climate (e.g. through CO_2 enrichment or sequestration), future regulation of land use through planning becomes mitigation tool. On the other hand, if it is assumed or determined that a change in the system has occurred as a result of climate change impacts, and actions related to land-use planning are developed, then it becomes adaptation.

Based on the relationship between land-use and climate change found by Dale (1997) then land-use and landscape planning have direct relation to climate change as well (Figure 3.6).

Table 3.10 Nine fundamental principles to be considered when designing adaptation policy (from Scheraga and Grambsh 1998).

Principle	Comment
1) The effects of climate change vary by region.	There is a regional texture to changes in climate, and therefore to the effects of climate change (Scheraga and Grambsch, 1998; Shriner and Street, 1998). In the same way there is a regional texture to ongoing climate change, there is a regional texture to the risks and opportunities presented by climate change. The human and ecological systems that are sensitive to climate change, and the degree to which they are vulnerable, will vary geographically (Scheraga and Grambsch, 1998).
2) The effects of climate change may vary across demographic groups	The effect of climate change will vary according to more or less vulnerable populations.
3) Climate change poses risks and opportunities	Identification of positive and negative effects of climate change should be identified with the ultimate goal of protecting public health and the environment. Policy-making should exploit those possibilities.
4) The effects of climate change must be considered in the context of multiple stressors and factors, which may be as important to the design of adaptive responses as the sensitivity to change	The assessment of the impacts of climate change on a system should consider as well the possibility of other stressors as well. Any assessment that is concerned with identifying the potential consequences of climate change and developing appropriate adaptive responses must consider 2 questions: (1) What are the existing stresses in human health and ecosystems within a particular region under current climatic conditions? (2) How might climate change exacerbate or ameliorate these stresses?
5) Adaptation comes to a cost	Any adaptation has a cost; as a result adaptation policy is economically justified.
6) Adaptive responses vary in effectiveness, as demonstrated by current efforts to cope with climate variability	The possibility of an adaptive proposal to be applied to present conditions as a reference of future situations in instructive.
7) The systemic nature of climate impacts complicates the development of adaptation policy	An adaptation strategy that may protect one particular system may, inadvertently, increase risks to other systems. As a result society may have to choose between alternative outcomes" A comprehensive (systemic) approach must be taken to the development of adaptation strategies to identify possible tradeoffs that society may have to make between future outcomes, reduce risks effectively, exploit opportunities presented by climate change and maximize social well being.
8) Maladaptation can result in negative effects that are as serious as the climate-induced effects being avoided	When a comprehensive approach is taken to the development of strategies for adapting to climate-induced effects, one must account for potential non-climate related side effects of the adaptive strategies to avoid maladaptation.
9) Many opportunities for adaptation make sense whether or not the effect of climate are realized	A better approach is to have several possibilities-scenarios to have the possibility to respond to any situation.

3.6 Landscape models, climate change and forest harvesting

Among other approaches, research on the impact of climate change on landscape change has used landscape models. Reviews to models of landscape change have been done thoroughly by Baker (1989), Sklar and Costanza (1991), and Suffling (1995).

In this section, attention is given to LANDIS and BFOLDS. These landscape models have been suggested for studying climate change impacts (BFOLDS) and climate change impacts and harvesting (LANDIS). Here their characteristics are reviewed and a comparison between them conducted.

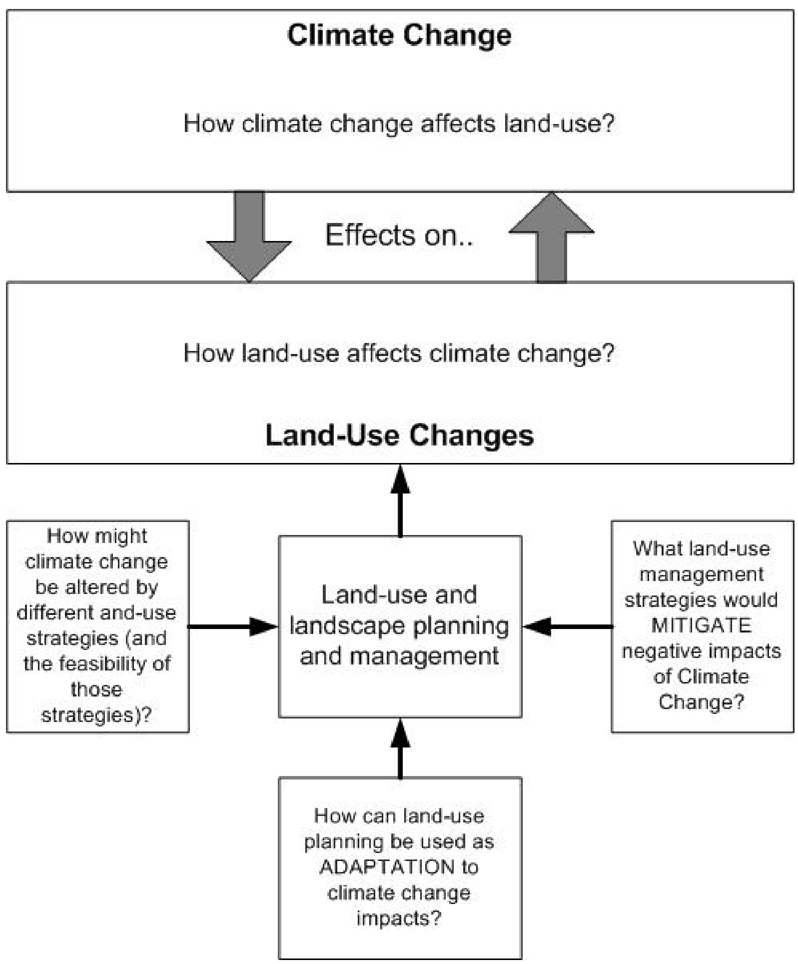


Figure 3.6 Relationship between land-use change and climate change (Dale, 1997).

3.6.1 LANDIS

LANDIS is a spatially explicit model designed to simulate forest landscape change over large spatial and temporal domains (He et al., 2000). The major modules of the LANDIS model are forest succession, seed dispersal, wind and fire disturbances, and harvesting. LANDIS is based on an object-oriented modeling approach operating on raster GIS maps (He et al., 1999). Each cell is a spatial object containing unique species, environment, disturbance, and harvesting information. LANDIS simulates tree species as the presence or absence of 10-year age cohorts in each cell, not as individual trees. Succession at each site is a competitive process driven by species life history attributes. Species' competitive ability is mainly the combination of shade tolerance, longevity, vegetative reproduction capability, seeding capability, and land type suitability (Mladenoff and He, 1999). For each cell, species birth, growth, death, regeneration, random mortality, and vegetative reproduction are simulated in 10-year time steps (He et al., 2002).

The LANDIS harvest module allows the heterogeneity of stands to be captured both within cells and among cells within the stand. Users can specify the removal method such as clear cutting, selection cutting, and shelter wood cutting.

Impacts of climate change have been studied using LANDIS. He et al. (2002) have used LANDIS to study landscape change under forest harvesting and climate warming. As LANDIS does not directly simulate climate variables, authors used results from the model LINKAGES in which individual species responses to warming climate conditions, that integrated soil, climate, and species data were derived (He and Mladenoff, 1999).

3.6.2 BFOLDS

The Boreal Forest Landscape Dynamic Simulator (BFOLDS) (Perera et al., 2003) is an integrated disturbance regime model, composed of a crown fire regime simulation module (FSM) and a vegetation transition module (VTM). It is designed to simulate fire-induced forest landscape dynamics over large areas (>10 M ha) for medium time frames (up to 300 years), at one-year time steps and at 1 ha cell-based spatial resolutions.

For the FSM, diverse fuel statistics are used to allow the model to stochastically place potential ignitions in the study area, by querying a historical database in which fire history is recorded. Based on various characteristics like species, age, moisture, aspect, and other fire indices, a cell can ignite or not. .If it ignites, then according to the characteristics of its neighbours and wind (in a 5 x 5 window), the fire can advance or stop. Once fire is modeled the VTM is applied to simulate forest cover transition and early recruitment of tree species.

This model has not included human-induced disturbances. Nevertheless, its design allows both one to include climate change because BFOLDS has several portals for climate input (A. Perera personal communication):

1) spatial stratification of succession algorithms,
2) causation of ignition of fires,
3) directing the spread of ignited fires, and
4) extinguishment of spreading of fires.

As climate models improve and spatial climate information becomes more available, the possibility to use BFOLDS in constructing scenarios of potential landscape change resulting from changes in climate will improve accordingly.

LANDIS and BFOLDS are designed for application to North American forests thus making them relevant to do research in the boreal forest. Table 3.11 and Table 3.12 compare LANDIS and BFOLDS.

Choosing the most appropriate model depends on the model accessibility, resources needed, and facilities for handling data. The final decision depends on the particularities of the process under study.

Table 3.11 Comparison between BFOLDS and LANDIS regarding their capabilities to include changes in climate and harvesting.

LANDIS

Some model characteristics	***References***	***Possibilities in modeling Climate Change and / or Harvesting***	***Advantages***	***Disadvantages***
LANDIS is a spatially explicit model designed to simulate forest change over large, heterogeneous landscapes, and over long time-scales. The major modules of the LANDIS model are forest succession, seed dispersal, wind and fire disturbances, and harvesting. LANDIS simulates at 10 year steps for each site; species are recorded as the presence or absence of 10 year age cohorts, not as individual trees. LANDIS has the capability in simulating forest succession at varied cell sizes (e.g. 10 x 10 or 500 x 500 m)	(He et al., 2000)	This model has been used to investigate forest species response to climate warming (He et al. 1999), and to study landscape change under forest harvesting and climate warming-induced fire disturbance (He et al. 2002).	This model allows for the inclusion of harvesting in modeling landscape change and has a module for this purpose.	The 10 year time step period might not be adequate to capture the landscape dynamic. To include climate change it is needed to use another additional model (i.e. APACK). It can be time consuming.

Table 3.12 Comparison between BFOLDS and LANDIS regarding their capabilities to include changes in climate and harvesting.

BFOLDS

Some model characteristics	***References***	***Possibilities in modeling Climate Change and /or harvesting***	***Advantages***	***Disadvantages***
Integrated disturbance model, composed of a crown fire regime simulation model (FSM), and a vegetation transition model (VTM). It is designed to simulate fire-induced forest landscape dynamics over large areas (>10M ha) for medium time frames (up to 3000 years), at one-year time steps and at 1-ha cell-based spatial resolution.	Perera et al. (2003)	BFOLDS allows the inclusion climate variables (see text), and simulates land cover changes under different climate change scenarios. Climate is used mainly in the way it influences fire. It is not used directly in the model. The model has not been used to simulate harvesting.	Total access to the model for this thesis. The model's developers are directly accessible and most of the information is ready to be used in boreal forest. As model developers can participate directly, it is not necessary to spend a lot of time in learning how to use the model. The time step (1 year) seems to be appropriate to monitor probable landscape change in periods as short as 60 years, as well as other possible output manipulations.	Harvesting is not included in the model. Therefore, in order to use it for climate change research, it is necessary to devise ways to use the available information to include other land use changes, such as harvesting.

3.7 The importance of the forest industry in Canada within the context of climate change

This section reviews the relevance of the Canadian forest not only for Canadians but also for the world. Forest management becomes very important when considering the impacts of potential climate change because the negative impacts of climate change on forests can seriously harm the welfare of social and natural sectors. The following elaborates on these above statements.

3.7.1 The forestry Industry in Canada

Forests were already important for indigenous communities before the settlers came from Europe in the 16 century. They used wood for shelter, tool making, means for transportation, and hunting. With European colonization, exported forest products filled the British demand for war ship construction. During the last century, forest exports supplied the U.S. construction industry (Saskatchewan Centre for Soil Research, 2002). At present, the forest sector remains relevant for Canada not only because of its ecological importance, but also because of its effect on the national economy.

Increasing public interest in forest practices, global demand, market pressures, and preservation of biodiversity, among others, influence the way that forests are managed in Canada. (Natural Resources Canada, 2003b). The forest industry is Canada's largest source of foreign exchange (Ontario Ministry of Natural Resources, 2002a) so a lot of pressures on the forest use exists from that. The relevance of the forest in Canada is summarized in Table 3.13. Table 3.14 shows the important revenues and benefits that have been reported from the forest sector, which have impact on the Canadian economy. Canadian forests comprise 10% of the global forests, thus the way in which Canada manages its forest resources has social, economical and environmental impacts within and beyond its borders. In the context of climate change, the Canadian forests play a key role in the way mitigation and/or adaptation is performed. They have an important role as sinks of CO_2, which can help in ameliorating the climate change problem. Conversely if no adequate management is applied Canadian forests can become an important source of CO_2, affecting warming trends. The consequences of this management have implications for the global climate (just as the importance of preserving systems like the Amazonia).

Table 3.13 Some figures and facts about forests in Canada (Natural Resources Canada, 2004c).

Some facts on Forestry in Canada
-Canada has 10% of the world's forests. -45% (417.6 million hectare [ha]) of Canada's land area is forested Ownership is 71% provincial, 23% federal and territorial, and 6% private. -18.6 million ha (4.45% of the total forested area in Canada) were affected by insect defoliation in 2001; 2.8 million (0.67% of the total forested area in Canada) were lost due to forest fires. -Revenues from the sale of timber from provincial Crown lands were 1.9 billion in 2000. -The forest sector's contribution to the Canadian economy (GDP) was 2.8 % of 29.9 billion, in 2002. -Direct employment was 361 300 in 2002, or 2.3% of total employment in Canada; wood industries, 177 300; paper and allied industries, 109 200; logging, 52 900; and forestry services 22 000. Employment is spread all across Canada but it is primarily in Quebec (122 700), British Columbia (87 300) and Ontario (86 200). -Canada's forests are the engine behind an industry worth about $47 billion. -The forest-related tourism industry is worth several billion dollars annually. -In 2001, Canada was the world's largest forest products exporters (18.4%). -Forest products were a major contributor to Canada's balance of trade in 2002 ($32.6 billion).

Potential shortages in wood availability as a result of climate change impacts, and their consequent impact on society, support the importance of planning the use of forests in such a way that various stakeholders can benefit. There is a need to be creative in the search for integrated sustainable planning and management that preserves and uses of the forest under diverse scenarios.

The Standing Senate Committee on Agriculture and Forestry of the Parliament of Canada (Standing Senate Committee on Agriculture and Forestry, 2003), based on feedback on climate change issues from various sectors reported the risks that climate change impacts pose for Canadian society. For forests, the Senate reports that socio-economic effects may include changes in timber supply and rent value, changes in land values, loss of forest for recreation, and dislocation of parks and natural areas. Anticipatory adaptation by the forest sector is needed, and more detailed studies of the effects of climate change on agriculture and forestry should be undertaken. The Senate reported the need for research on climate change impacts to establish potential for planning adaptation and mitigation measures to help Canadians deal with this phenomenon in the short term.

Table 3.14 Some economical figures about the natural resources sector in Canada (Natural Resources Canada, 2004c)

Facts for 2002 as of October 2003	Forestry	Minerals	Energy	Total Natural Resources	Canada
Gross Domestic Product ($ billions)	$29.9 (2.8%)	$38.1 (3.6%)	$65.3 (6.2%)	$133.3 (12.7%)	$1 050.9 (100%)
Direct employment (thousands of people)	361 (2.3%)	355 (2.3%)	225 (1.5%)	941 (6.1%)	15 411 (100%)
New capital investments ($ billions)	$2.7 (1.3%)	$4.5 (2.2%)	$38.2 (18.6%)	$45.4 (22.1%)	$205.3 (100%)
Trade ($ Billions) Domestic Exports (excluding exports)	$43.1 (11.8%)	$46.7 (13.1%)	$49.7 (13.6%)	$140.5 (38.5%)	$365.1 (100%)
Imports	$10.5 (3.0%)	$47.2 (13.5%)	$17.3 (5.0%)	$75.0 (21.5%)	$348.4 (100%)
Balance of Trade	+$32.6	+$1.9	+$33.2	+$67.7	+$47.9

1 All dollar amounts are in current Canadian dollars. “Minerals” includes uranium mining; “Energy” includes coal mining. Balance of trade is the difference between total exports and imports of goods. Services and capital flows are not includes

Note: totals may not add due to rounding

3.7.2 The forestry industry in North Western Ontario

The Ontario’s forest sector presents a similar pattern to the national one. The forest products industry provided 187,000 direct and indirect jobs in 1998 (Ontario Ministry of Natural Resources, 2002a). The value of forest industry production in Ontario was $12 billion, or 5.4 percent of the manufacturing gross domestic product in 1998 (Ontario Ministry of Natural Resources, 2002e). Many of those jobs involved were located in remote areas, where alternate opportunities are limited (Ontario Ministry of Natural Resources, 2002e). Thus a negative impact of climate change on forest can negatively impact on society, both locally and provincially. In North Western Ontario, many communities depend on the forest industry, but the economic impacts of this sector go beyond this geographic area as other, indirect jobs located in the Southern Ontario benefit from the Paying attention to the potential risks for the forest that can happen in a scenario of climate change is urgent. Policy-making able to adapt to any situation is needed. Thus studies of potential scenarios of climate change are important to give planners information for generating better policy.

Locally in northwestern Ontario many people depend on the forestry sector. Populations are decreasing (Table 3.15). Although this research is not a demographic and economic exercise, it is clear that communities in northwestern Ontario and similar regions have few options to survive and sometimes residents have to emigrate. Thunder Bar and other communities in northwestern Ontario depend on the nearby forest. Shortages in wood supply either for inadequate management in the long term or because of impacts of climate change can threat those communities locally, and possibly nationally.

Table 3.15 Population trends for North Western Ontario (Source: Statistics Canada, Census 1996 and 2001).

Catchment Area	Population 2001	% Change 91 to 96	% Change 96 to 01	Population Density 2001
District of Thunder Bay	150,860	-0.75	-4.3	1.5
District of Kenora	61,802	7.8	-2.5	0.2
District of Rainy River	22,109	0.72	-4.4	1.4
North Western Region	234,771	1.5	-3.8	0.5

Integral management and planning of forests is a complex issue as it entails considering actors with very divergent interests. Planning and management that is not comprehensive and adaptive should be avoided. Research in climate change impacts is relevant in this context as it can deliver valuable information useful for planners and managers. This thesis intends to contribute to that.

This brief discussion has highlighted the importance of the Canadian forest at global, national and provincial level. As Canada has 10% of the world forest it bears responsibility for managing that ecosystem responsibly.

3.7.3 Regional Land-use planning in Ontario

It is important to review the planning framework in Ontario that regulates forest land-use and management. This section describes the Ontario's Living Legacy initiative and other background information important to the context of climate change impacts on forests and other Ontario ecosystems.

3.7.3.1 Lands for Life and the Living Legacy exercises

The "Ontario's Living Legacy" (the OLL) is based on the "Lands for Life" (the LL) exercise of land-use planning in Ontario. They were eventually bases on a broad participatory process (Ontario Ministry of Natural Resources, 2002c). The LL and the OLL were directed to plan the use of the land in Ontario, with the dual goal of environmental preservation and economic development and using a sustainability approach. The main objectives of the LL and the OLL are shown in Table 3.16.

Table 3.16 Objectives of the LL and the OLL (Ontario Ministry of Natural Resources, 2002c).

-Completing Ontario's system of provincial parks and other protected areas; -Recognizing the land use planning needs of the resource-based tourism industry; -Providing the forest, mining, and other resource industries with greater land and resource use certainty; and, -Enhancing angling, hunting and other Crown Land recreation opportunities

The amount of land covered in this exercise and other details in the OLL are shown in Table 3.17. These processes were directed to 39 M ha of Ontario Crown (Government of Ontario, 1999), and were developed between 1997-1999 (Government of Ontario, 1997).

Table 3.17 Some Characteristics of the LL (Ontario Ministry of Natural Resources, 2002c).

-The Land Use Strategy affects over 45 per cent of Ontario. -A total of 378 new parks and protected areas will be established across the planning area from Peterborough to the 51st parallel. -The protected areas system will be enlarged by 2.4 million hectares, bringing Ontario's total protected lands to more than 9.5 million hectares, an area that would cover all of southern Ontario south of Algonquin Park, or nearly three-quarters the size of England. -Nine featured areas have been identified and will become important tools for increasing world interest in visiting Ontario.

The planning exercise was divided in three geographic areas: Boreal West, Boreal East, and Great Lakes – St. Laurence. Both the LL and OLL exercises were a response to the previous planning in Ontario, mostly by the Ontario Ministry of Natural Resources. The provincial government tried to take a more participatory planning process, developed by means of round table recommendations and other public input.

The OLL, in establishing its role as a framework for planning land-use and management pointed out:

> This strategy [the OLL] is a guidance document that sets a framework for future land and resource management of Crown Lands in the planning area […] it provides guidance and direction of what activities are proposed to certain area and what activities are permitted. (Government of Ontario, 1999)

The document stated also that "any new or revised plans for Crown Lands will be consistent with the intent of the strategy" (p.2) which makes this planning document an important framework for proposed modification of land use and landscape planning. The OLL was concerned with "long-term health of ecosystems", which supports any proposal that tries to examine factors affecting long-term system behaviour. Research related to climate change should find a prime place in this strategy. The OLL points out that "Human life, property, and natural resources values are protected for hazards, such as fires, floods and erosion" (p.2) As the Canadian Climate Impacts and Adaptation Research Network (2002) emphasized, there is a linkage between climate change and hazards issues supported by the documentation of the influence of climate and climate change on fire frequency (Suffling, 1993; 1998). This research lays the foundation for propositions regarding the possible direct and indirect effects of climate change on forest fires.

As these policy exercises aimed to simultaneously serve at both conservation and economic purposes, they established an "Enhanced Management Area" designation (Table 3.18). Such management areas were devised to include a diverse spectrum of sectors dependent on those Crown Lands. To reinforce the LL and OLL, the Ontario Forest Accord (Ontario Ministry of Natural Resources, 2003), was established among stakeholders to reinforce both protection of areas allocated to preservation, while considering forestry industry needs.

Table 3.18 Designations in Lands for Life and Ontario's Living Legacy (Government of Ontario, 1998; Ontario Ministry of Natural Resources, 2002c)

LL	OLL
-New Provincial Parks -New Conservation Reserves -Stewardship reserves -Enhanced management areas -Heritage waterways -Great Lakes heritage coastlines -General use areas -Undesignated	-Provincial Park -Conservation Reserve -Forest reserve -General use area
Enhanced management areas are divided as follows: -Natural heritage -Recreation quality -Remote access -Scenic -Resource-based tourism -Wildlife -Wildlands recreation	In the LL, "Enhanced Management Areas" are classified in different land use designation and are divided as follows: -Natural heritage -Recreation -Remote access -Fish and wildlife -Great Lakes coastal areas -Resource based tourism -Intensive forestry

It is important to note that there are diverse types of protected areas and designations in Ontario that contribute to landscape management in the province (Ontario Ministry of Natural Resources, 2004a).

3.7.3.2 The Legacy Forest

In 1999, the Ontario provincial government approved the Living Legacy Trust which was intended to support projects related to resource management in the LL and OLL area. Three years later, the Living Legacy Trust approved funding for the Living legacy proposals from Lakehead University. The Legacy Forest is an area selected for research on sustainability of Intensive Forest Management (Crowe and McCauley, 2002). It is composed of Quetico Provincial Park (unharvested) and the southern half of the Dog River-Matawin Forest (area under harvesting) (Crowe and McCauley, 2002). The characteristics of the study area allow comparison of the effects on a harvested area against a preserved one, which offers possibilities to research diverse aspects of landscape dynamics. The Legacy Forest consortium associates research in several areas of the forest, and store and share the information that they obtain in an on line data warehouse (in www.legacyforest.ca). The project's partners belong to universities, forestry companies, the conservation sector, and the community, so as to represent a diverse spectrum of stakeholders. As the Legacy Forest consortium tries to understand better and sustainable ways to use the forest, climate change impacts have been a concern and researchers working in this area have been accepted into the program.

3.8 Summary and Conclusions

According to evidence from changes in diverse ecosystems, climate change is occurring. Species are likely to migrate to ecosystems more adequate for their development and survival. Migration can be hindered in some places as landscapes are increasingly fragmented. Under certain situations species, and accordingly, biodiversity may be lost.

The Canadian boreal forest has provincial, national and global significance. Climate plays a very important role in forest dynamics, thus any change in climate is expected to increase disturbances, and so to affect the structure and composition of this important ecosystem.

Scenario construction techniques are useful for impact analysis on ecosystems. The use of general Circulation Modes is the most reliable technique among others for constructing those scenarios.

The use of stochastic weather generators is an efficient way to produce weather data when data sets are incomplete. CLIMGEN is an adequate generator for application in Canada, as it can generate ample sets of weather variables.

Mitigation has received more attention than adaptation which can be explained in various ways. One is that it is easier to locate and control emission sources, than to face the whole set of impacts in an area and plan adaptation measures. To start adaptation measures, the first premise is to assume that change has been already happened. This can involve political issues as important actions like the Kyoto Protocol have been dealing with mitigation, in an attempt to avoid more emissions. For some governments, accepting that climate change has already happened can put them in difficult situation in front of citizens they represent. To be effective, one must use adaptation and mitigation together. Because some activities (e.g. afforestation) can be seen both as mitigation and/or adaptation measures, it is important to integrate these two aspects together.

A review of characteristics of land-use and landscape change, demonstrates that they have are both mitigation and adaptation. Because planning can regulate the way in which land-use is practiced, it has potential to be the means for both adaptation and mitigation.

Two models reviewed, LANDIS and BFOLDS, can deal with the impacts of climate change and harvesting on landscapes. The structure of LANDIS considers both harvesting and fire, giving it an advantage over BFOLDS, the latter has included only fire as disturbance. The 10-year step in LANDIS can be used to understand certain but BFOLDS has a 1-year step. Climate change can be included in both models. In LANDIS, it is necessary to use an additional model to study species' reactions to changes in climate, whereas BFOLDS can use more direct application of climate data giving it an advantage as a climate change research tool. Also the accessibility of the author to the programmers of BFOLDS made it more feasible that LANDIS.

Forests in Canada are important to the welfare and economies of both the provinces and the nation as a whole. They are also globally significant. All this points to the need to plan and manage forests according to various scenarios in the future including climate change. The way Canadians use their forests, might negatively affect not only the country but also the world in regards to the role of the Canadian forest in the global ecosystem.

Land-use planning at regional level is regulated under the Ontario Living Legacy. The plan pursues sustainable development through environmental protection and at the same time, allows for using the land from an economic production point of view. Climate change finds a place within this strategy as the potential impacts it can have on the environment can hinder the objectives of the plan. It is possible to conclude that climate change research has room in the OLL land-used planning strategy, and so it has potential for use as a mitigation and /or an adaptation tool.

4 Identification of climate change impact in North-Western Ontario Boreal Forest and the effects on the forestry sectors

4.1 Introduction

This research relates to the analysis of climate change impacts on the southern boreal forest landscape of northwestern Ontario. The focus is on the impacts on the forestry and conservation sectors, which are strongly forest dependent. The study area is located near the junction of three biomes: the Boreal, the Great Lakes- St. Lawrence, and the Prairie (Figure 4.2). Any change in forest vegetation can affect the way land and natural resources are used, and thus, affect how socioeconomic sectors relate one another. Thus the main research objective was to describe scenarios of land cover change as a result of climate change and this can be applied to analysis of land use conflict. These scenarios will help in the development of adaptation actions for climate change though land-use and landscape planning policy.

Boreal forest ecosystem dynamics are principally driven by disturbances such as wildfire, harvesting, and defoliating insects (Parker, 1998; Suffling, 1995). To analyze the impact of climate change and of harvesting on the boreal forest, the Boreal Forest Landscape Dynamics Simulator (BFOLDS)(Perera et al., 2003) was used (see Section 3.6.2). BFOLDS does not account for harvesting or other anthropogenic interventions, so a method to relate actual harvesting needs (2.0 million of cubic meters of timber per year for the whole study area) to BFOLDS' was devised.

Results are useful in terms of land-use, and help in revealing situations in which the needs of one sector (i.e. forestry), might compromise the integrity of another (e.g. conservation) through changes in land cover and land use by other sectors. The final results yielded information to establish a framework for developing land-use and landscape planning policies as adaptation tools to climate change impacts.

4.2 Methods

The major steps in this research are shown in Figure 4.1, and are described in following sections.

4.2.1 Study area

The study area is the Dog River-Matawin Forest management unit, in northwestern Ontario, Canada. This is a 964,000 ha southern boreal forest east of Quetico Provincial Park presently under harvesting (Figure 4.2 and Figure 4.3). The forest cover in the area is currently dominated by black spruce (*Picea mariana*), poplar (*Populus* spp.), white birch (*Betula papyrifera*), and jack pine (*Pinus banksiana*).

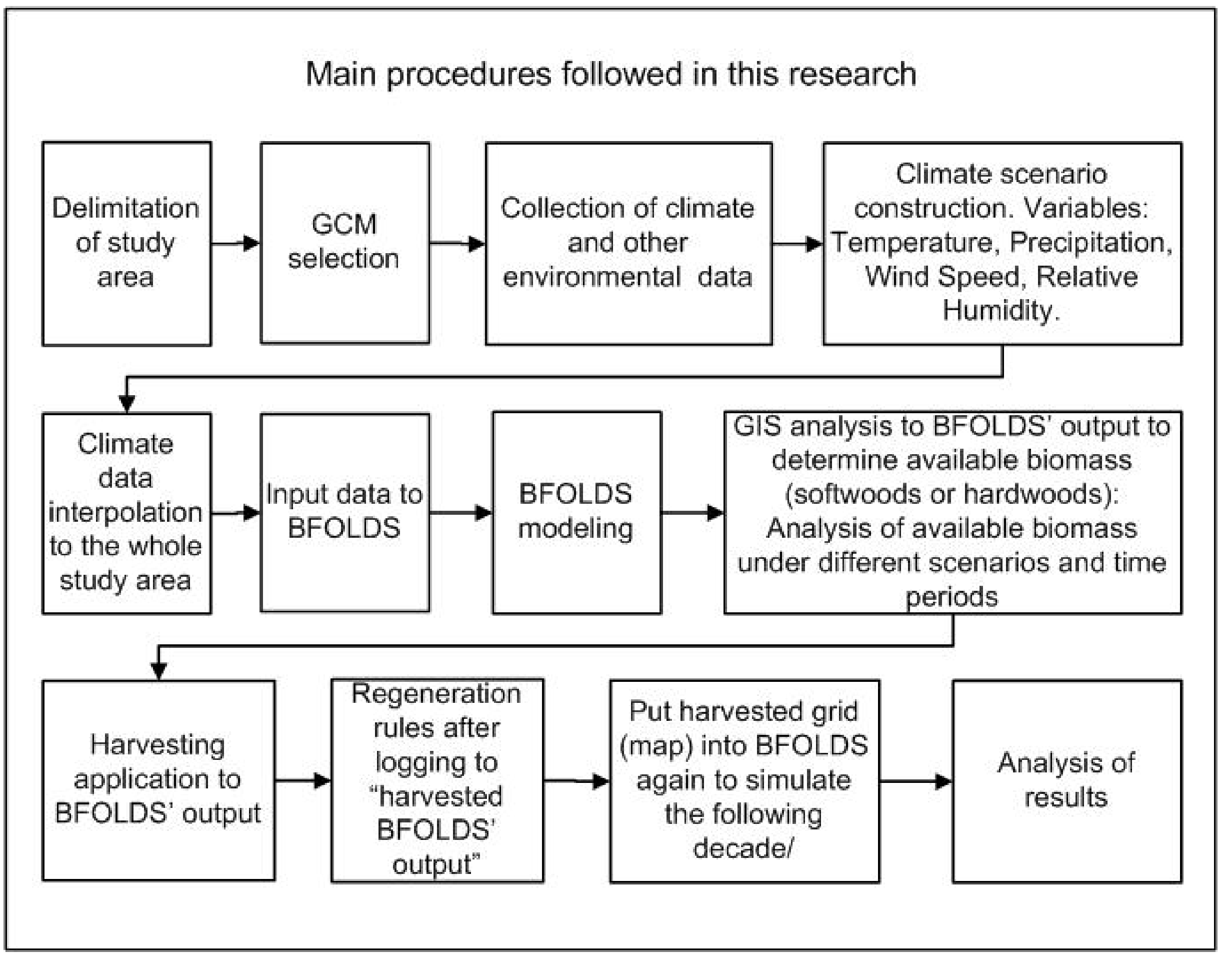


Figure 4.1 Main steps followed in this research

4.2.2 Scale of the analysis

The temporal scale was 10 yr (grain[22]) and 60yr (extent[23]). It means that observations were taken every 10 years for a total period of 60 years (10 x 6). Although the model used in this exercise provides yearly figures, the 10 year reporting period was considered sufficient information for planning purposes. The spatial scale was 1 ha (grain), and 964, 000 ha (extent), meaning that the spatial resolution/grid size was 1 ha for a total area of 964,000 ha which corresponded to the total of the study area.

4.2.3 Variables

The independent variables in this study were climate (from one baseline climate and two climate change scenarios), as well as the variables indicated on Table 4.2. These variables were used directly within BFOLDS. Harvesting was also an independent variable and was applied outside the BFOLDS at the end of each10-year simulation. The dependent variable was timber volume availability. The harvest was divided into hardwood and softwood (total, harvestable, and logged in each case), which reflected the needs of the forestry industry, and not the actual forest composition, in which softwood and hardwood are mixed in different proportions.

4.2.4 Construction of climate baseline

Weather data used in this research were obtained from the Fire Weather Archive Database (Ontario Ministry of Natural Resources et al., 2003) made available by the Landscape Ecology Laboratory at the Ontario Forest Research Institute. The five closest climatological stations to the study area (Table 4.1) were selected from that database to construct the climate baseline 1961-1990. Each station was treated separately so five datasets were generated. Data variables used were: mean temperature (°C), relative humidity (%), wind speed (km/hr), and precipitation (mm). As the database is related to the fire regime, it contains data from April to October on average. No information from November to March exists on it.

[22] Grain is determined by the finest level of resolution, or measurement, made in an observation (Gergel and Turner 2002).
[23] Extent of an observation set is established by the total area or period sampled (Gergel and Turner 2002).

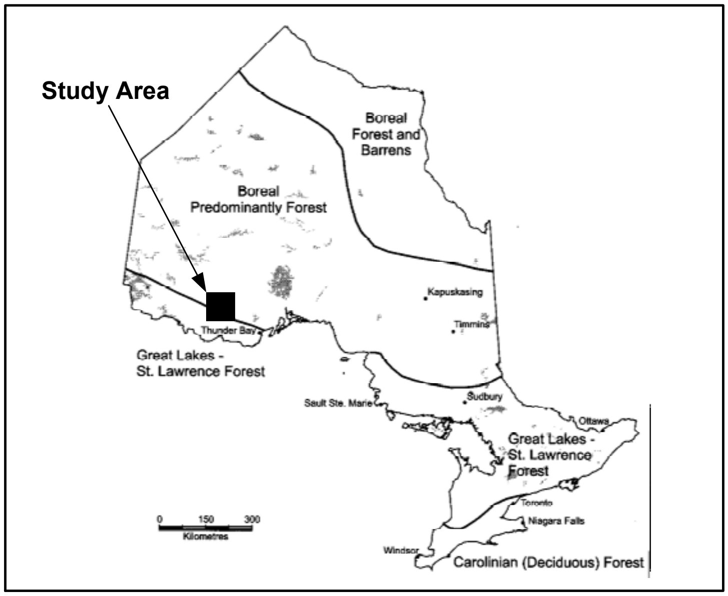


Figure 4.2 Location of study area in Ontario. Note the location in relation to other biomes (from Thompson, 2000).

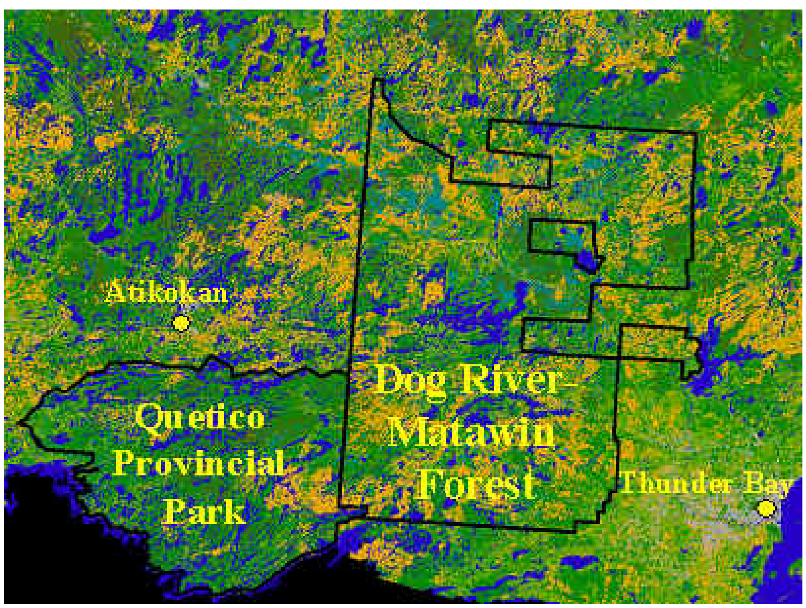


Figure 4.3. The Dog River-Matawin forest (from the Observatory Earth, 2004).

Table 4.1 Climatological stations selected for this study from the Fire Weather Archive Database (Ontario Ministry of Natural Resources et al., 2003).

Station Name	Latitude (degrees)	Longitude (degrees)	Elevation (m)	Period of record
Sioux Lookout	50.0363	-91.9248	390.10	01/10/1963 to 02/11/1990
Ignace	49.4036	-91.6354	446.50	05/05/1963 to 08/11/1990
Thunder Bay	48.3714	-89.336	184.40	16/04/1963 to 16/10/1990
Upsala	49.0371	-90.6603	483.70	20/04/1963 to 11/10/1990
Shebandowan	48.6131	-90.2051	457.00	16/04/1963 to 22/09/1990

4.2.4.1 Missing Data

The weather database used in the modeling did not contain missing data for the period analyzed (1961-1990) so there was no need to use a weather generator. The dataset for 2010 to 2060 used in this study was constructed by twice repeating the 30 year weather data set, and reassigning corresponding years. For example 2011 corresponded to 1961, 2012 to 2022 and so forth.

4.2.5 Climate change scenarios selection

Scenario selection was developed through the following procedure. Diverse General Circulation Models from the Canadian Climate Impact Scenarios (2002a) web site were studied. This site offers the possibility of producing scatter plots of climate models, based on coordinates provided by the user. Using this tool, the coordinates of the study area's centroid were provided. Temperature and precipitation were selected as variables to generate the plots (Figure 4.4). The four seasons of the year were selected as well for the 2050s time slice using SRES scenarios (see Appendix 1). Experiments that were consistently (a) the warmest, (b) those with the less change (almost no change in temperature and precipitation in the four seasons), (c) the wet plus warm, and (d) the driest in the four seasons were selected[24]. To increase the likelihood of getting the more adequate scenarios for this study, a study of yearly plot graphs was also completed for 2050. The process yielded two scenarios for this analysis: the CCSRNIES a21 (warmest) (Emori et al., 1999), and the CGCM2 A22 (the least change)

[24] Consistent was considered a scenario that were approximately either warm, with least change, wet plus warm, or dry in the four seasons, and yearly as well (see Appendix 1).

(Flato and Boer,
2001).

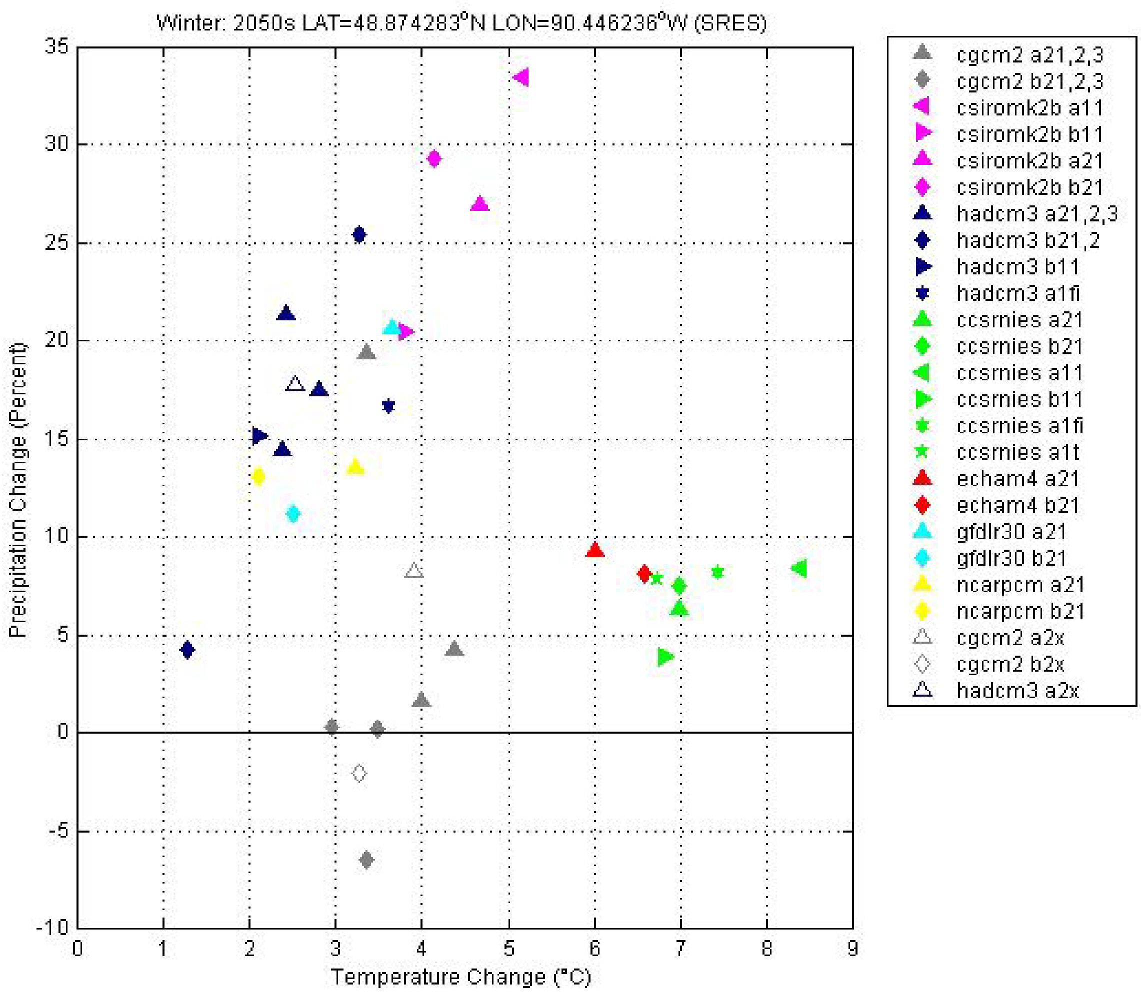


Figure 4.4 Scatter plot obtained from the Canadian Impact Scenarios Web Site for winter 2050s. (see text).

4.2.6 Scenario construction

To construct scenarios of climate change, a calculation of the difference (or ratio) between the parameters for the time slices, 2020s and 2050s, in the climate change simulation and the baseline period was performed (as indicated by the Canadian Institute for Climate

Studies, 2000). Differences and ratios were calculated as the average of the four GCM grid cells closest to the study area (Canadian Institute for Climate Studies, 2000b). See Figure 4.5.

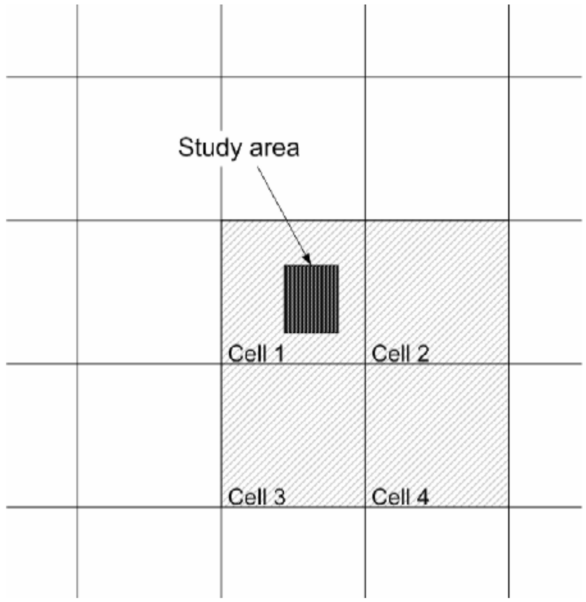


Figure 4.5 Differences and ratios were calculated as the average of the four GCM grid points closer to the study area, in this cases nodes indicated with 1, 2, 3, and 4.

Running different computer algorithms based on van Vagner (1987), weather data (mean temperature, humidity, wind, and precipitation) from the baseline climate, and from the climate change scenarios were used to create fire weather indexes[25]. Indexes obtained were duff moisture code (a rating of the moisture content of loosely compacted decomposing organic layers of moderate depth); fine fuel moisture code (a rating of the moisture content of litter and fine curred fuels); and build-up index (a rating of the total fuel available for spreading a fire) (Van Wagner, 1987). Fire indexes were then interpolated on the study area using method by Flanningan and Wotton (1989). Interpolated layers were put into BFOLDS. While the model was running during a fire season, the following steps were applied: a) for every probable fire ignition, get interpolated values to see if it can ignite; and b) for every pixel ignited, get interpolated values to see if fire can spread to other pixels. In this way

[25] The Canadian Forest Weather Index provides an estimation of potential fire danger and behaviour in the area from which data are recorded (Van Wagner, 1987).

indexes derived from the climate change scenarios and the baseline weather data showed impacts of changes in climate during the modeling.

4.2.7 Other spatial data used in the modeling

Other data layers were also used in the modeling processes. The GIS layers are shown on Table 4.2. This information was supplied by the Landscape Ecology Laboratory at the Ontario Forest Research Institute.

Table 4.2 Spatial data layers used as inputs for modeling.

Layer	Spatial resolution	Source
Slope and aspect	100 m	Digital elevation model (Centre for Topographic Information, 2000) corrected for watershed and stream networks.
Time since last fire	100 m	Ontario forest history database (Perera et al., 1998).
Geoclimate zone	1000 m	Forest ecoregions map of Ontario (Hills, 1959; Rowe, 1972).
Soil nutrient status	100 m	Soil texture database (Ontario Ministry of Natural Resources, 1977). Corrected using a flow accumulation index lowlands and 30 m LANDSAT-TM land cover classification (Spectranalysis 1999) for outcrops and treed bogs.
Soil moisture	100 m	Soil moisture database (Agriculture and Agri-Food Canada, 1996; Ontario Ministry of Natural Resources, 1977).
1962-2002 daily occurrence of fire ignitions	Point-source data	Fire Science and Technology Unit, Aviation Forest Fire Management Branch (Ontario Ministry of Natural Resources et al., 2003).
1962-20002 daily fire weather indices (FFMC, DMC, DC)	Point-source data	
1962-2002 daily wind speed and direction data	Point-source data	

4.2.8 Information sources for the initial vegetation map

To construct the vegetation database, forest inventory information for 2004 for the Dog River-Matawin was obtained from the Legacy Forest Data Warehouse (www.legacyforest.ca). Information lacking within the study area, like the buffer area (20 km around the study area), and the Abitibi forest (a private forest located within the study area) was obtained through classification of a LANDSAT image[26] provided also by the Legacy Forest. These buffer areas were not considered in the quantifications indicated below.

4.2.9 General modeling approach

To simulate possible changes in land cover BFOLDS (Perera et al., 2003) was used. Weather data for the baseline and the climate change scenarios were converted to fire indexes (Section 0) and input to the model as well as the other layers indicated in Section 4.2.7. The model was run for periods of 10 years from 2010 to 2060. A GIS procedure was applied that calculated, allocated, and simulate succession after logging. Those processes are described in the following sections.

4.2.9.1 Harvesting simulation

The harvesting strategy and goals to be applied were based on the actual harvest planning objectives set by the Ontario Ministry of Natural Resources (OMNR) for the study area and described on Table 4.3 (P. Wiltsey, personal communication, February 6, 2004).

Table 4.3 Actual timber demanded in the Dog-River Matawin forest.

Timber Demand			
Softwood		Hardwood	
Yearly	Every 10 years	Yearly	Every 10 years
≈1.2 x 10^6 m3 ± 20%	≈12 x 10^6 m3 of	≈ 8 x 10^5 m3 ± 20%	≈ 8 x 10^6 m3 of

[26] Landsat 7 ETM scene (July 1, 2002) Path 26 Row 26.

Harvesting was applied as follows (Figure 4.6): using the information from the forest inventory (species, age), a vegetation map was generated which was the initial input to BFOLDS. Subsequent maps were generated directly by BFOLDS. The model was run for a total period of 60 years, and stopped every 10 years (in years 10, 20, 30, 40 and 50), under the three climate scenarios described earlier

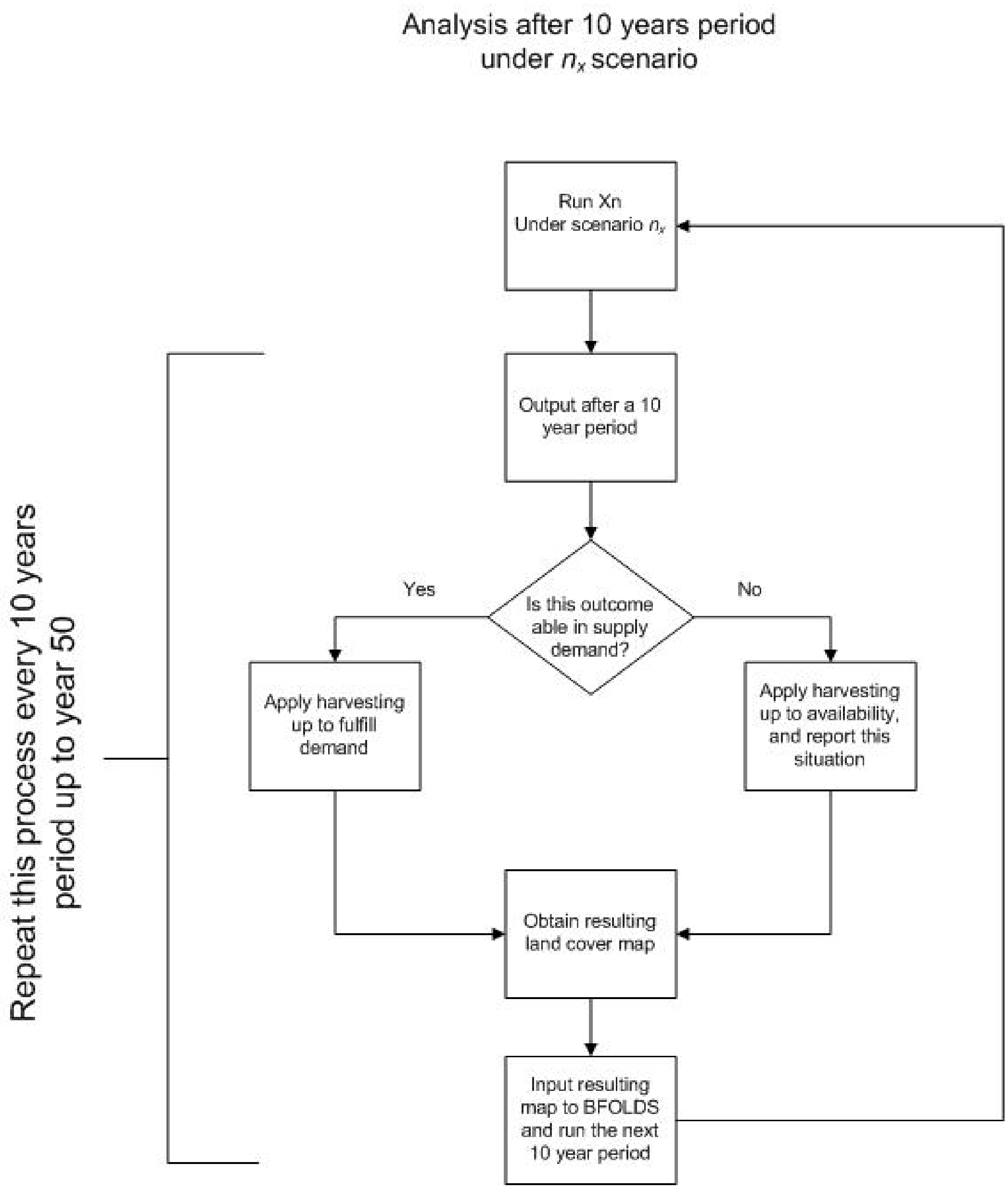


Figure 4.6 Rationale to be applied every 10 year period onto BFOLDS' output

Potential harvestable cells were allocated and selected up to a maximum that fulfilled timber demand. The study area contains protected forests and protected areas that were not allocated for harvest, no matter which species or stand ages were present in them. The same procedure was undertaken for every 10 years, up to the year 50 so that the final land cover accounted for fire and harvesting disturbances, as well as for the influence of changes in climate.

Although the 1-year time step of BFOLDS allows for doing the process every year, the amount of information, limited computing capability, and resources dictated 10 year outputs as a feasible goal. This can indicate changes during the study period. These analyses used GIS procedures indicated in the following section.

To apply harvesting to BFOLDS' outputs, a Geographic Information System (GIS) analysis was applied, using ArcView© 3.2b, and the extensions, Spatial Analyst, Grid Tools (Jeness, 2004), and Spatial Tools (Hooge, 1998). Other Avenue codes were also developed as indicated in Appendix 3.

An example of the formulae used is indicated in Table 4.5 (the rest of the equations are included in Appendix 2), the quantification of available hardwood and softwood timber. Each 1 ha cell (pixel) contained information about the species, and after calculation, yield in m3. Formulae to calculate normal volumes were derived from the Normal Yield Tables for Ontario (Plonski, 1974). Calculations were done using ArcView and the Avenue code in Appendix 3. The minimum age limits (minimum operability limit) for allocating and logging were set according to the planning directions for Dog-River Matawin (P. Wiltsey, Personal communication, February 2004). Maximum age limits (maximum operability limit) were set by the same equations, which tend to have a limit beyond which yield is not well reflected. Formulae considered Site Class, Working Groups (dominant species) and Age to obtain yield (in m^3). Note that formulae calculate biomass only within maximum and minimum operability limits. Other biomass outside operability limits were not quantified and considered in the analysis of available biomass for harvesting. The following sections detail the harvest procedure.

4.2.9.1.1 Process A

This default procedure is shown in Figure 4.7.

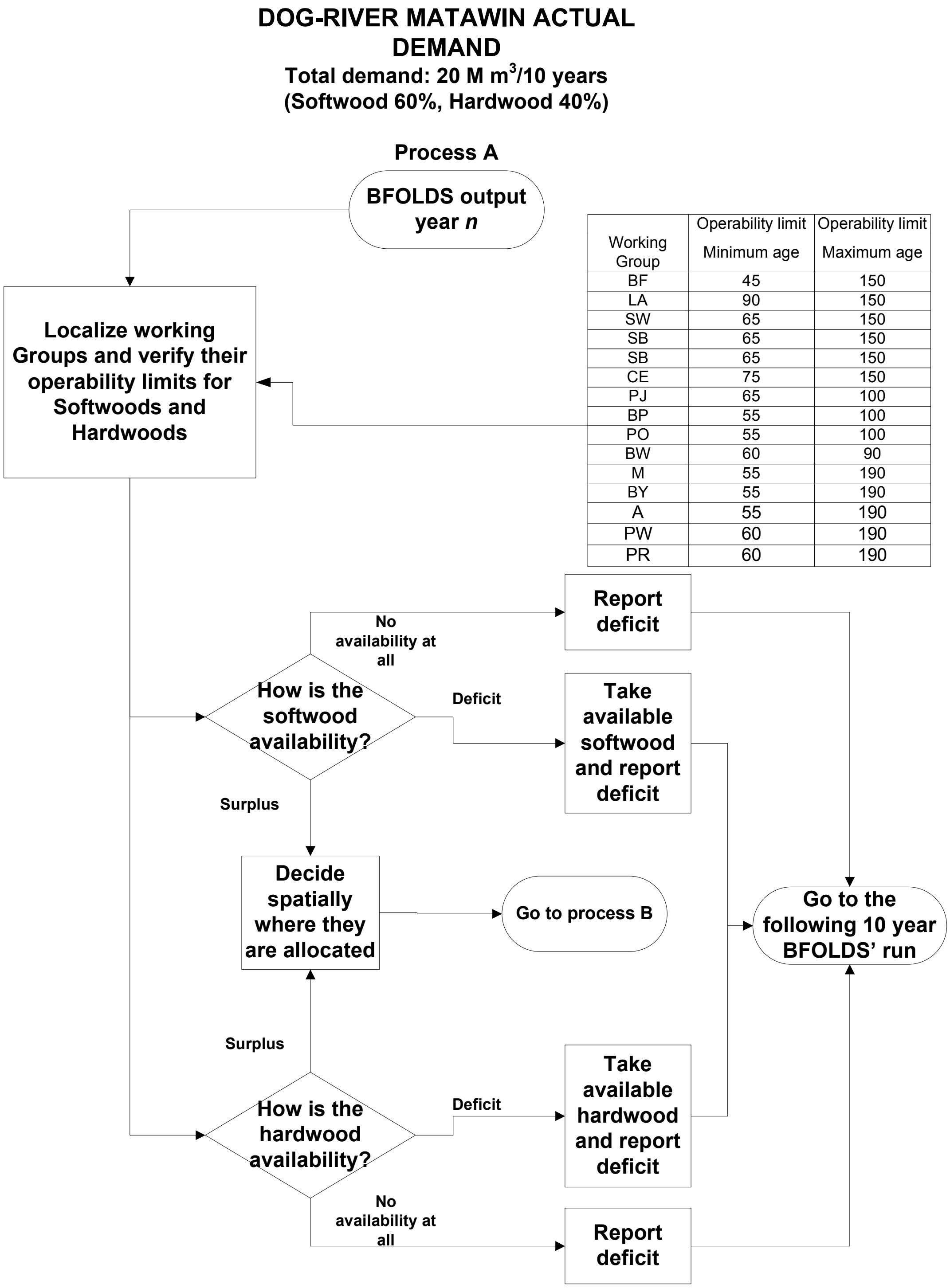
a) From a BFOLDS' output, cells were allocated both for conifers and hardwoods. Criteria for selecting cells were: lower and higher age limits to harvest according to planning objectives (Table 4.5)

b) This procedure could result in three possibilities: (1) there was no timber available at all. In this case the deficit was reported and the analysis of the following BFOLDS's output (next 10 years run) was done. (2) There was a deficit. In this case all available timber was harvested out and the deficit reported, then the next BFOLDS' output period was analyzed (next 10 years run). (3) There was a surplus. In this case there was a need in deciding spatially where to harvest timber using selection of stands based on Density Analysis (Process B).

4.2.9.1.2 Process B

This process was followed when a surplus of timber availability was found (Figure 4.8).

a) The location of useful timber was undertaken through Density Analysis. This method helped to determine where denser groups of harvestable cells were located, and so to be selected. (Section 4.2.9.2).
b) Once useable stands for hardwoods and softwoods stands were harvested, regeneration rules after logging (Table 4.6 and Script 4 in Appendix 3) were applied. This was translated into change of species and age in the harvested cells in the dataset. Age was converted to "1" (year) and changes to the corresponding working group were made according to the regeneration rules. These rules considered the previous species in the same cell, as well as soil texture, and moisture (Table 4.6). When the substitution considered a probability, a random number generator was used to obtain a result and to assign certain species to be planted (Table 4.6).



Working Group	Operability limit Minimum age	Operability limit Maximum age
BF	45	150
LA	90	150
SW	65	150
SB	65	150
SB	65	150
CE	75	150
PJ	65	100
BP	55	100
PO	55	100
BW	60	90
M	55	190
BY	55	190
A	55	190
PW	60	190
PR	60	190

Figure 4.7 Harvesting application to the Dog-River Matawin forest: process A.

c) With this procedure new grids were obtained which accounted for climate change and harvesting.

Appendix 4 shows the exact sequence followed during this process. This analysis was applied 5 times under each scenario (years 10, 20, 30, 40, and 50), to get a response until year 60. Having three scenarios, 10 replications under each of them and 5 applications of harvesting as described here, a set of 30 maps (10 per scenario at each 10 year period), was obtained. The number of maps generated was 180.

4.2.9.2 Density Analysis

The allocation of cells followed the analysis of density of points described in Table 4.4, using ArcView©, the Spatial Analyst extension, and Avenue code described in Appendix 3. To perform this analysis, the centroid of each susceptible cell to be allocated to harvest, was obtained. No cell that was under or above the operability age limits was considered for this analysis. The value to weight density values was the yield in m^3 for each cell (or centroid). After applying the density analysis on each centroid and its value, a grid showing different values of density was obtained. After a reclassification of the resulting grid, nine classes of density values were obtained: the ones with "9" represented the greatest density. With that reclassification, and using map algebra, the grids (the original dataset) were combined with the reclassified grid (the one with values from 9 to 1). This allowed ranking of each cell in so that those which had high value corresponded with greatest densities. They were chosen first, then the ones with value 8, then 7, and so on, until demand was fulfilled. The complete analysis is summarized in Figure 4.9.

Table 4.4 Density calculations (based on ESRI 2002).

Description	Procedure	Interpretation
Density calculation spreads point values over a surface. The magnitude at each location sample location (in this case a cell's centroid) is distributed over the study area, and a density value is calculated for each cell in the output raster.	Points that fall within a search area are summed and then divided by the search area size to get each cell's density value.	Each cell selected for harvesting has a yield value in m3/ha of timber. This is the value used to calculate density. The higher the value obtained in the analysis the denser cells are grouped.

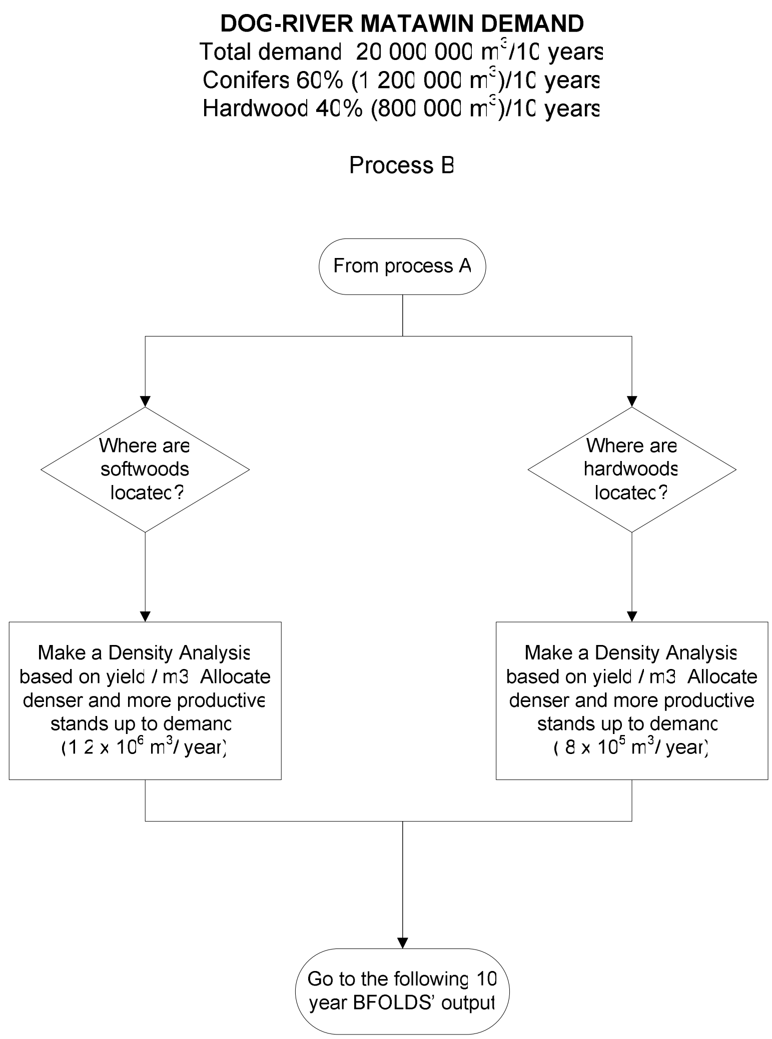


Figure 4.8. Harvesting application to the Dog-River Matawin forests: process B.

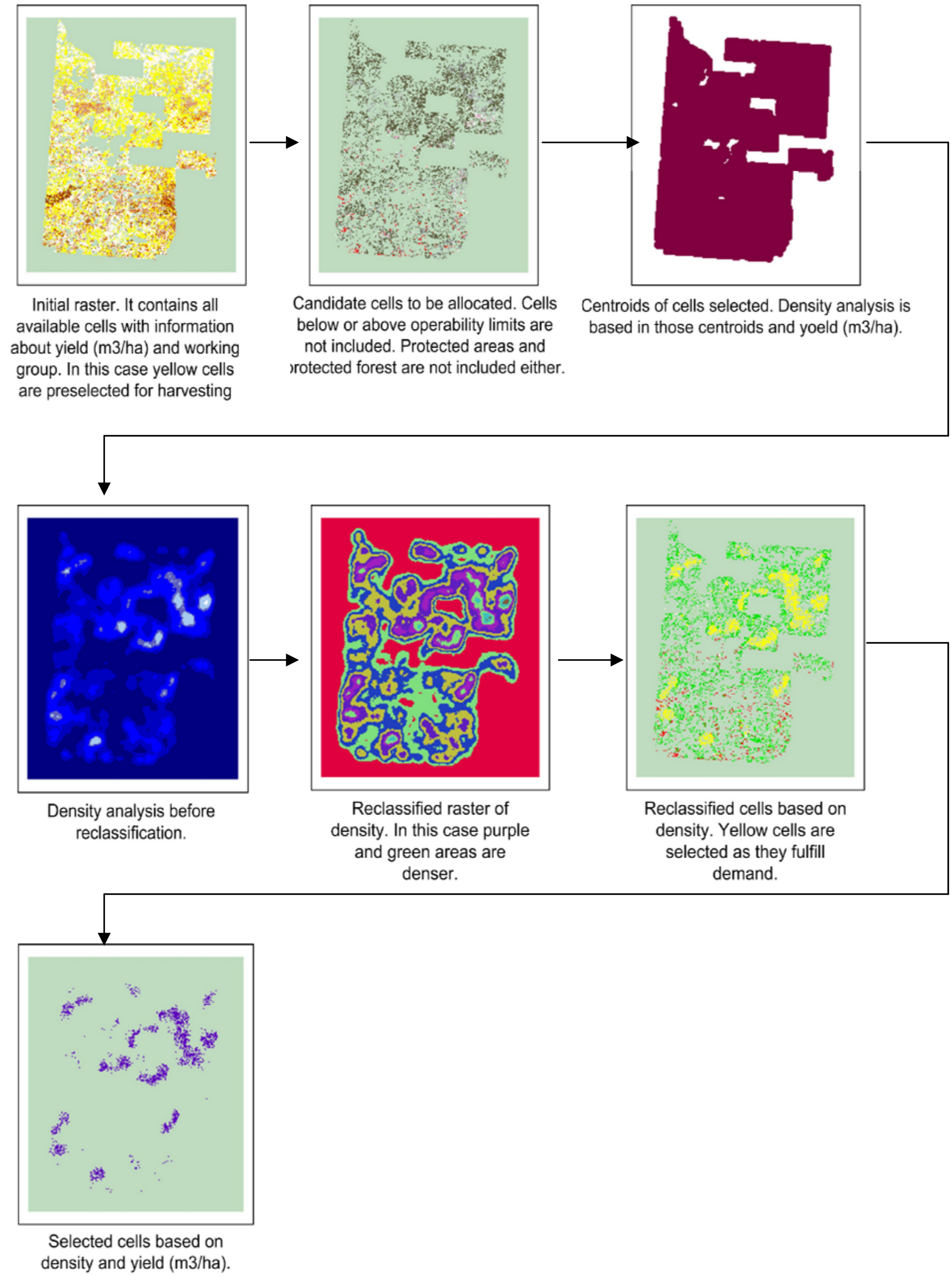


Figure 4.9 Example of the process to select and allocate candidate cells for forest harvesting (not to scale).

4.2.9.3 Fire control and insects simulation

Fire control/management modeling was not included in this thesis. There were several reasons for this. First, BFOLDS' design was set in such a way that fire, ignition-burning-spreading, was based on stochastic procedures, more than as a mixed natural/managed procedure. To date, there is no fire management module in BFOLDS so management is not allowed. Second, the internal procedure in the model related to fire is a process that is not open. As a result it is not easy to manipulate fire as a managed process. This is the reason why a fire suppression simulation could not be applied like that of harvesting. Harvesting could be applied to partial results expressed in maps of land cover, so it was applied to them. Improved versions of the model might allow fire management. The study area is currently under management that includes logging and fire management, so the inclusion of those two processes (plus insect diseases) in modeling could provide a more realistic output. The fact that fire management was not included in the modeling has implications for results obtained. Figures gathered in this thesis can underestimate the amount of timber available as fire regime is only a natural stochastic process in the model. If fire management were included, there is a possibility in having more timber than that reported here. These facts point towards taking into account these considerations while reading results from this thesis.

As the modeling developed in this thesis was spatial, it was not possible to include insect disturbances as there are no adequate spatial insect models.

Table 4.5 Equations derived to obtain Gross Merchantable Volume (m^3/ha), based on the Normal Yield Tables (Plonski, 1974).

<table>
<tr><th>Species, Working Group (WG), and Low Operability Limit (LOL)</th><th>Site Class</th><th>Equation
(y= Gross Merchantable Volume [m^3/ha]; x=Age [Years])</th><th>R^2
(between m3/ha and Age)</th></tr>
<tr><td rowspan="5"><table><tr><th>Species</th><th>WG</th><th>LOL</th></tr><tr><td>Black Spruce</td><td>SB</td><td>65</td></tr><tr><td>White Spruce</td><td>SW</td><td>65</td></tr><tr><td>Spruce All</td><td>S</td><td>65</td></tr><tr><td>Balsam Fir</td><td>B</td><td>45</td></tr><tr><td>Cedar</td><td>CE</td><td>90</td></tr><tr><td>Larch</td><td>L</td><td>90</td></tr><tr><td>Other Conifer</td><td>OC</td><td>90</td></tr></table></td><td>0</td><td>$y = -0.0332x^2 + 9.1924x – 195.32$</td><td>$R^2 = 0.997$</td></tr>
<tr><td>1</td><td>$y = -0.0172x^2 + 5.6928x – 162.5$</td><td>$R^2 = 0.9974$</td></tr>
<tr><td>2</td><td>$y = -0.0194x^2 + 6.3018x – 290.11$</td><td>$R^2 = 0.9996$</td></tr>
<tr><td>3</td><td>$y = -0.0191x^2 + 6.0889x – 343.65$</td><td>$R^2 = 0.9981$</td></tr>
<tr><td>4</td><td>$y = -0.0191x^2 + 6.0889x – 343.65$</td><td>$R^2 = 0.9981$</td></tr>
<tr><td rowspan="5"><table><tr><th>*Species*</th><th>*WG*</th><th>*LOL*</th></tr><tr><td>Jack Pine</td><td>PJ</td><td>65</td></tr><tr><td>Scots Pine</td><td>PS</td><td>65</td></tr></table></td><td>0</td><td>$y = -0.0573x^2 + 9.5927x – 146.54$</td><td>$R^2 = 0.992$</td></tr>
<tr><td>1</td><td>$y = -0.0573x^2 + 9.5927x – 146.54$</td><td>$R^2 = 0.992$</td></tr>
<tr><td>2</td><td>$y = -0.0372x^2 + 7.0448x – 129.55$</td><td>$R^2 = 0.9987$</td></tr>
<tr><td>3</td><td>$y = -0.0254x^2 + 5.3293x – 125.31$</td><td>$R^2 = 0.9957$</td></tr>
<tr><td>4</td><td>$y = -0.0254x^2 + 5.3293x - 125.31$</td><td>$R^2 = 0.9957$</td></tr>
</table>

Table 4.6 Regeneration rules after harvesting (based on Racey et al.1989).

FROM:	To:	AND:	AND:	AND:	AND:
Ab	Ab				
Bals. Pop.	Bals. Pop.				
Po	Po				
Bw	Bw			Sandy soil: P=0.5 Pj, P=0.5 Pr	Loamy soil: Sw
Mh	Mh				
By	By				
Sw	Bf				
L	Sb				
Pr	P=0.5 Pr, P=0.5 Pw				
Pw	P=0.5 Pw, P=0.5 Pr				
Aspen	Moist sites (3 or 4): Aspen	Dry sites (1 or 2): Pj		Fresh to dry sites (1-3): Pj, Sw or Sb	
Ce	Mineral soil (Not 5): Bf	Organic soil (5): Sb			
Bf	Rapidly drained sites (1 or 2): Aspen	Moist, poorly drained sites (3 or 4): Fb			
Sb	Organic soil (5): Sb	Dry sites (1 or 2): Pj	Fresh sites (2 or 3): P=0.5 Pj, P=0.5 Sb		
Pj	Moist sites (3 or 4): Sb	Dry sites (1 or 2): Pj	Fresh sites (2 or 3): P=0.5 Pj,P=0.5 Sb		

P = Probability
Ab = Black Ash
Bw = White Birch
Mh = Hard Maple
By = Yellow Birch

Sw= White Spruce
L = Larch
Pr =Red Pine
Pw =White Pine
Ce = Cedar

Bf = Balsam For
Sb = Black Spruce
Pj = Jack Pine
Po= Poplar

5 Results

Study results show that there will be an impact both from climate change and harvesting in the study area that are described in the following. There will be some differences in fire regime among scenarios, mainly in the percentage of area burned. Differences in species composition among scenarios will be not so evident; however, changes will happen every decade. Impacts of climate change and harvesting also will result in a deficit in timber availability at some point in the 60 year period for total available and logged timber under all scenarios. Another situation for the forest will be its tendency to become younger every decade.

The study results will be presented through the parameters outlined in Table 5.1. The fire regime is presented first. Second, data regarding the forest composition, based on hardwood and softwood present, is shown. Third, stand age class of harvestable timber is analyzed. Fourth, available and logged (harvested) timber is analyzed. Next, the total timber harvested, and the details of hardwood and softwood (in volume) are described. Lastly, stage age class for harvested timber (in volume) is explored. The chapter ends with a summary of research findings, touching upon issues that will be expanded upon in the final chapter.

Excepting for data in Sections 5.2 to 5.5, volumes and areas indicated in this study correspond to harvestable timber. Harvestable timber was defined as the one that be potentially available for logging because of its age, and being within operability limits (there are minimum and maximum ages that define operability limits on each working group (Table 4.5 and Appendix 2). Equations used to calculate timber volume were applied only to harvestable timber (that is, timber within operability limits), and not to cells outside those limits. Statistics about timber volume concern harvestable and harvested timber. In the case of pre-harvest species composition, the unit used is hectares, not volumes, as it is the only way to know to which species corresponded each cell in the map, regardless of age. Some terms are used interchangeably. For instance, the term, *available* is the same as *harvestable;* and *logged*, is the same as *harvested. Pre-harvest* mean trees that are present but are not necessarily harvestable.

A final clarification. When the auxiliary "will" is written to describe results in the following sections, it means a scenario in the future, and not a prediction.

Table 5.1 Order of discussion of results

Fire Regime		
Forest composition: hardwood and softwood		
Available timber		
Total	*Hardwood*	*Softwood*
	Species composition (%)	Species composition (%)
Age Class Distribution		
	Density Analysis	Density Analysis
Detail volumes	Detail volumes	Detail volumes
Harvested timber		
Total	*Hardwood*	*Softwood*
Detail volumes	Detail volumes	Detail volumes
	Chart	Chart
Percentage of logged over available (under three Scenarios)		
	Age Class Distribution	Age Class Distribution

5.1 Fire regime

As indicated in Section 3.2.1.1, fire is one of the more important drivers in boreal systems (besides harvesting in the present forest in northwestern Ontario). Summaries of *Number of Fires* and *Percentage of area Burned* in each decade in the model are indicated in Table 5.2 and Table 5.3. Those tables depict *Number of Fires* and *Percentage of Area Burned* during years 2010 to 2060. Regarding the *Number of Fires*, the baseline and the CGCM2 A22 will follow a similar trend along the 60 year period. CCSRNIES A21 will differ from the other two scenarios in year 2010 and 2020 by about 20 fires (Table 5.2). By year 2030, the number of fires under CGCM2 A22 and CCSRNIES A21 will be about the same as that of the baseline, and for 2050 and 2060 the number will be less than the baseline. As a result, little change in number of fires between the scenarios and the baseline will be observed.

Table 5.2 Number of Fires. Summary statistics for the baseline and two GCM Scenarios (n=10).

Baseline

Year	2010	2020	2030	2040	2050	2060
Mean	26.70	28.70	31.80	39.30	34.60	24.70
Standard Error	5.32	6.42	6.67	7.14	9.87	4.67
Median	27.00	26.00	23.00	43.50	18.00	24.00
Standard Deviation	16.82	20.30	21.11	22.58	31.22	14.78

CGCM2 A22

Year	2010	2020	2030	2040	2050	2060
Mean	29.90	35.50	36.60	38.60	19.60	24.40
Standard Error	6.34	6.12	5.15	11.64	4.66	4.10
Median	26.50	38.50	35.50	23.50	18.00	19.50
Standard Deviation	20.04	19.35	16.29	36.82	14.75	12.97

CCSRNIES A21

Year	2010	2020	2030	2040	2050	2060
Mean	47.60	47.75	31.40	49.00	22.90	22.20
Standard Error	11.73	10.88	6.83	13.29	5.28	2.44
Median	37.50	43.00	22.00	33.50	15.50	23.50
Standard Deviation	37.10	30.78	21.61	42.03	16.68	7.73

Table 5.3 Percentage of area burned. Summary statistics for the baseline and two GCM scenarios. (n=10).

Baseline

Year	2010	2020	2030	2040	2050	2060
Mean	5.26	4.27	4.73	7.74	3.91	4.49
Standard Error	1.70	1.72	1.26	2.27	1.15	1.41
Median	3.89	2.21	4.61	6.86	3.01	1.95
Standard Deviation	5.37	5.43	4.00	7.17	3.62	4.45

CGCM2 A22

Year	2010	2020	2030	2040	2050	2060
Mean	3.15	4.51	6.05	8.65	2.55	13.07
Standard Error	1.38	1.19	1.54	3.31	0.75	4.91
Median	1.93	4.63	6.14	3.24	2.05	6.37
Standard Deviation	4.36	3.75	4.87	10.47	2.37	15.52

CCSRNIES A21

Year	2010	2020	2030	2040	2050	2060
Mean	14.35	10.20	4.16	9.77	2.71	13.55
Standard Error	4.07	2.76	1.27	3.34	1.03	6.87
Median	13.88	7.10	3.51	5.06	1.47	3.42
Standard Deviation	12.86	7.82	4.02	10.56	3.24	21.74

Percentage of Area Burned will differ from the trend observed for the *Number of Fires* among scenarios. In this case, the CCSRNIES A21 scenario will differ from the other two in years 2010 and 2020 with a difference in area burned of about 10%. In the three following decades, the three scenarios will show a very similar trend. By year 2060, there will be an important difference between the baseline and the other two scenarios of about 10%. Looking at the two parameters together, there appears that by year 2060 bigger fires will occur as more area burned with fewer fires will happen. It can be concluded here that there will not be a large difference in number of fires among scenarios, but in terms of percentage of area burned especially from CCSRNIES A21 by year 2010, 2020, and 2060, the difference will be significant. One clear indication is that by year 2060, bigger fires in the scenarios of climate change in relation to the baseline will occur. It suggests an impact of the warming climate on the simulation in fire regime.

5.2 Composition of the forest based on hardwood and softwood

Figure 5.1 shows a sequence of changes in the landscape from year 2010 to 2050 in a sample of the area. In this thesis results about the forest composition are always related to the percentages in area that each kind of timber was occupied. They are not timber volume statistics.

Hardwood and softwood composition were derived from BFOLDS output (Figure 5.2 and Table 5.4). Results indicate a general decrease in hardwood and an increase in softwood for the three scenarios along the 60 year period. On average, there will be a decrease in softwood of about 10% from year 2010 to 2060. Regarding the differences among scenarios for each decade, there will always be more hardwood in the CCSRNIES A21 than the baseline and the CGCM2 A22 during the 60 years. On the contrary, there will be less softwood under CCSRNIES A21 along the 60year period than the other two scenarios. That decrease will be about 10% from year 2010 to 2060.

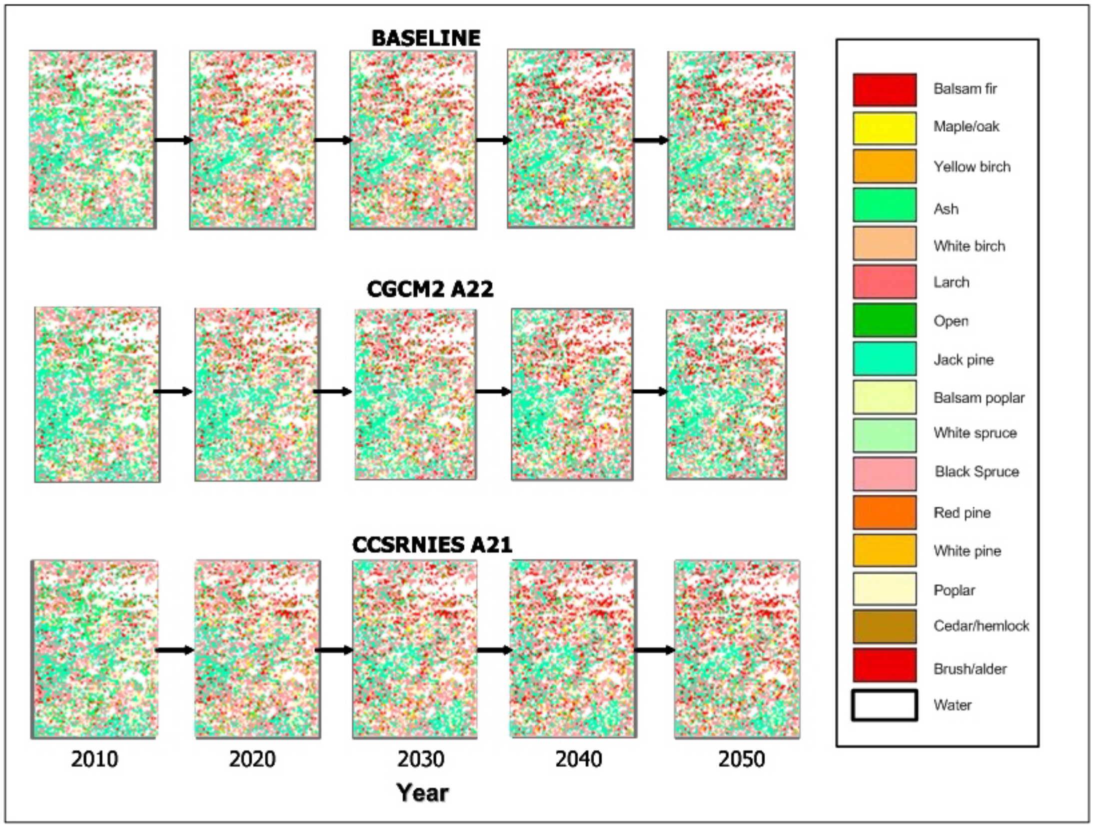


Figure 5.1 Sequence that shows how the landscape change in a section of the study area (not to scale).

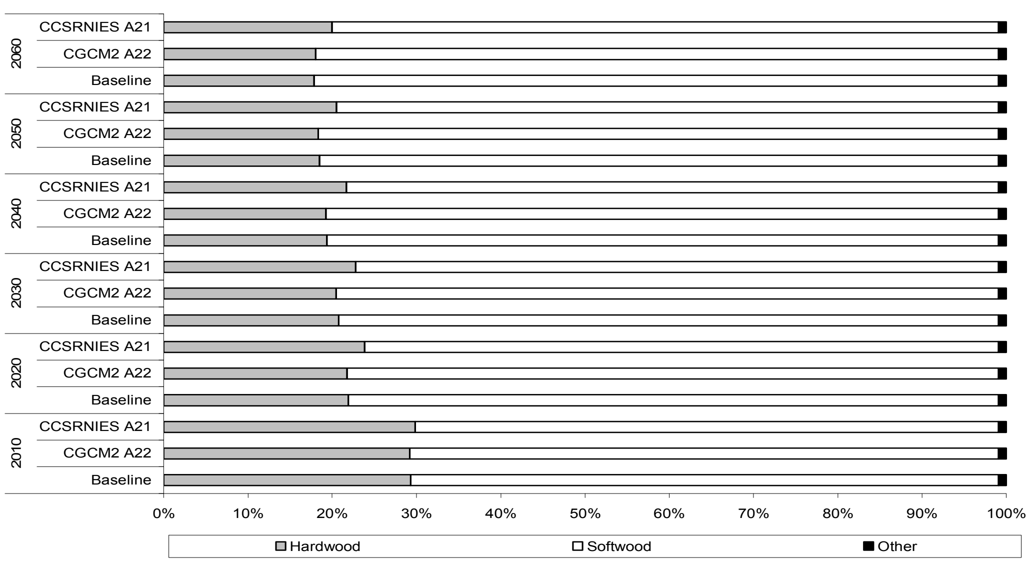


Figure 5.2 Graphic representation of the percentage of occupancy of hardwood and softwood before harvesting. This analysis considered all stands not only the mature ones.

Table 5.4 Forest composition in percentage of area occupied: hardwood and softwood.

	2010			2020			2030			2040			2050			2060		
	%			%			%			%			%			%		
	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR
Hardwood	29.32	29.22	29.87	21.91	21.77	23.84	20.77	20.46	22.77	19.37	19.23	21.71	18.50	18.35	20.52	17.83	18.03	19.99
Softwood	69.76	69.85	69.21	77.16	77.30	75.23	78.30	78.61	76.30	79.70	79.84	77.36	80.57	80.72	78.56	81.24	81.04	79.08
Other	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93

5.3 Hardwood and softwood species composition

Regarding species composition, on Figure 5.3 and Figure 5.4 do not show dramatic change in species composition among scenarios every decade, but changes will be present among decades (e.g. from year 2010 to 2060) the details of which are discussed in the following sections. These statistics are based on the area (ha) occupied by each dominant species in the study area. They are not volume statistics. Appendix 5 shows raw statistics for species composition.

5.3.1 Hardwood species composition

Results for hardwood show a similar change in species composition (area occupied by this kind of timber) among the three scenarios every 10 years (Figure 5.3). The most notable changes in composition through time are: maple/oak, white birch, and poplar. For maple/oak there will be an increase from 2010 to 2060 in the order of 1%. There will be a decrease in white birch of about 5% under each 10 year period, starting about 29% in 2010 and ending in 14% in year 2060 Table 5.5. with poplar there will be an increase from about 71% to 83% in year 2060. As changes in species composition are so close in the three scenarios as to suggest that, for the 60 year period climate change will not greatly impact this parameter. However other factors, like the application of regeneration after logging, will potentially influence species composition.

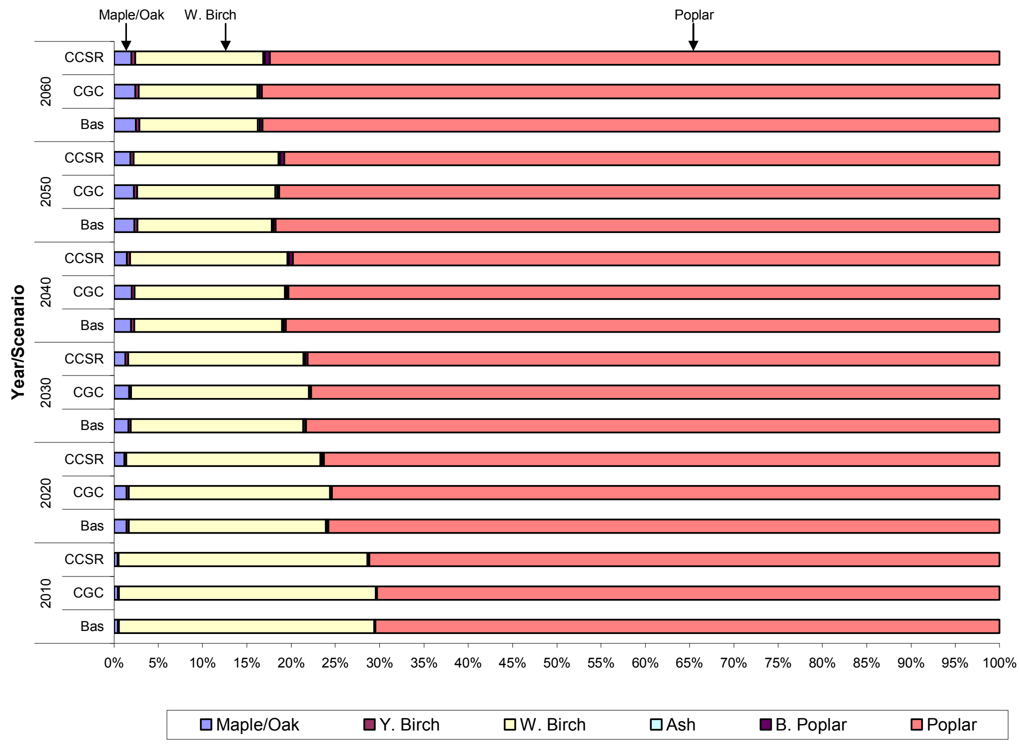


Figure 5.3 Graphic representation of the percentage of occupancy of hardwood before harvesting. This analysis considered all stands, not just the mature ones.

Table 5.5 Percentage of occurrence of hardwood before harvesting

	2010			2020			2030			2040			2050			2060		
	%			%			%			%			%			%		
	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR
Maple/Oak	0.48	0.48	0.44	1.45	1.45	1.16	1.64	1.69	1.30	1.96	2.00	1.48	2.29	2.25	1.85	2.48	2.41	1.99
Y. Birch	0.07	0.06	0.07	0.22	0.22	0.22	0.27	0.26	0.29	0.31	0.32	0.33	0.35	0.34	0.37	0.38	0.40	0.42
W. Birch	28.83	29.02	28.10	22.28	22.72	21.94	19.48	20.05	19.82	16.70	16.99	17.79	15.18	15.62	16.38	13.38	13.39	14.44
Ash	0.12	0.12	0.11	0.16	0.16	0.14	0.16	0.17	0.15	0.18	0.18	0.16	0.19	0.19	0.17	0.20	0.19	0.18
B. Poplar	0.05	0.02	0.10	0.10	0.06	0.24	0.15	0.12	0.31	0.23	0.22	0.43	0.28	0.25	0.46	0.34	0.34	0.58
Poplar	70.46	70.29	71.18	75.80	75.38	76.29	78.30	77.71	78.13	80.62	80.29	79.81	81.71	81.34	80.78	83.22	83.27	82.40

5.3.2 Softwood species composition

In the case of softwood, a similar pattern to that of hardwood will be observed: less change in species composition (area occupancy) among scenarios each decade but changes through the 60 years. The most relevant cases of species change will be balsam fir, jack pine, black spruce and cedar/hemlock (Figure 5.4). There will be an increase in balsam fir from 3% to 8% under the three scenarios, an increase in jack pine from 27% to 40%, and a decrease in black spruce from 65% to 50%. Finally, there will be a major decrease in cedar/hemlock from % to 0.78%. Jack pine appears to be more common under the CCSRNIES A21 (the warmest) scenario which indicates the impact of climate change.

A similar conclusion as that for hardwood can be drawn for softwood. As changes in composition will be similar for the three scenarios each decade, there will not be a great impact of climate change on species composition in the 60 year period. The observed variations will be a response to other factors like regeneration after logging, which promotes certain species over others.

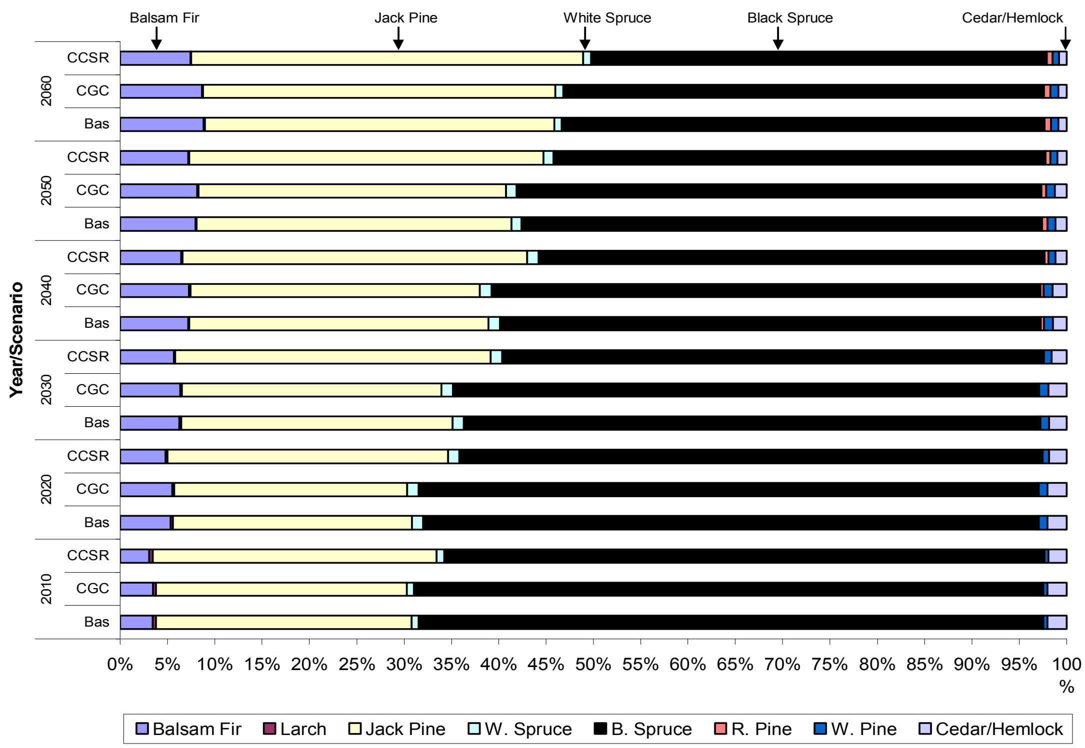


Figure 5.4 Graphic representation of the percentage of occupancy of softwood before harvesting. This analysis considered all stands not just the mature ones.

Table 5.6 Percentage of occurrence of softwood before harvesting

	2010			2020			2030			2040			2050			2060		
	%			%			%			%			%			%		
	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR	Bas	CGC	CCSR
Balsam Fir	3.44	3.46	3.10	5.36	5.50	4.78	6.26	6.46	5.65	7.17	7.26	6.44	7.97	8.14	7.17	8.84	8.66	7.41
Larch	0.34	0.34	0.33	0.22	0.22	0.22	0.17	0.18	0.18	0.14	0.14	0.15	0.12	0.12	0.13	0.09	0.09	0.10
Jack Pine	27.01	26.47	30.01	25.27	24.59	29.64	28.69	27.90	33.31	31.63	30.63	36.45	33.26	32.53	37.44	36.93	37.21	41.38
W. Spruce	0.76	0.75	0.81	1.17	1.21	1.20	1.19	1.24	1.21	1.19	1.25	1.18	1.05	1.10	1.06	0.81	0.86	0.89
B. Spruce	65.86	66.39	63.32	64.94	65.43	61.46	60.71	62.79	57.07	57.16	57.95	53.50	55.01	55.45	51.97	51.02	50.81	48.15
R. Pine	0.12	0.11	0.11	0.13	0.13	0.14	0.19	0.18	0.22	0.34	0.34	0.36	0.55	0.53	0.51	0.66	0.63	0.57
W. Pine	0.46	0.46	0.41	0.88	0.88	0.73	0.97	1.01	0.80	0.94	0.96	0.76	0.86	0.91	0.75	0.81	0.86	0.72
edar/Hemlo	2.01	2.01	1.91	2.03	2.04	1.82	1.82	1.94	1.56	1.44	1.47	1.16	1.19	1.23	0.98	0.84	0.87	0.78

5.4 Stand age class of harvestable timber

Results show that the forest will become younger every 10 year period under each climate change scenarios. Differences among scenarios in relation to stand age class will be not dramatic. Charts of age class from year 2010 to year 2060 were produced. For the purpose of this discussion only year 2010 (Figure 5.5) and year 2060 (Figure 5.6*)* are shown so as to see the change between the initial and the final years of the exercise. The rest of the charts (from 2010 to 2060) are shown in Appendix 6. These charts consider all trees regardless of age, so this is a “big picture” of what will happen with age class distribution in the whole forest based on area occupancy. Note that by year 2010, the area will contain trees of 280-289 years. By year 2060 age class will decrease to 190-199 years. The relevant finding here is how the forest will turn younger every 10 years.

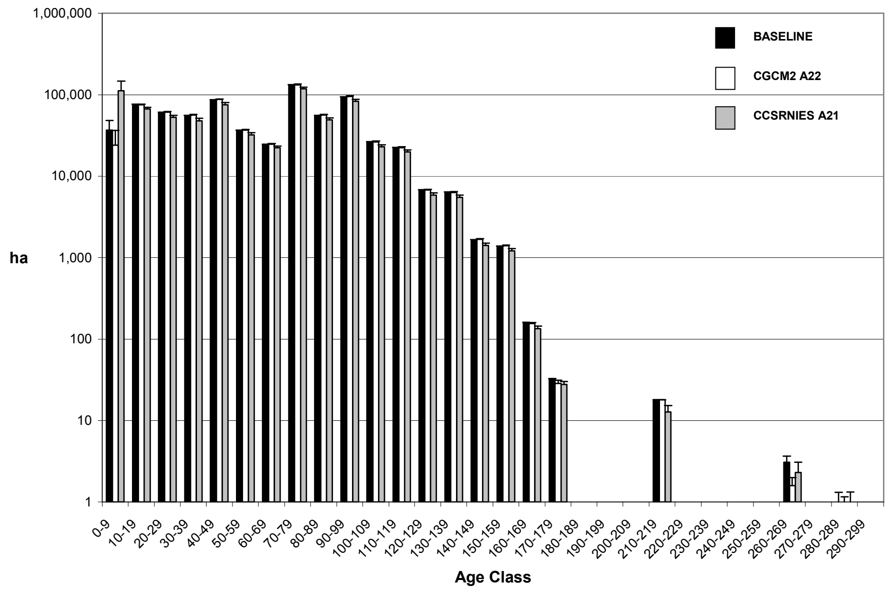


Figure 5.5 Stand age class distribution pre-harvest in year 2010 (mean ± s.e., n=10). All working groups under the three scenarios are shown.

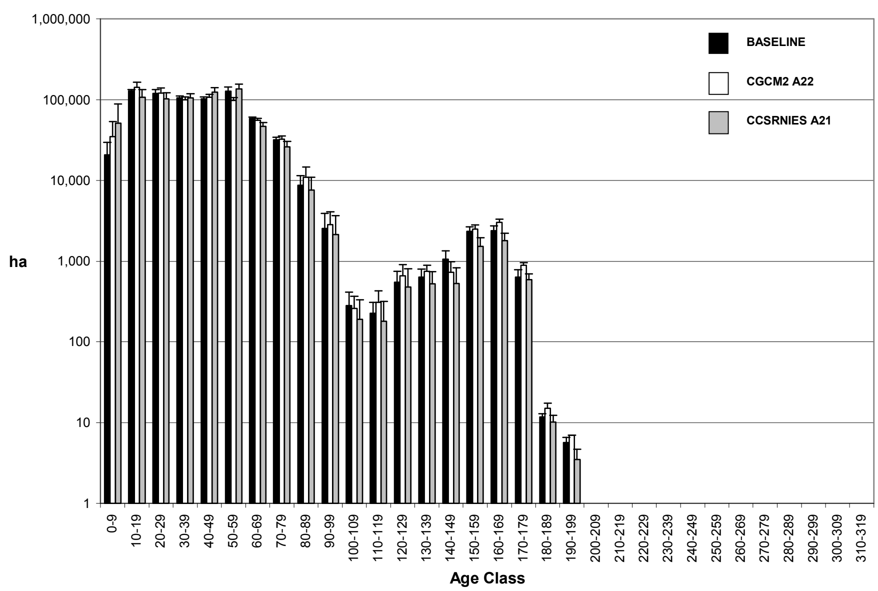


Figure 5.6 Stand age class distribution pre-harvest in year 2060 (mean ± s.e., n=10). All working groups under the three scenarios are shown. Note that the oldest age class (190-199) contained less old forest under CCSRNIES A21 compared to the baseline (about 10%).

5.5 *Old forest occurrence during simulations*

To analyze the proportion of old against young forest occurrence, the area occupied by trees younger than 99 years, and trees older than 100 years was tabulated. All scenarios indicate that in every decade the forest covered by young stands will increase (Table 5.7.and Table 5.8). There will be differences among the three scenarios. CCSRNIES A21 will consistently be the scenario with more area occupied by young stands, and less old forest compared to the baseline. CGCM2 A22 will have less area of young stands and more of old ones than the baseline. The situation will be more extreme situation under the CCSRNIES A21. A younger forest resulted each decade because of harvesting.

Table 5.7 Area occupied by trees according to age.

	Younger than 99 (ha)			Older than 100 (ha)		
	Baseline	**CGCM2 A 22**	**CCSRNIES A21**	**Baseline**	**CGCM2 A22**	**CCSRNIES A21**
2010	650,269.80	649,481.60	657,811.10	64,317.30	65,106.00	56,775.90
2020	627,103.10	623,504.40	642,854.80	87,484.00	91,083.40	71,731.30
2030	645,005.50	638,491.50	663,200.50	69,582.20	76,096.40	51,387.50
2040	674,794.20	669,265.50	688,971.00	39,791.90	45,321.20	25,615.80
2050	697,440.80	692,925.70	702,902.60	17,513.96	21,661.82	11,684.80
2060	706,689.30	705,479.70	708,804.70	8,136.04	9,107.20	5,830.39

Table 5.8 Area occupied by trees according to age. Difference between the scenarios and the Baseline.

	Younger than 99 (%)		Older than 100 (%)	
	CGCM2 A 22	**CCSRNIES A21**	**CGCM2 A 22**	**CCSRNIES A21**
2010	-0.12	1.16	1.23	-11.73
2020	-0.57	2.51	4.11	-18.01
2030	-1.01	2.82	9.36	-26.15
2040	-0.82	2.10	13.90	-35.63
2050	-0.65	0.78	23.68	-33.28
2060	-0.17	0.30	11.94	-28.34

5.6 *Summary of statistics for timber selected (available and logged)*

As a result of the BFOLDS runs and GIS analysis, numbers related to mature timber were obtained. Table 5.9 summarizes the data for timber to be allocated for harvesting, and the complete statistics are Appendix 5. Timber availability will diminish towards 2060, for total timber, hardwood and softwood. Diminishing trends are mainly a result of harvesting rates applied in the modeling. That decrease will be more acute for hardwood than for softwood, but by the end of the study period, deficits will be commonplace. The timber logged will follow a corresponding trend. Figures and tables from these results are shown in the following sections. As logging is a function of location and productivity, in some cases not all available timber was logged during the simulation. This explains why Table 5.9 shows timber remaining in almost all decades.

5.7 Density Analysis

An analysis based on density of centroids of stands (in this case 1 ha cells), allowed for ranking and allocating them for harvesting. Once available cells were identified, density analysis selected candidate cells for harvest based on their productivity (volume of timber present), and their location. In this way, groups of cells were ranked from 9 to 1, being 9 the denser and more productive. One common characteristic in the three scenarios of climate will be the tendency to have less dense useful cells over time (see Figure 5.7 and Figure 5.8 as examples. Another set of maps can be found in Appendix 7). In all cases, available hardwood will result in a less dense map than available softwood, as the former is more spatially dispersed compared to softwood. Maps show less and less dark spots as time goes further, but this does not mean that there are less trees present in the study area. All the area is forested but stands are either outside operability limits, and/or they are less densely distributed. Numbers in each map correspond to the available timber. The 10-year targets for hardwood are 8,000,000 m^3 ± 20% and for softwood 12,000,000 m^3 ± 20%, totaling 20,000,000 m^3 ± 20%. This analysis considers only where cells are located and their productivity. It does not include aspects like transport distances to the mills, and ease of access to reach productive cells. If included, these important parameters, less timber would be available.

Table 5.9 Summary statistics for available, harvested and remaining timber. Total, hardwood, and softwood are indicated (n=10).

			Tot mature timber available (m3)	Tot mature timber logged (m3)	Tot. mature tim remaining (m3)	Mature hardwood (m3)			Mature sSoftwood (m3)		
						Available	Logged	Remain	Available	Logged	Remain
2010	Baseline	Mean	71,894,564.58	19,943,907.34	51,950,657.24	27,893,223.53	7,971,741.57	19,921,481.96	44,001,341.05	11,972,165.77	32,029,175.28
		St. Error	1,178,393.12	13,011.35	1,178,727.93	358,066.97	14,637.79	360,237.86	845,559.64	7,405.82	845,724.42
		Median	72,952,067.69	19,947,939.16	52,989,992.18	28,200,987.26	7,993,405.87	20,211,976.71	44,751,080.42	11,975,144.50	32,778,015.47
		St. Dev.	3,726,406.23	41,145.49	3,727,464.99	1,132,307.17	46,288.76	1,139,172.13	2,673,894.34	23,419.25	2,674,415.45
	CGCM2 A22	Mean	73,096,634.00	19,892,148.05	53,198,689.82	28,113,813.44	7,980,698.15	20,133,115.29	44,982,820.55	11,917,246.03	33,065,574.52
		St. Error	1,347,668.63	24,559.10	1,341,646.35	439,271.34	6,609.75	435,263.75	915,080.25	26,062.50	912,749.76
		Median	74,191,140.43	19,906,093.39	54,385,926.45	28,515,997.95	7,985,766.82	20,553,672.88	45,740,590.69	11,940,872.44	33,819,240.83
		St. Dev.	4,261,702.39	77,662.69	4,242,658.27	1,389,097.94	20,901.86	1,376,424.85	2,893,737.83	82,416.86	2,886,368.19
	CCSRNIES A21	Mean	63,940,060.27	19,815,036.90	44,125,023.37	24,735,664.69	7,851,832.19	16,883,832.50	39,204,395.58	11,963,204.71	27,241,190.87
		St. Error	3,553,057.54	40,934.64	3,565,330.31	1,356,096.57	36,837.68	1,360,845.32	2,209,041.36	16,542.20	2,217,215.56
		Median	65,604,652.06	19,813,248.33	45,771,102.95	25,216,186.90	7,862,868.36	17,308,864.66	40,388,465.16	11,987,277.86	28,462,238.29
		St. Dev.	11,235,754.50	129,446.71	11,274,564.38	4,288,353.89	116,490.96	4,303,370.74	6,985,602.16	52,311.04	7,011,451.24
2020	Baseline	Mean	41,649,273.78	19,898,354.01	21,750,919.77	10,460,935.13	7,906,751.89	2,837,981.39	31,188,338.64	11,991,602.12	19,196,736.52
		St. Error	1,959,850.27	67,324.82	1,902,505.18	414,102.24	68,076.59	359,987.62	1,548,909.99	2,654.70	1,550,047.59
		Median	42,945,851.92	19,977,111.26	23,044,205.66	10,739,146.45	7,988,997.02	2,749,293.82	32,073,715.44	11,993,793.25	20,088,610.70
		St. Dev.	6,197,590.74	212,899.76	6,016,249.61	1,309,506.28	215,277.07	1,138,380.81	4,898,083.46	8,394.89	4,901,680.87
	CGCM2 A22	Mean	43,540,519.13	19,956,532.47	23,583,986.66	11,029,681.70	7,989,641.68	3,040,040.02	32,510,837.43	11,966,890.79	20,543,946.65
		St. Error	1,300,519.98	23,916.12	1,301,176.44	259,064.10	5,537.43	258,614.30	1,046,374.79	18,580.16	1,047,381.34
		Median	44,329,008.87	19,984,255.78	24,380,921.49	11,139,991.93	7,996,085.01	3,152,415.26	33,151,670.04	11,987,509.82	21,196,773.68
		St. Dev.	4,112,605.29	75,629.42	4,114,681.20	819,232.63	17,510.88	817,810.23	3,308,927.64	58,755.62	3,312,110.62
	CCSRNIES A21	Mean	34,825,061.73	19,390,808.86	15,434,252.86	9,006,942.19	7,406,283.48	2,667,764.51	25,818,119.54	11,984,525.38	13,833,594.16
		St. Error	3,216,413.72	279,253.96	2,995,778.78	757,761.03	278,607.62	543,106.25	2,463,788.76	3,865.07	2,464,464.12
		Median	35,119,652.05	19,895,520.06	15,178,563.81	9,197,164.39	7,919,056.98	1,238,711.70	25,922,487.65	11,984,363.35	13,939,852.11
		St. Dev.	10,171,193.24	883,078.55	9,473,484.30	2,396,250.78	881,034.65	1,717,452.77	7,791,184.14	12,222.44	7,793,319.83
2030	Baseline	Mean	25,858,765.29	15,622,980.06	10,235,785.23	3,915,167.16	3,915,167.16	0.00	21,943,598.14	11,707,812.90	10,235,785.23
		St. Error	1,861,597.52	542,327.54	1,333,267.97	304,951.76	304,951.76	0.00	1,560,649.07	256,921.90	1,333,267.97
		Median	27,381,054.32	16,140,638.30	11,155,687.05	4,170,864.60	4,170,864.60	0.00	23,108,524.86	11,980,226.61	11,155,687.05
		St. Dev.	5,886,888.26	1,714,990.26	4,216,163.53	964,342.15	964,342.15	0.00	4,935,205.69	812,458.38	4,216,163.53
	CGCM2 A22	Mean	27,570,830.66	16,133,181.69	11,437,648.97	4,155,481.39	4,155,481.39	0.00	23,415,349.27	11,977,700.31	11,437,648.97
		St. Error	1,394,371.64	223,446.38	1,224,604.51	224,520.09	224,520.09	0.00	1,176,054.91	17,210.07	1,224,604.51
		Median	28,371,414.67	16,327,028.73	11,894,080.07	4,331,021.01	4,331,021.01	0.00	24,044,771.79	11,997,447.71	11,894,080.07
		St. Dev.	4,409,390.29	706,599.49	3,872,539.49	709,994.86	709,994.86	0.00	3,719,012.17	54,423.03	3,872,539.49
	CCSRNIES A21	Mean	19,447,894.89	13,549,993.07	5,897,901.82	3,075,392.79	3,075,392.79	0.00	16,372,502.10	10,474,600.28	5,897,901.82
		St. Error	3,105,166.26	1,214,353.92	2,008,517.38	567,387.19	567,387.19	0.00	2,563,561.76	745,565.39	2,008,517.38
		Median	19,375,585.47	14,705,858.48	4,669,726.99	2,722,902.30	2,722,902.30	0.00	16,652,683.18	11,964,617.35	4,669,726.99
		St. Dev.	9,819,397.90	3,840,124.26	6,351,489.64	1,794,235.84	1,794,235.84	0.00	8,106,694.10	2,357,684.77	6,351,489.64
2040	Baseline	Mean	18,447,128.45	13,792,896.68	4,654,215.06	2,554,472.14	2,554,472.14	0.00	15,892,639.60	11,238,424.54	4,654,215.06
		St. Error	1,590,648.03	827,389.77	976,246.22	89,241.87	89,241.87	0.00	1,510,157.31	748,070.38	976,246.22
		Median	18,999,304.51	14,594,765.10	4,452,685.67	2,631,296.29	2,631,296.29	0.00	16,449,072.95	11,994,099.10	4,452,685.67
		St. Dev.	5,030,070.73	2,616,436.19	3,087,161.62	282,207.56	282,207.56	0.00	4,775,536.74	2,365,606.26	3,087,161.62
	CGCM2 A22	Mean	19,811,215.53	13,559,270.98	5,758,087.76	2,559,811.63	2,559,811.63	0.00	17,251,403.90	11,493,316.15	5,758,087.76
		St. Error	1,540,692.62	1,035,801.53	921,344.13	109,331.50	109,331.50	0.00	1,450,237.06	983,458.84	921,344.13
		Median	19,739,683.88	14,571,712.42	5,350,353.47	2,575,237.77	2,575,237.77	0.00	17,323,097.26	11,988,197.95	5,350,353.47
		St. Dev.	4,872,097.84	3,275,492.04	2,913,545.97	345,736.56	345,736.56	0.00	4,586,052.26	3,109,969.92	2,913,545.97
	CCSRNIES A21	Mean	12,851,643.09	10,146,627.20	2,705,015.89	2,154,369.83	2,154,369.83	0.00	10,697,273.26	7,992,257.37	2,705,015.89
		St. Error	2,634,291.40	1,523,002.36	1,365,554.72	188,211.98	188,211.98	0.00	2,466,183.80	1,350,015.24	1,365,554.72
		Median	11,431,075.15	11,216,163.78	171,599.60	2,409,174.58	2,409,174.58	0.00	9,009,894.92	8,801,918.73	171,599.60
		St. Dev.	8,330,360.83	4,816,156.34	4,318,263.18	595,178.52	595,178.52	0.00	7,798,757.95	4,269,123.03	4,318,263.18
2050	Baseline	Mean	15,192,549.44	13,953,217.95	1,239,331.49	3,992,221.04	3,992,221.04	0.00	11,200,328.40	9,960,996.91	1,239,331.49
		St. Error	1,426,722.48	986,642.51	638,694.66	168,471.73	168,471.73	0.00	1,291,721.13	836,336.42	638,694.66
		Median	15,395,683.98	15,395,683.98	0.00	4,109,531.25	4,109,531.25	0.00	11,286,152.73	11,286,152.73	0.00
		St. Dev.	4,511,692.63	3,120,037.58	2,019,729.86	532,754.39	532,754.39	0.00	4,084,780.87	2,644,727.98	2,019,729.86
	CGCM2 A22	Mean	16,397,592.26	14,431,726.07	1,965,866.19	4,007,428.82	4,007,428.82	0.00	12,390,163.44	10,424,297.25	1,965,866.19
		St. Error	1,608,308.33	952,735.60	895,803.97	157,722.06	157,722.06	0.00	1,470,945.57	824,883.98	895,803.97
		Median	16,404,215.10	16,042,681.36	322,294.79	4,167,712.65	4,167,712.65	0.00	12,200,355.15	11,860,450.52	322,294.79
		St. Dev.	5,085,917.50	3,012,814.52	2,832,780.88	498,760.95	498,760.95	0.00	4,651,538.32	2,608,512.17	2,832,780.88
	CCSRNIES A21	Mean	11,247,080.97	9,993,027.27	1,254,053.69	3,433,421.77	3,433,421.77	0.00	7,813,659.19	6,559,605.50	1,254,053.69
		St. Error	2,169,997.19	1,489,073.66	808,923.60	259,491.72	259,491.72	0.00	1,922,636.34	1,235,749.12	808,923.60
		Median	8,307,252.30	8,307,252.30	0.00	3,158,652.91	3,158,652.91	0.00	5,148,599.39	5,148,599.39	0.00
		St. Dev.	6,862,133.62	4,708,864.37	2,558,041.03	820,584.87	820,584.87	0.00	6,079,909.95	3,907,781.83	2,558,041.03
2060	Baseline	Mean	10,093,433.00	9,689,540.16	403,892.84	1,026,206.33	1,026,206.33	0.00	9,067,226.66	8,663,333.82	403,892.84
		St. Error	846,057.54	656,911.75	222,598.37	281,710.23	281,710.23	0.00	978,572.20	780,286.80	222,598.37
		Median	9,792,811.33	9,792,811.33	0.00	756,878.78	756,878.78	0.00	8,051,238.37	8,051,238.37	0.00
		St. Dev.	2,675,468.87	2,077,337.35	703,917.85	890,845.97	890,845.97	0.00	3,094,517.01	2,467,483.53	703,917.85
	CGCM2 A22	Mean	9,757,225.39	8,271,299.63	777,337.47	577,925.43	577,925.43	0.00	9,179,299.96	8,401,962.49	777,337.47
		St. Error	1,209,490.47	1,177,890.47	519,780.26	167,826.06	167,826.06	0.00	1,239,703.04	804,087.85	519,780.26
		Median	8,470,231.53	8,470,231.53	0.00	475,496.46	475,496.46	0.00	7,975,929.61	7,975,929.61	0.00
		St. Dev.	3,824,744.68	3,724,816.71	1,643,689.52	530,712.60	530,712.60	0.00	3,920,285.23	2,542,749.06	1,643,689.52
	CCSRNIES A21	Mean	8,207,101.92	7,093,312.40	720,197.88	841,837.22	841,837.22	0.00	7,365,264.70	6,645,066.82	720,197.88
		St. Error	1,427,114.82	1,039,722.24	720,197.88	296,984.70	296,984.70	0.00	1,507,522.83	947,068.83	720,197.88
		Median	7,156,638.13	7,156,638.13	0.00	422,154.78	422,154.78	0.00	6,283,314.52	6,283,314.52	0.00
		St. Dev.	4,512,933.30	3,287,890.42	2,277,465.68	939,148.07	939,148.07	0.00	4,767,205.77	2,994,894.61	2,277,465.68

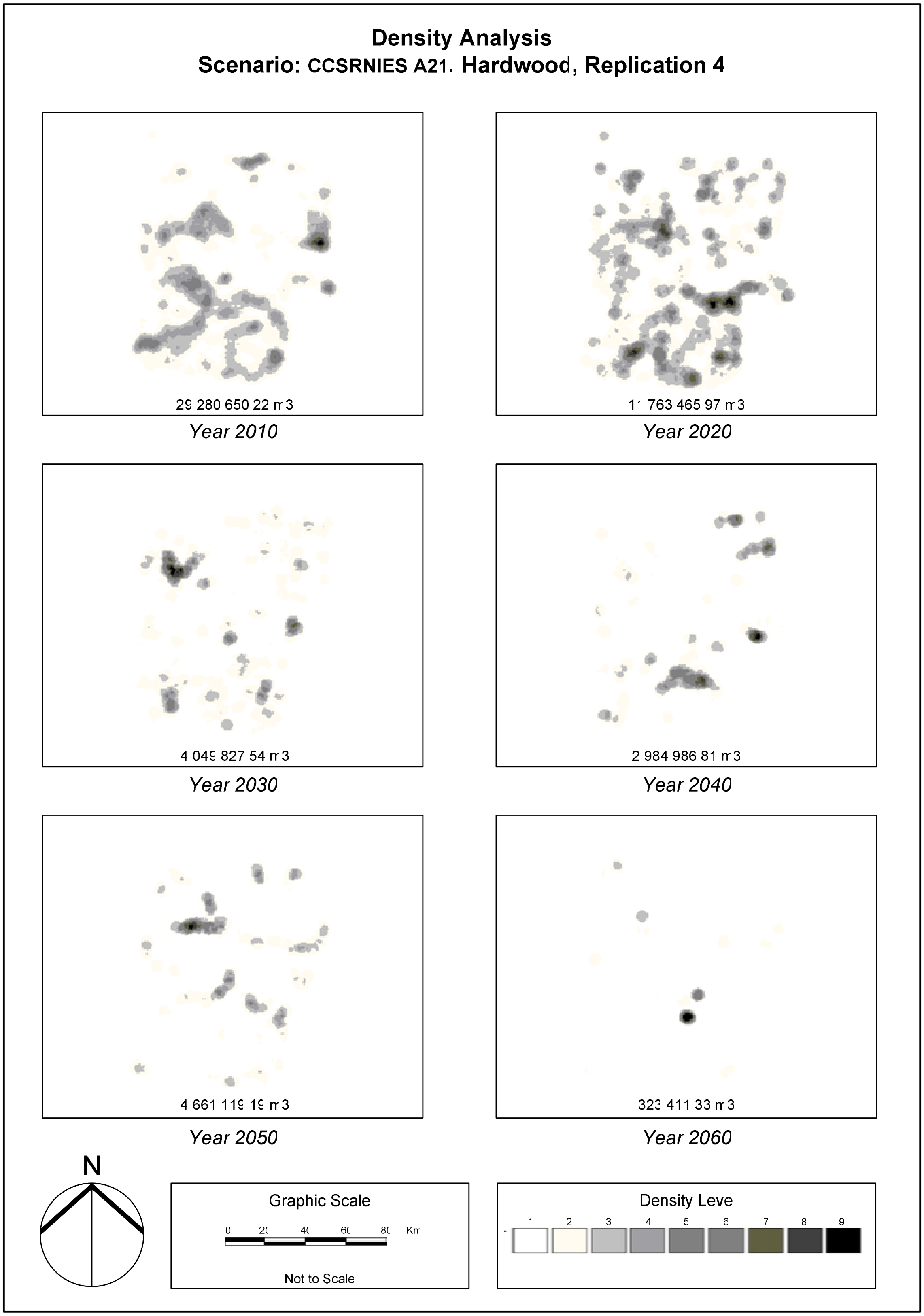


Figure 5.7 Density analysis sample for hardwood (volume indicated inside each map correspondes to timber available each year).The target for hardwood every 10 year was 8,000,000 $m^3 \pm 20\%$.

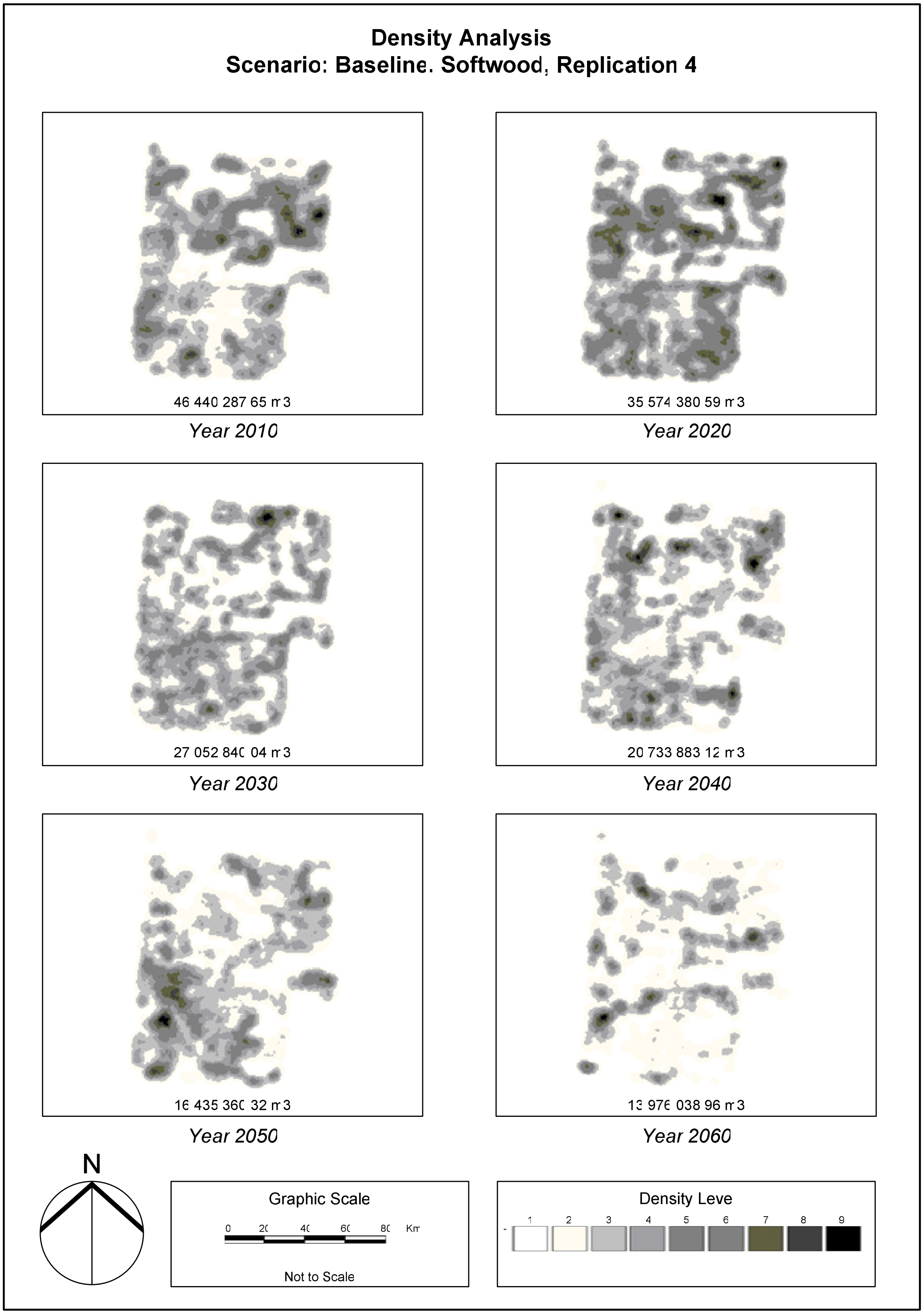


Figure 5.8 Density analysis sample for softwood (volume indicated inside each map correspondes to timber available each year).The target for softwood every 10 year was 12,000,000 m^3 ± 20%.

5.8 Timber availability among scenarios

In this section, research findings in relation to timber presence and availability are detailed and explained. Timber availability varies among scenarios in every decade. To explain this trend, a description of the total timber and then trends for harvestable hardwood and softwood is made. Timber available and logged is reported by volume (m^3), and as indicated before, analysis only considers stands that were selected on the basis of their location and age within operability limits.

5.8.1 Total harvestable biomass

There will be differences among scenarios in total timber available for harvest (Figure 5.9). The most notable difference will occur between the CCSRNIES A21 and the baseline scenario. The difference will diminish towards year 2060. This diminution can be a result of having less mature (and harvestable) trees to cut in the three scenarios. The three scenarios appear to concur at the end of the simulation as no more timber is available to harvest. Values and percentages in Table 5.10 are indicated with respect to the total timber under the baseline scenario. Those values are independent from the harvesting targets. Note also a decrease in harvestable timber each decade, resulting in a deficit from year 2030 in the CCSRNIES A21 scenario and year 2040 for the baseline and the CGCM2 A22. The impacts of a warming climate can this be the cause of the earlier deficit in the warmest scenario (CCSRNIES A21). The increase of fires at the beginning of the simulation impacted the whole modeling from the very beginning. This trend was the cause of having an earlier deficit in the CCSRNIES A21 compared to the other two scenarios as it had more fires and more percentage of area burned from year 2010.

By the time a deficit occurs, the differences between the CCSRNIES A21 and the baseline will be of 24.79% or 6,410,870 m^3 on average. There will also be a 10 year gap between the points when timber becomes a deficit in the baseline and the CCSRNIES A21. The difference between the CGCM2 A22 and the baseline scenario will be not as dramatic as the one already described between CCSRNIES A21 and the baseline (Table 5.10), but still there will be a difference in timber availability of two of three years, and close to 8%.

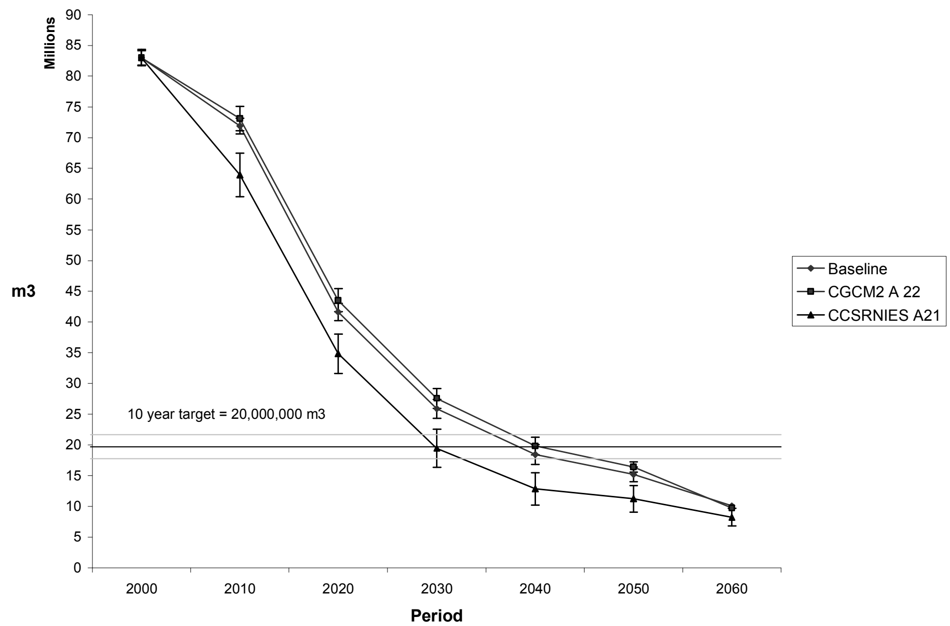


Figure 5.9 Total biomass harvestable (mean ± s.e., n=10). Note the reference line of the 10 year target for harvesting.

Table 5.10 Difference in volume and percentages between the scenarios and the baseline for total timber available.

Year	Difference in volume (m3) between baseline and CGCM2 A22	Percentage	Difference in volume (m3) between the baseline and CCSRNIES A21	Percentage
2010	-1202069.42	1.67	7954504.31	-11.06
2020	-1891245.35	4.54	6824212.05	-16.38
2030	-1712065.37	6.62	6410870.4	-24.79
2040	-1364087.08	7.39	5595485.36	-30.33
2050	-1205042.82	7.93	3945468.47	-25.97
2060	336207.61	-3.33	1886331.08	-18.69

A graphic vision of data from Table 5.10, shows that in the medium term, both scenarios will have less timber available, with respect to the baseline (Figure 5.10). CGCM2 A22 will have more available biomass than the baseline up to year 2050 when the situation will change to have less available timber. It is also clear that the warmest scenario (CCSRNIES A21) will have less available timber (up to 5 times less in year 2020 and 2040) than the CGCM2 A22 (See also Table 5.9 on page 115). The big fires that occurred in the beginning of the simulation are the probable cause of this (Table 5.2 and Table 5.3), which together with harvesting impacted the rest of the simulation.

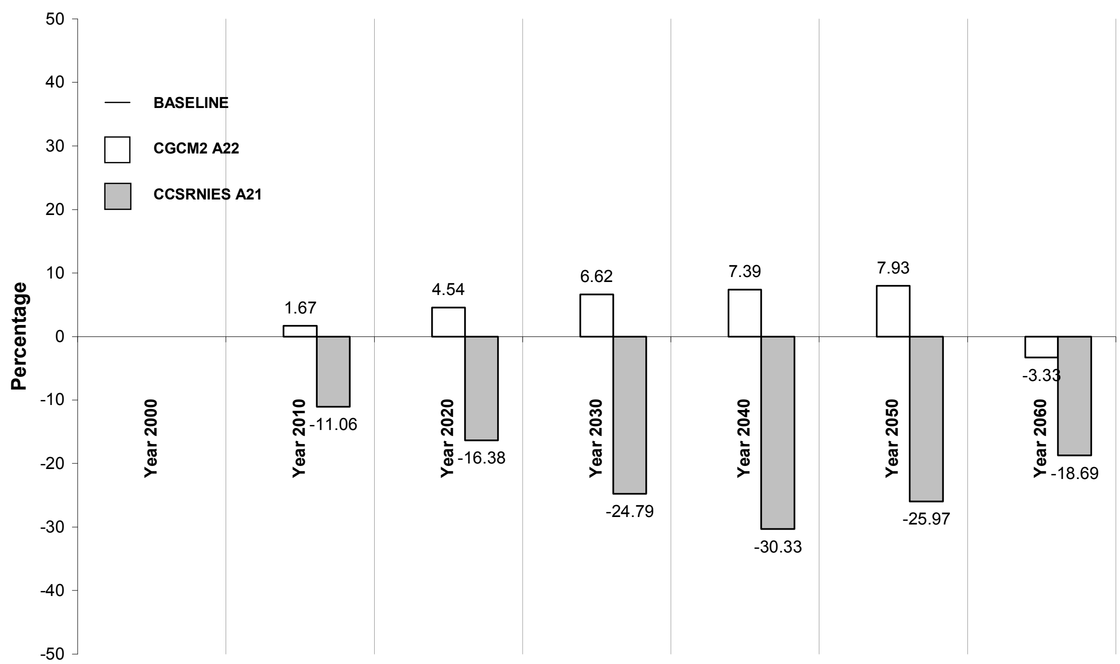


Figure 5.10 Difference in percentage between the scenarios and the baseline for total biomass harvestable.

All scenarios will have deficits around year 2035. Projected climate warming will result in deficits occurring sooner (up to 10 years for CCSRNIES A21 with respect to the baseline).

5.8.2 Harvestable hardwood

In the case of harvestable hardwood, deficits will start in year 2020 and will continue to year 2060 (Figure 5.11). There will be only a small difference in timber availability among the three scenarios, suggesting that harvesting will be rapidly depleting hardwood, and can be more important in this respect than the effect of climate change in the same period of time.

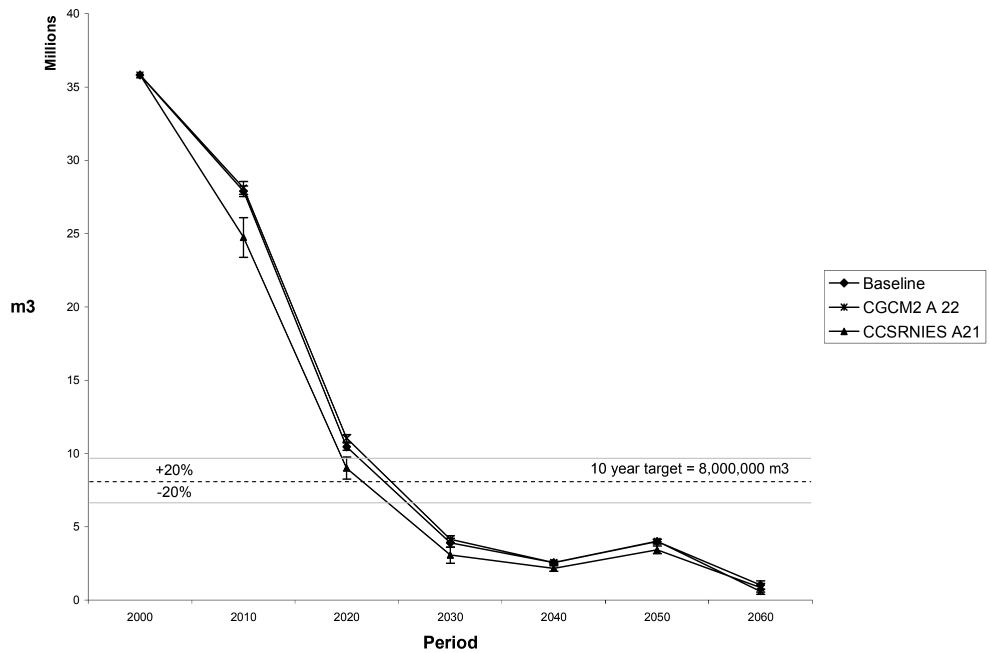


Figure 5.11 Harvestable hardwood (mean ± s.e., n=10).

The difference in percentage of hardwood available among the climate change scenarios and the baseline (Table 5.11 and Figure 5.12) will follow a similar trend as that in the case of total harvestable timber (Section 5.8.1). The CGCM2 A22 will have more available timber from the year 2010 to 2050, but then it will have less availability similarly to total harvestable timber revised in Section 5.8.1.

Table 5.11 Difference in volume and percentages between the scenarios and the baseline for total harvestable hardwood.

Year	Difference in volume (m3) between baseline and CGCM2 A22	Percentage	Difference in volume (m3) between the baseline and CCSRNIES A21	Percentage
2010	220,589.91	0.79	3,157,558.84	-11.32
2020	568,746.57	5.44	1,453,992.95	-13.90
2030	240,314.23	6.14	839,774.37	-21.45
2040	5,339.49	0.21	400,102.31	-15.66
2050	15,207.79	0.38	558,799.26	-14.00
2060	448,280.91	-43.68	184,369.11	-17.97

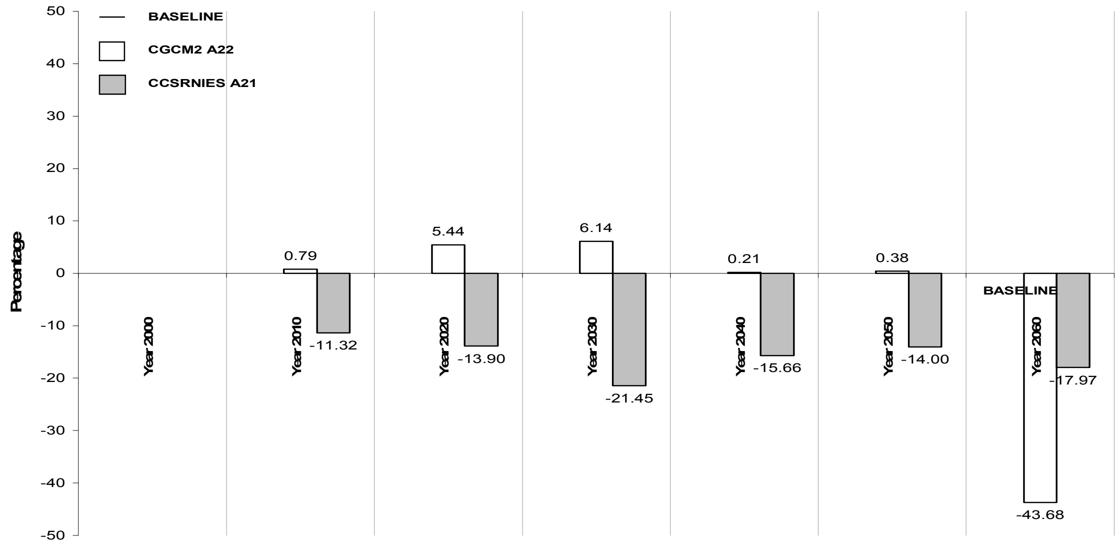


Figure 5.12 Difference in volume and percentages for total available hardwood. Comparison between the scenarios and the baseline.

5.8.3 Harvestable softwood

Harvestable softwood will fulfill demand for almost 50 years under the baseline and the CGCM2 A22 scenarios, but CCSRNIES A21 will have a deficit around year 2030 (Figure 5.13). The other two scenarios will have deficits by year 2050. As with total timber available, deficits will occur ten years earlier with CCRSNIES A21 than with the baseline.

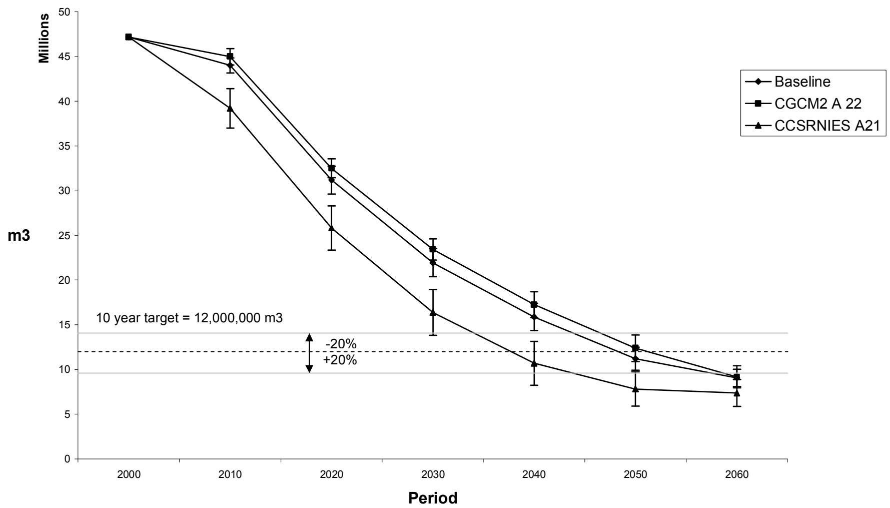


Figure 5.13 Harvestable softwood (mean ± s.e., n=10).

Table 5.12 shows the differences in harvest volume between CGCM2 A22 and CCSRNIES A21 and the baseline. There will be up to 5,195,000.00 m^3 (32.69%) less harvestable softwood by year 2040 in the CCSRNIES A21 scenario with respect to the baseline. That volume is considerable keeping in mind the goal of harvesting 12,000,000 m^3 ± (20%) of softwood which constitutes around 50% of that needed softwood, every 10 years.

Table 5.12 Difference in volume and percentages between the scenarios and the baseline for total softwood available.

Year	Difference in volume (m3) between baseline and CGCM2 A22	Percentage	Difference in volume (m3) between the baseline and CCSRNIES A21	Percentage
2010	981479.55	2.23	4796945.42	-10.90
2020	1,322,498.79	4.24	5370219.1	-17.22
2030	1471751.13	6.71	5571096.04	-25.39
2040	1358764.3	8.55	5195366.34	-32.69
2050	1189837.04	10.62	3386667.21	-30.24
2060	112073.3	1.24	1701961.96	-18.77

Figure 5.14 shows graphically data from Table 5.12. Trends here will be similar to those already indicated for total timber and hardwood. In the medium term, both scenarios appear to offer less timber than the baseline.

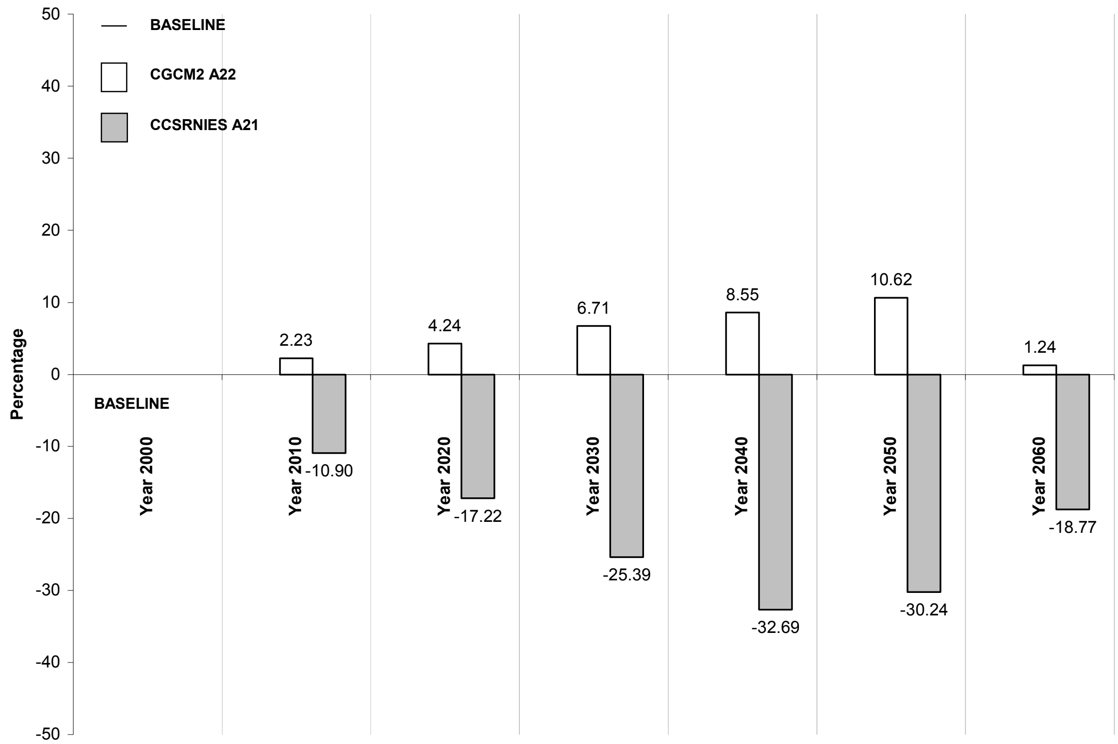


Figure 5.14 Total softwood harvestable. Differences in percentages between the scenarios and the baseline.

These findings indicate that, for total harvestable timber, the CCSRNIES A21 scenario will produce less available timber that the other two. One explanation is the impact of a warmer climate on the fire regime at the beginning of the simulation (Table 5.2 and Table 5.3), which constitutes an important disturbance that impacts the rest of the modeling. Harvesting also contributed to this situation in all simulations. CCSRNIES A21 scenario will have a deficit by year 2030 and will occur about 10 years before it does in the baseline and the CGCM2 A22 scenarios. The latter will be very similar to the baseline case and deficits will start by year 2040.

The harvestable hardwood deficit will start around 2020 under the three scenarios. Harvestable softwood will follow a similar trend as that for total harvestable timber. Here, the CCSRNIES A21 scenario will supply less softwood and a deficit will start by year 2040. This also occurs10 year before it does in the other two scenarios. CGCM2 A22 scenario will have slightly more softwood available than the baseline but in general both will have the same timber availability. The baseline and the CGCM2 A22 scenarios will have deficits by year 2060. Thus harvestable timber both climate change (timing of deficit-outset) and harvesting (amount of mature timber available) will introduce stresses on timber supply.

5.9 Timber harvested

Now results for total timber, hardwood and softwood logged are presented. Here statistics are derived from volume of mature and denser located cells as for logged timber in former sections.

5.9.1 Total biomass harvested

With total harvest, some differences among scenarios will be observed (Figure 5.15). Total timber logged will fulfill demand up to year 2020 under the three scenarios. However from 2030 onwards, demand will not be fulfilled under any of the scenarios. After year 2030, there will be a notable difference between CCSRNIES A21 and the baseline. The biggest difference between these two scenarios is in the year 2050, (Figure 5.15), at 28.38 % which corresponds to almost 4,000,000 m^3. The difference between those scenarios will diminish a little by year 2060, when the difference will be 26.79 % (2,596,227 m^3). There will also be a difference of about 5 years between the time at which those two scenarios start having deficits occurring at about year 2030. The difference in volume between the CGCMA A22 and the baseline will be much less apparent.

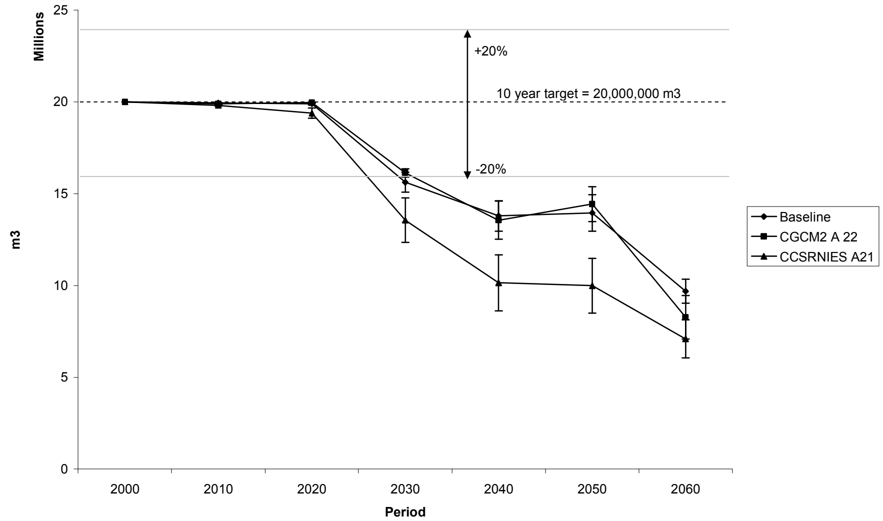


Figure 5.15 Total biomass harvested (hardwood and softwood). Mean ± s.e., n=10.

As in the former cases, there will be greater timber availability for CGCM2 A22 with respect to the baseline but the CCSRNIES A21 scenario will have less timber harvested. By year 2030 there will be a deficit from year 2030 under all the three scenarios. The difference between CGCM2 A22 and the baseline will not be so evident. In the case of the difference between CCSRNIES A21 and the baseline, in year 2020 there will be a difference between them that will start at 2.55%, (507,545.15 m3), reaching up to 28.38% (3.960,190.68 m3) in year 2050 (Figure 5.16).

Table 5.13 Difference in volume and percentages between the scenarios and the baseline for total biomass harvested.

Year	Difference in volume (m3) between baseline and CGCM2 A22	Percentage	Difference in volume (m3) between the baseline and CCSRNIES A21	Percentage
2010	51,759.29	-0.26	128,870.44	-0.65
2020	58,178.46	0.29	507,545.15	-2.55
2030	510,201.63	3.27	2,072,986.99	-13.27
2040	233,625.70	-1.69	3,646,269.48	-26.44
2050	478,508.12	3.43	3,960,190.68	-28.38
2060	1,418,240.53	-14.64	2,596,227.76	-26.79

As for total available timber, all scenarios will develop deficits beginning around year 2030. Here also the impact of climate change will be observed in accessibility to timber and in volume differences among scenarios. A similar situation will occur with harvested hardwood and softwood. The next sections explain these findings.

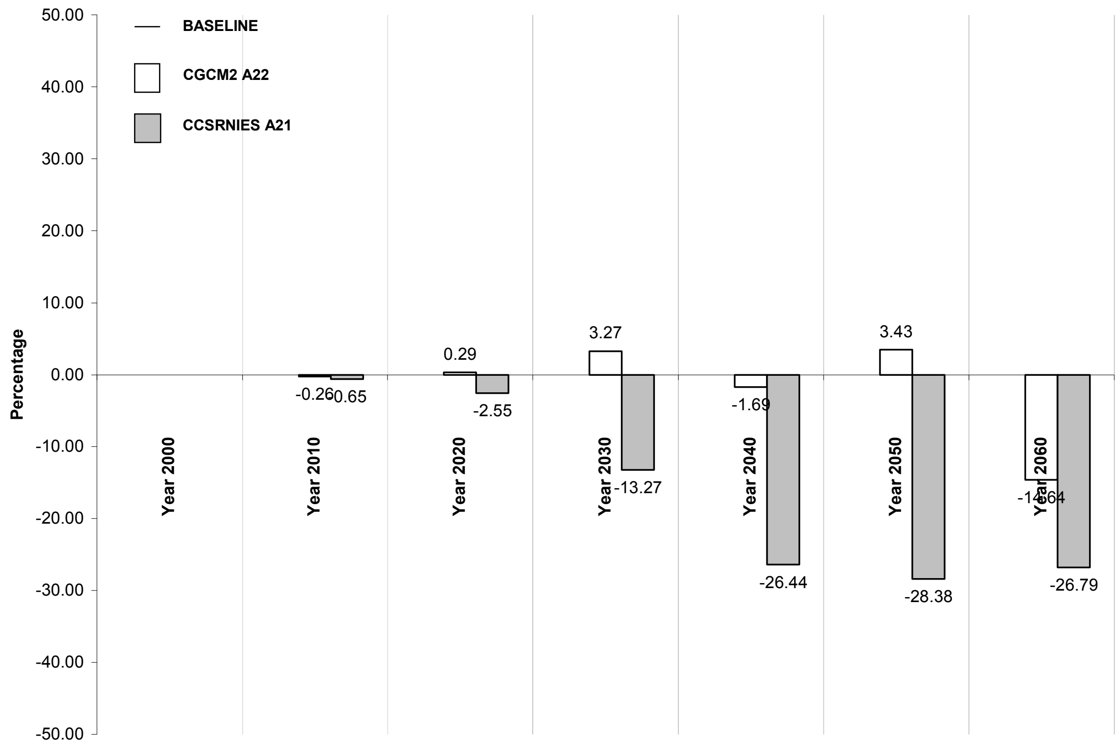


Figure 5.16 Total biomass harvested. Differences in percentages between the scenarios and the baseline.

5.9.2 Total hardwood harvested

Hardwood harvested will follow a similar trend as that of for total biomass harvested. Here, demand will be fulfilled up to year 2020 under the three scenarios, but by year 2030, there will be a difference of about 25% between the baseline and the CCSRNIES (Figure 5.17), which will diminish to 10% by years 2040 and 2050. By year 2060 the three scenarios will have deficits with about 1,000,000 m^3 of hardwood timber logged.

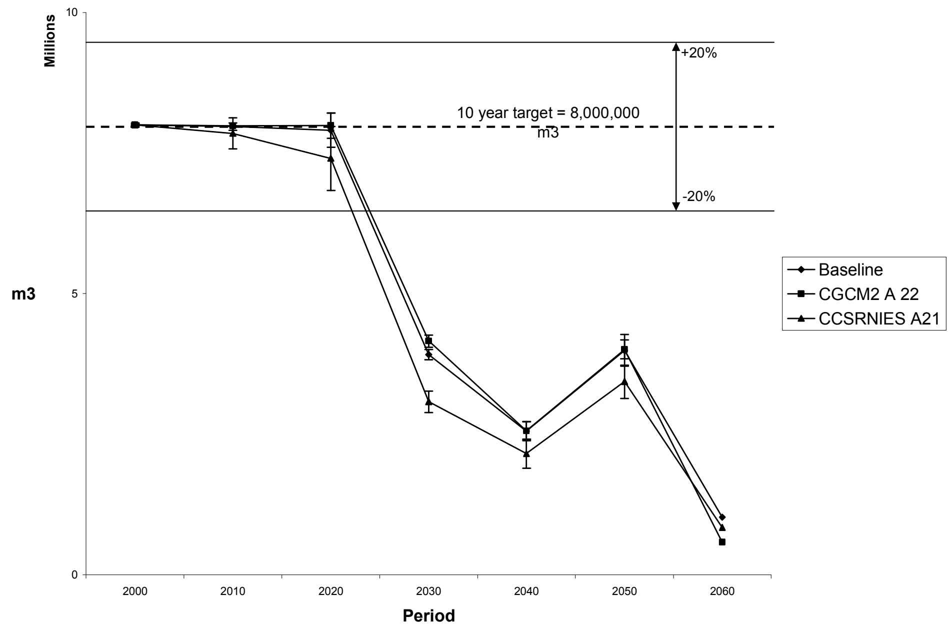


Figure 5.17 Hardwood harvested (mean ± s.e., n=10).

Regarding the difference in percentages of hardwood harvested among scenarios (Table 5.1 and Figure 5.18), the trend will be similar to those noted in earlier in the results: CGCM2 A22 will have more hardwood logged than the baseline by year 2020 (0.11 %), reaching a 6.14% difference by year 2030. After that year, CGCM2 A22 will provide less timber (up to 43.68% less). CCSRNIES A21 will always have less timber than the baseline. This difference will reach up to 21.45% by year 2030.

Table 5.14 Difference in volume and percentages between the scenarios and the baseline for total harvested hardwood.

Year	Difference in volume (m3) between baseline and CGCM2 A22	Percentage	Difference in volume (m3) between the baseline and CCSRNIES A21	Percentage
2010	8,956.58	0.11	119,909.38	-1.50
2020	82,889.79	1.05	500,468.41	-6.33
2030	240,314.23	6.14	839,774.37	-21.45
2040	5,339.49	0.21	400,102.31	-15.66
2050	15,207.79	0.38	558,799.26	-14.00
2060	448,280.91	-43.68	184,369.11	-17.97

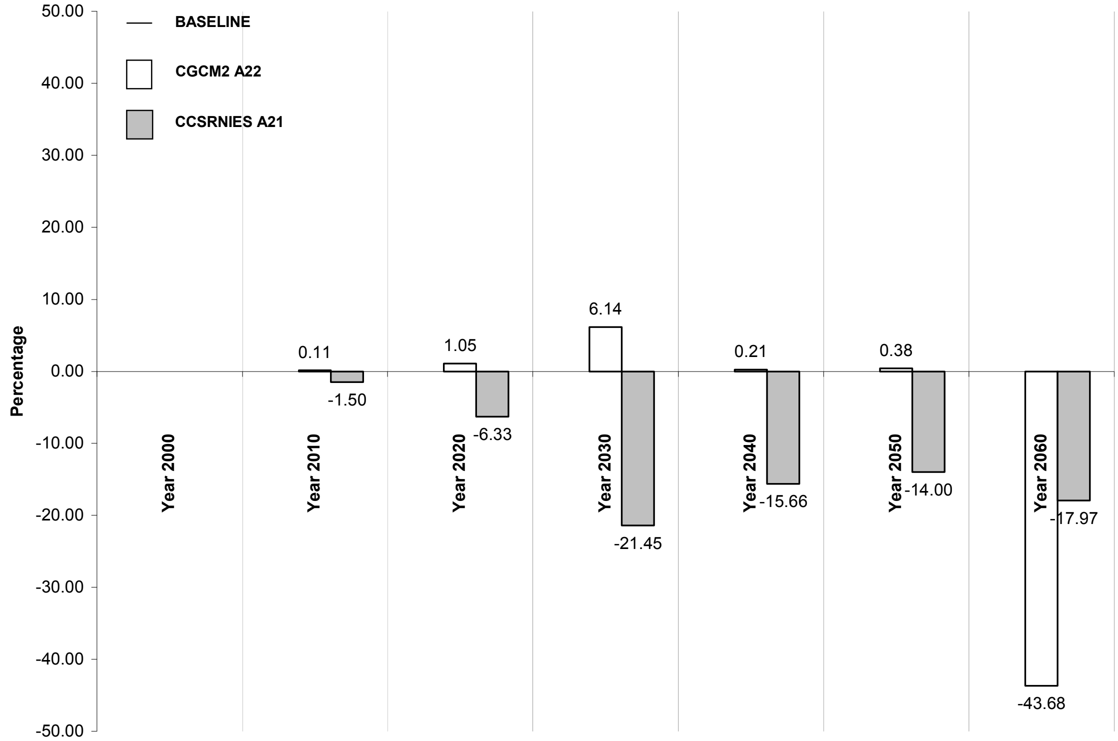


Figure 5.18 Total hardwood harvested. Differences in percentages between the scenarios and the baseline

5.9.3 Total softwood harvested

Deficits in harvested softwood volumes will begin to occur by year 2050 for GCM2 A22, for the baseline by year 2050, and for CCSRNIES A21 by 2035, which is 15 years earlier (Figure 5.19). There will be also differences in volume between the CCSRNIES A21 and the baseline of more than 30% and up to about 3,400,000.00 m^3, which is almost a third of the demand for softwood (Table 5.15. Differences in time when a deficit first occurred and in volume important for planning purposes and will be discussed later.

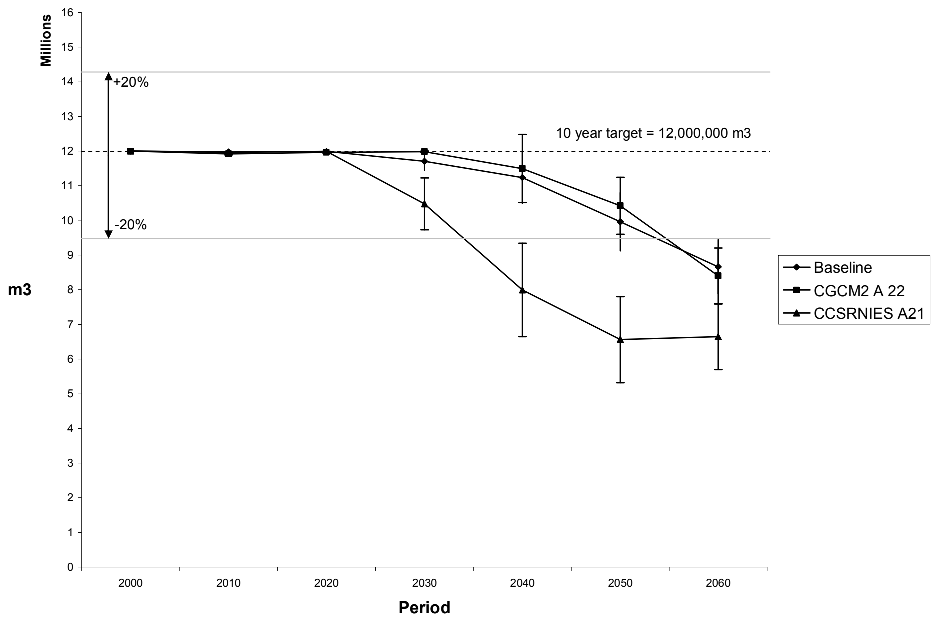


Figure 5.19 Softwood harvested (mean ± s.e., n=10).

Table 5.13 also shows the percentages in timber harvested between CCSRNIES and the CGCM2 A22 and the baseline. As it is shown, there will be differences up to close to 3,500.000 m^3 by year 2050 for the case of CCSRNIES A21. CGCM2 A22 will have smaller differences.

Table 5.15 Difference in volume and percentages between the scenarios and the baseline for total softwood harvested.

Year	Difference in volume (m3) between baseline and CGCM2 A22	Percentage	Difference in volume (m3) between the baseline and CCSRNIES A21	Percentage
2010	54,919.74	-0.46	8,961.06	-0.07
2020	24,711.33	-0.21	7,076.74	-0.06
2030	269,887.41	2.31	1,233,212.62	-10.53
2040	254,891.61	2.27	3,246,167.17	-28.88
2050	463,300.34	4.65	3,401,391.41	-34.15
2060	516,073.30	5.96	1,297,961.96	-14.98

With respect to the difference in percentage of total softwood harvested among CGCM2 A22, CCSRNIES A21 and the baseline, again the trends will be similar to the ones for total timber and hardwood logged, and in the medium term (60 years) the two climate change scenarios will provide less timber available than the baseline (Figure 5.20).

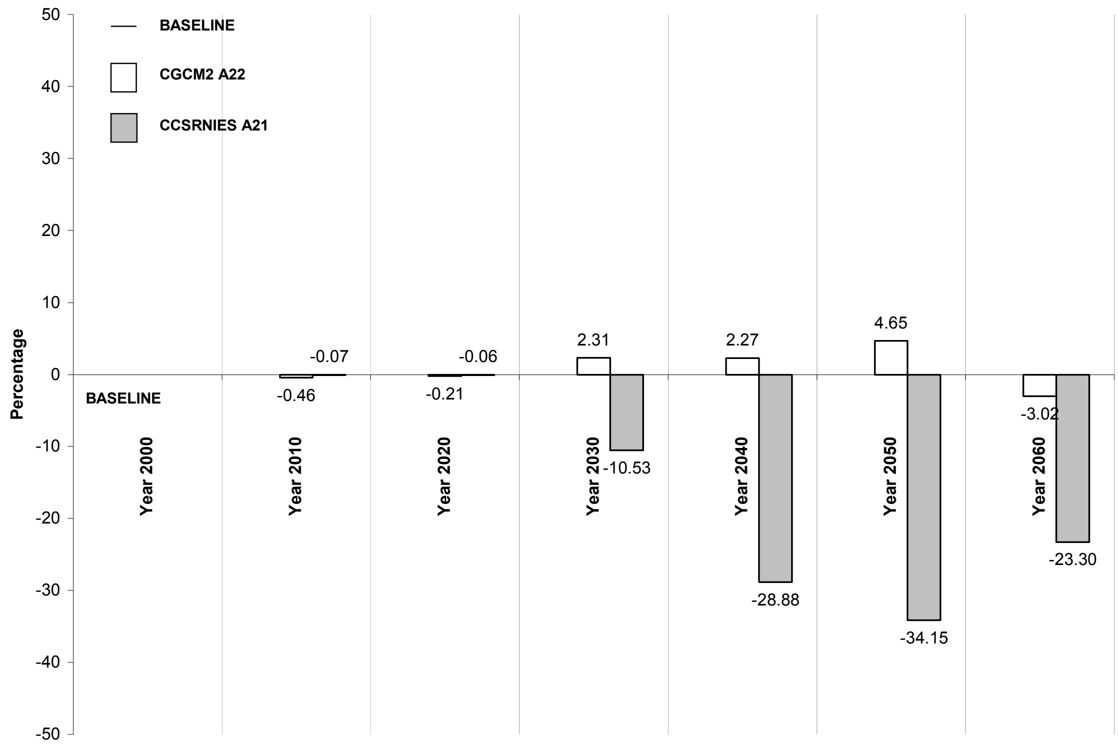


Figure 5.20 Total softwood harvested. Difference in percentage between the scenarios and the baseline.

5.10 Percentage of harvested over available timber

For reference, Figure 5.21, Figure 5.22, and Figure 5.24 show the three scenarios separately and the trends regarding the percentage of harvested over available timber. Clearly, show for hardwood at year 2030 all available timber will be logged. Nevertheless demand will not be fulfilled according to the planning objectives (8,000,000 m^3 ± 20%) as indicated above.

In the case of softwood, baseline and CGCM2 A22 will fulfill demand until year 2050. By year 2060, however 100% of the available timber will be logged without fulfilling demand (Table 5.9). CCSRNIES A21 will present first deficit at year 2040, and so the 100% of the available timber will be logged.

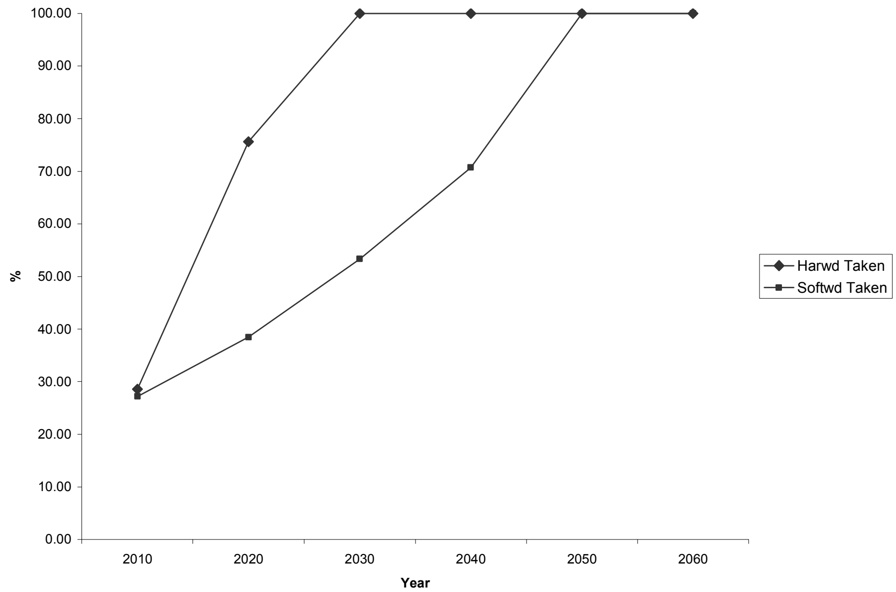


Figure 5.21 Percentage of logged over available biomass: baseline.

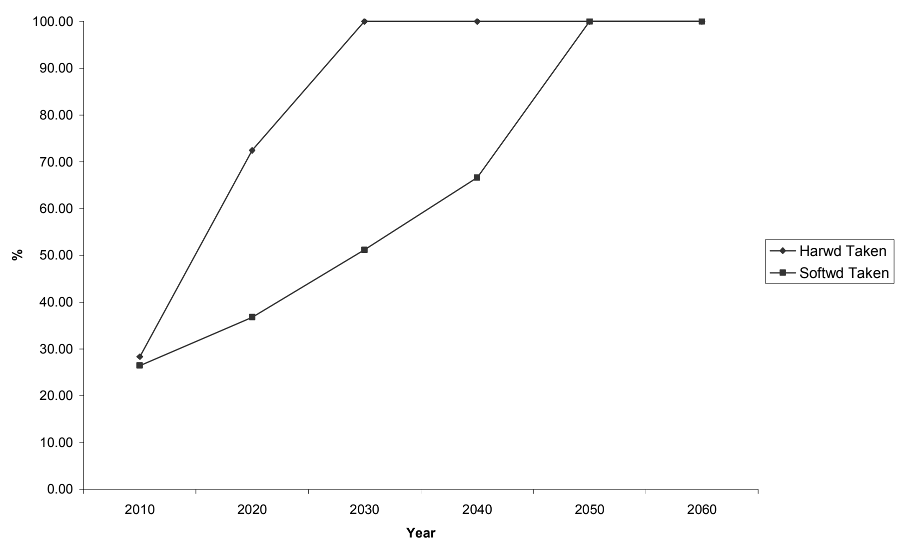


Figure 5.22 Percentage of logged over available biomass: CGCM2 A22.

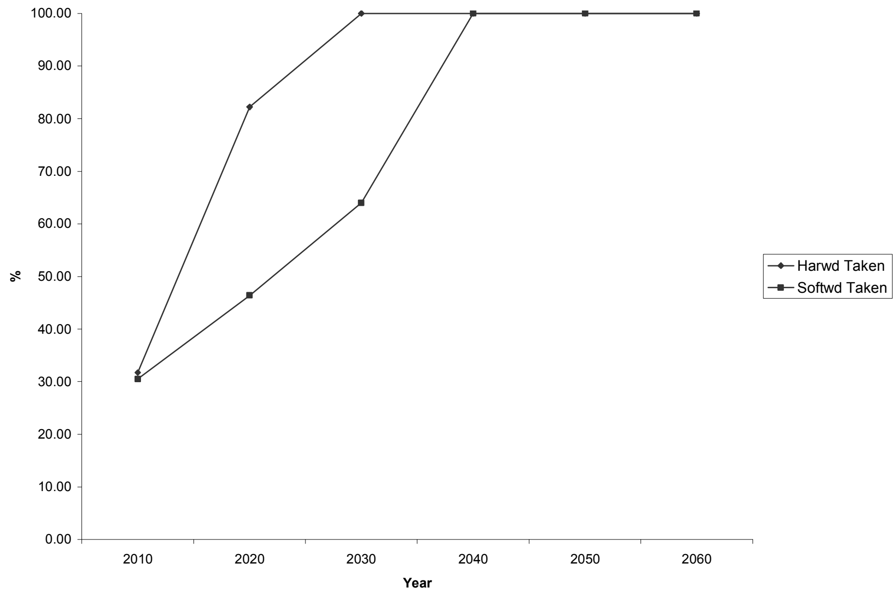


Figure 5.23 Percentage of logged over available biomass: CCSRNIES A21.

5.11 Timber harvested: stand age classes

In this section data regarding the stand age classes for hardwood and softwood that will contribute to the total amount of harvested timber are presented. Information about harvested timber is expressed in volume. Stands analyzed correspond only to those within operability limits, so age classes start with 40-41 and end in 180-189 years. Thus age classes correspond to the highest and lowest operability limits for all species.

5.11.1 Hardwood stand age class harvested

The contributing age classes for harvested hardwood are shown on Figure 5.24, and Figure 5.25. Only the 2010 and 2060 figures are shown here, but the rest are in Appendix 6. By 2010, harvestable age classes for hardwood will range from 50-59 to 130-139 years. The major contributing[27] age classes will be stands younger than 100 years. By year 2060 the contributing age class will decrease to 50-79, and the volume of timber available will be less than 100,000 m^3 (note that the target is 8,000,000 m^3 ± 20% every 10 years).

[27] "Contributing" consisted of those cells that provided timber that was logged.

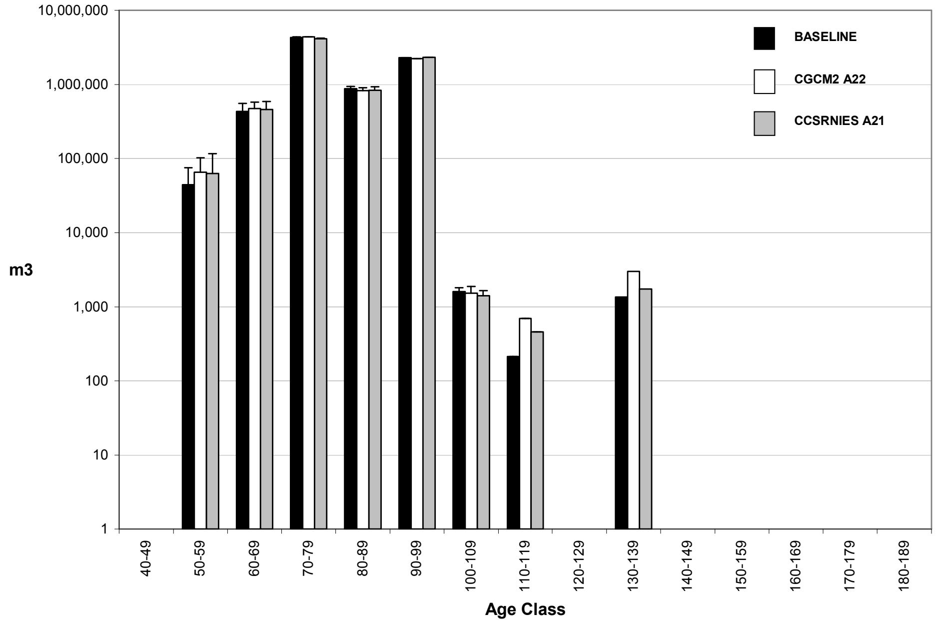


Figure 5.24 Stand Age class of harvested hardwood in year 2010 (mean ± s.e., n=10*)*.

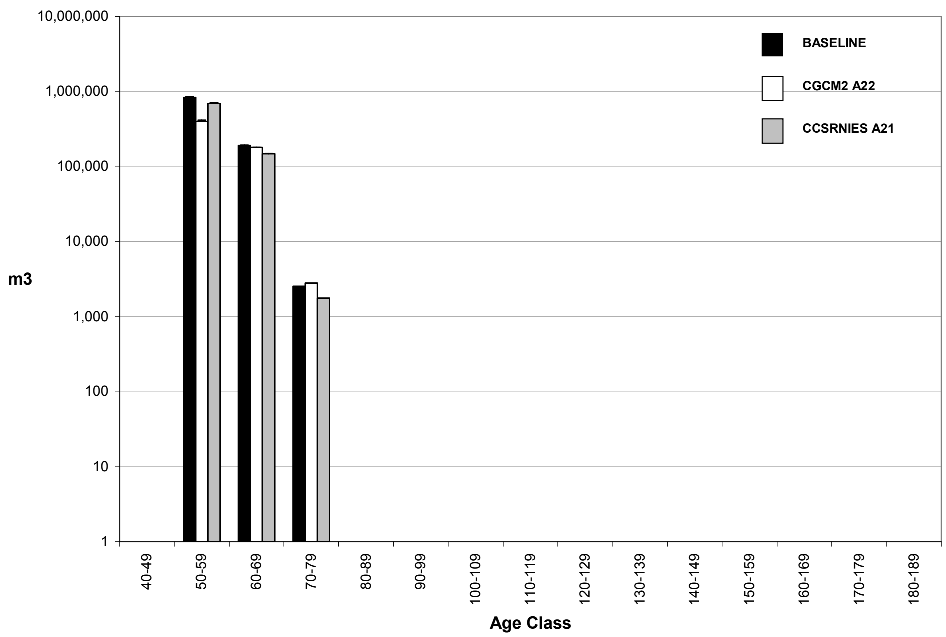


Figure 5.25 Stand age class of harvested hardwood in year 2060 (mean ± s.e., n=10).

5.11.2 Softwood stand age class harvested

In the case of softwood the contributing age classes will range from 40 to 189 years. The class 90-99 will provided the most timber by 2010 under the three scenarios (Figure 5.26, and Figure 5.27). Following a similar trend as that of hardwood, softwood age classes will be younger in every 10 year period. By 2010 the most contributing age class will be 90-99. By year 2060 the 60-69 age class will contribute the most.

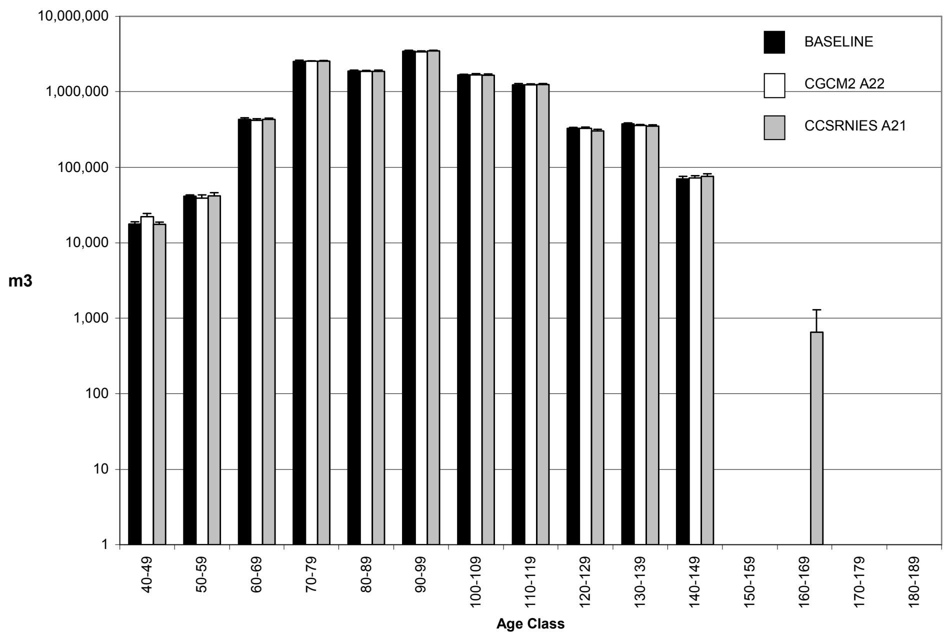


Figure 5.26 Stand age class of harvested softwood by yeas 2010 (mean ± s.e., n=10).

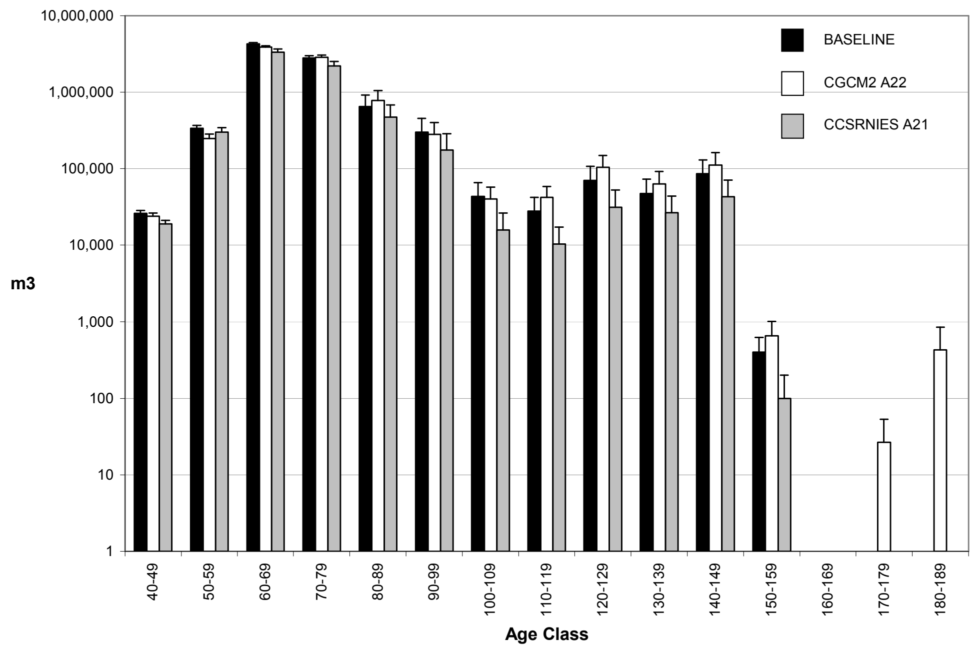


Figure 5.27 Stand age class of harvested softwood in year 2060 (mean ± s.e., n=10).

5.12 Summary of Findings

a) The fire regime was reported from BFOLDS using data from *Number of Fires* and *Percentage of Area* burned. Results show that there will be little difference in number of fires among the three scenarios during the 60 year simulation. The more important differences in percentage of area burned will happen between the CCSRNIES A21 in year 2020, 2030, and 2060 with respect to the baseline (up to 12%). CGCM2 A22 will have less percentage of area burned than the baseline (2% less) by year 2020, and by the years 2060, the difference will increase to about 10%. In the rest of the years, scenarios will present very similar trends. By year 2060 CCSRNIES A21 and CGCM2 A22 will show an increase in area burned relative to the baseline. By year 2060 CCSRNIES A21 and CGCM2 A22 will have bigger fires than the baseline.

b) For forest composition regarding hardwood and softwood, the study shows a decrease of about 10% in hardwood from year 2010 to 2060, and an increase of similar proportion in softwood in the three scenarios. From year 2020 to 2060, CCSRNIES A21 will have more hardwood (2%) than the baseline and a similar decreasing proportion in softwood. The CGCM2 A22 scenario will be similar to the baseline in terms of species composition.

c) Little change will be observed in species composition both for hardwood and softwood among scenarios. Dominant species for hardwood will be, poplar (increased), white birch (decreased), and maple/oak (increased). For softwood, the dominant species will be, balsam fir (increased) jack pine (increased), and black spruce (decreased). Changes in proportion in species composition will vary among decades.

d) Age classes of harvestable timber show that the forest will became younger during the 60 year period. Stand Age classes older than 100 years will be less common.

e) Density analysis showed that wood will be scarcer in each succeeding decade and harvestable areas will be more scattered.

f) In correspondence with (d), there will be a general decrease in timber availability for harvesting, and logging of hardwood will decrease more than that of softwood. Towards 2060, there will be deficits in timber harvested in all scenarios analyzed.

g) There will be differences both in timber volume available and harvested for hardwood and softwood, and in the temporal access to the resource. Deficits can be reached 10 years before the baseline in some cases.

h) In the case of hardwood there will be deficits from 2030 whereas softwood will have deficits by 2050.

i) The age classes contributing most to timber harvested by year 2010 will range from 50 to 139 years. By 2060, the most contributing age classes will be from 50 to 79 years. For softwood, by 2010, these age classes will range from 40 to 189 years and the most contributing age class will be 90-99. By 2060, the most contributing age class will changed to 60-69.

j) Harvesting and the simulated regeneration after logging applied influence species composition and stand age class. Regeneration rules applied promoted softwood over hardwood. Harvesting rates applied promoted big plantations of young stands.

k) Findings described in (a) to (i) indicate that, under the conditions of this study, the two scenarios of climate change (CGCM2 A22 and CCSRNIES A21) will have different impacts on timber availability and forest age. In this regard, the CCSRNIES A21 will differ the most from the baseline as the climate change impacts influence the fire regime from the beginning of the simulation. That impact together with harvesting impacted the rest of the modeling. The CGCM2 A22 scenario was the one with closer trends than that of the baseline over the entire simulation. This results from the small changes in precipitation and temperature in the 2050's relative to the baseline scenario (Section 4.2.5).

6 Discussion and conclusions

Canadian forests have long played an important role in Canadian life, so their condition and potential change can directly impact the welfare of the nation (Drushka, 2003). Any measure that helps to better plan and manage such a valuable ecosystem should be welcomed.

The main objective of this thesis has been to asses the role of land-use and landscape planning as tools for adapting to climate change impacts. The object of the study was the boreal forest landscape in north western Ontario, which is currently under harvesting regime. The premise was that there are links among society, land-use, and climate change (Dale, 1997; IPCC, 2001a), so a change in any of them could affect the others, which always results in landscape change (Noss, 2001). Results obtained in this thesis have helped to assess the role of climate change impacts on landscape change. They also helped to explore the implications of potential scenarios for the forestry sector, and then for the environment and society.

In this discussion section, the probable causes of the results in Chapter 5 are analyzed. The chapter also includes the implications of those results for different stakeholders in the study area and beyond. Finally some methodological issues are discussed and some planning recommendations are proposed.

6.1.1 Climate change impacts on the forestry industry in north western Ontario

Three key findings that applied to all three scenarios (baseline and CGCM2 A22, and CCSRNIES A21) over the 60 years of the model: (1) species composition will not vary among scenarios, but over time, (2) the forest will become younger, and (3) timber availability will diminish and harvest demands will not be fulfilled (30 years from now on average). Climate change will have an impact in two ways. First, in the volume of timber that will be available (m^3). Second, in the timing of the occurrence of timber deficits. In scenario CGCM2 (the one with less change in temperature and precipitation with regards to the baseline) trends in volume and the timing of the occurrence of deficits will be close to those trends that will result from the baseline scenario. The warmest scenario (CCSRNIES A21) will differ more from the baseline as climate change will impact fire regime in the beginning of the simulation. This scenario will show less timber available every decade (from 11 up to 30%), with a deficit relative to demand which will occur 10 years sooner than with the baseline. The following sections discuss particulars of these findings.

6.1.1.1 Hardwood and softwood species composition

Contrary to the expected trend in both climate change scenarios and the baseline more softwood than hardwood was produced over the 60 years. This finding agrees with Solomon(1986)'s predictions of increases in hardwood over softwood ***but*** until year 500, and

Table 6.1 Species composition in a 1000 year simulation. (H) means hardwood. Note how harwood dominance starts until year 500 of the simulation (from Solomon, 1986).

Dominant species		
Present day climate (year 0 to 400)	2 x CO_2 (year 400 to 500)	4 x CO_2 (year 500 to 1000)
Picea glauca (white spruce) *Picea mariana* (black spruce) *Pinus rubens* (red spruce) *Betula lenta* (sweet birch) (H) *Betula papyrifera* (paper birch) (H) *Betula alleghaniensis* (yellow birch) (H) *Abies balsamea* (balsam fir) *A. fraseri* (fraser fir)	*Picea glauca* (white spruce) *Picea mariana* (black spruce) *Pinus rubens* (red spruce) *Betula lenta* (sweet birch) (H) *Betula papyrifera* (paper birch) (H) *Betula alleghaniensis* (yellow birch) (H) *Abies balsamea* (balsam fir) *Abies fraseri* (fraser fir)	*Acer saccharum* (sugar maple) (H) *Acer rubra* (red maple) (H) *Acer saccharinum* (silver maple) (H) *Abies balsamea* (balsam fir) *Abies fraseri* (fraser fir) *Pinus strobus* (white pine) *Quercus alba* (white oak) (H) *Quercus. coccinea* (scarlet oak) (H) *Quercus. primus* (chestnut oak) (H) *Quercus. rubra* (northern red oak) (H) *Quercus selutina* (black oak) (H) *Quercus. macrocarpa* (bur oak) (H) *Quercus borealis* (gray oak) (H) *Quercus ellipsoidallis* (northern pin oak) (H) *Fraxinus pennsylvanica* (green ash) (H) *Fraxinus americana* (white ash) (H) *Fraxinus nigra* (black ash) (H) *Fraxinus cuadrangulata* (blue ash) *Tilia americana* (American basswood) (H) *Tilia heterophylla* (white basswood) *Thuja occidentalis* (northern white cedar) *Juniperus virginiana* (red cedar) *Larix laricina* (tamarack)

not before (Table 6.1). Our findings can be a result of the 60 years that appear to be short to show conspicuous changes towards hardwood. This trend can also be the response of jack pine to the fire regime (Suffling, 1995), in which big fires at the beginning of the simulation will promote an increase in this species in our simulation.

Another possibility explains this situation. The simulation used in this thesis included harvesting, so it was a managed landscape. The application of succession rules after logging following standard procedures in Ontario as indicated in Chapter 4 will influence forest composition. For example in the specific case of softwood, jack pine is the species used most often replacing logged timber, through planting. The cumulative effects of logging and regeneration rules applied will influence the resulting species composition. Alteration of those management actions can be used as an adaptation to climate change impacts as to reach a sustainable land-use.

6.1.1.2 Stand age composition of available timber

Results suggest that impacts of climate change on stand age class and of harvestable timber are present at the very beginning of the simulation. Additionally, harvesting will have a major role by removing mature trees to fulfill demand. The combined impact of the climate and harvesting, will also affect forest age in the following decades. Mature trees will be replaced by young plantations with species regeneration, including dictated by pot-logging regeneration. The simulation indicates there will not be enough extant mature timber to be logged in 60 years from now, using current industrial assumptions.

Age reduction in forests has implications for the natural and the economic aspects that have to be reviewed and handled doing planning. The shift to a younger forest affects the regional ecosystem and hinders the objectives of sustainable forest management attempted by the Government of Ontario (Ontario Ministry of Natural Resources, 2002d). From the industry point of view, this shift reduces the volume of timber produced by the forest, which affects the timber industry's ability to meet its demands. This can cause employment decline in the local economy which can result in social stresses. As the forestry industry also provides indirect employment, negative impacts can also go beyond the local area and impact Ontario employment as well. Having a majority of young forest in the area will not only affect the local environment but the global dynamic, due the importance of Canadian forests in the regulation of global climate.

Young forests, instead of mature forests with diversity in age classes, also have implications for the natural environment. By the time only young forest results from logging, many species might be lost. Key species have an important role in ecosystems (Paine, 1969).

Keystone species are essential to the resistance and resilience of forests to diverse stresses besides climate change (Noss, 2001), so their identification is needed to asses the ecosystems health. When present, such species indicate good conditions in the forest. Marten (*Martes americana*) is a good example. It uses mainly primary mature or over mature conifers, and mixed wood forests (Soutiere, 1979; Thompson and Harestad, 1994; Watt et al., 1996). Marten is considered indicative of the good health of the forest. Marten it is well distributed in North America from Alaska to Newfoundland (Strickland and Douglas, 1987), but its distribution is changing as a result of human impacts on ecosystems. The marten diet includes plants and animals (Thompson, 1991; Thompson and Curran, 1995) found in old growth forest but not in younger second growth forests (Thompson and Colgan, 1994). Although some studies reported this species can be active in second-growth forests, there is no evidence of their residence in such areas, and their preference is always to use old forests (Poole et al., 2004; Thompson and Curran, 1995). As a result of forest harvesting , population of marten in Newfoundland are decreasing at such a rate that now this species is classified as endangered in that Canadian province (COSEWIC Secretariat and Canadian Wildlife Service, 2004; Thompson and Curran, 1995). Examples like the marten illustrate the potential combined impact of harvesting and climate change on forests. Such indicators should be considered when setting harvesting objectives and monitoring forest conditions.

6.1.1.3 Location of useful stands

This study revealed a tendency for scarcer and more scattered harvestable timber over time. The rationale of this density analysis was based on location and yield per cell, and not on economic considerations. If other economic and logistic variables were to be included, like distances to the mill and accessibility, selection of candidate cells would, no doubt, deliver less timber than reported in this thesis. A full cost-benefit analysis may demonstrate that forestry operations will no longer be viable if such conditions emerge. Together, the stand age trend and the limited location of useful trees, point to a negative situation for the forest industry, with detrimental impacts on the local and regional economy.

6.1.1.4 Availability and deficit occurrence for timber

This study illustrates that climate change will impact timber availability. Total timber availability will be similar for the CGCM2 A22 and the baseline, but CCSRNIES A21 will provide less timber compared to the baseline (11 to 30 % less depending on the decade). Hardwood and softwood will have similar trends to total timber (see Sections 5.8.2 and 5.8.3).

Climate change will also impact the time when timber availability will no longer meet the industry demands. CGCM2 A22 and the baseline both reach this point of timber production deficit at year 2040, whereas CCSRNIES A21 will be in deficits 10 years earlier.

Various observations emerge. First, a shortage in timber will occur even without climate change (the baseline). Second, the warming scenario results in an increase in fire, which accelerates when the timber shortage occurs. The reduction in yield is the result of a liquidation of the natural forest and then planting young trees during the simulation, (the *falldown effect*[28] will affect timber availability during the simulation). This finding supports suggestions made by several authors about timber shortages about 20 years from now in Ontario (Ontario Ministry of Natural Resources, 2004b; Williams and Tanz, 1994).

The timber shortages occurring in all three scenarios are striking. Results indicate that a possible way to manage this forest under warming situations is setting harvesting goals that allow the forest to regenerate and provide a sustainable production. This methodology of this thesis can be used to assay different harvesting goals under different scenarios and devise adaptation options to climate change impacts.

Due to the lack of time and resources, it was not possible to simulate a longer period in this thesis. However, observed trends indicate an almost total reduction of mature timber not long after the 60 year simulation. Climate change will add stress to this situation in reaching deficits 10 years before than the baseline. This potentially hinders industry's long-term objectives in the area, as no timber will be available in the near future. The forest-dependent local community could be devastated by unemployment.

[28] Falldown effect has been defined as "a decline in timber supply or harvest level associated with the transition from harvesting the original stock of natural mature timber over one rotation to harvesting at a non declining level (typically equal to the annual increment) after conversion to a forest with a balanced age class structure." (Ministry of Forests, 2001).

This situation clearly points to the generation of an unhealthy ecosystem, and sustainable forest would be impossible under current management conditions. Planning the use of the forest use according to observed trends will help to modify those approaches and techniques that are not based on a long-term vision. This thesis will help in enrich the discussion and techniques in forest planning with a longer vision.

6.1.1.5 Potential impacts on protected areas

It is important to place the above impacts within a broader context and to consider impacts on protected areas. Given the predictions, local protected areas may be threatened in two ways. First, as timber availability diminishes, there may be increased pressure on protected areas that can contain valued harvestable timber. This pressure may result in conflict between the forestry and the protection sectors, and indirectly between different interests in the community that depends on those areas to survive. Second, climate change combined with harvesting, lead to fragmentation of the landscape matrix, whenever a protected area is located beside a managed forest (Quetico wilderness provincial park shares a border with the study area). For example, the dynamic illustrated in this study might be as follows. Fragmentation takes place as a result of logging and increased fire during a warming scenario. This process isolates protected areas from their surrounding landscape matrix, which impede species migration. Migration has been identified as one possible strategy available to species to adapt to climate change (Noss, 2001). A fragmented landscape will not provide this option. An additional aspect is the importance of having a representative system of protected areas. Current systems have been very difficult to construct and remain to be completed. Results indicate a very impacted forest landscape in terms of age (a resulting young forest) that does fulfill neither production nor sustainability in the future if current harvesting rates remain unchanged. Climate change can worsen the situation. Valuable ecosystems can be lost with this rate of fragmentation, and so the opportunity in being setting aside as protected. This can have negative consequences in the future for the whole ecosystem including humans. Currently, the Crown Forest Sustainability Act in Ontario regulates sustainable forest management in the province. Implementation is done through 4 manuals: the Forest Management Planning Manual (2004), the Forest Operations and Silviculture Manual, the

Forest Information Manual, and the Scaling Manual (Ontario Ministry of Natural Resources, 2002b). As indicated in Chapter 4, actual harvesting targets in the study area were used in the simulation run in this thesis. It was assumed here that those targets were set within that legal and operational framework. Results here indicate that at least within the frame of this thesis, sustainability looks difficult to achieve. Studies like this can help in assay different scenarios of harvesting under climate change, and help improving legislation and policy making for sustainability.

6.2 Inherent uncertainty in planning

There are no simple, mechanistic solutions to environmental problems, because we are dealing with complex systems (Mitchell, 2002). Many factors, actors and drivers are present in this inherently uncertain environment. One needs to consider this uncertainty in the planning context. Adaptive approaches (Holling, 1995) which include flexibility and willingness to learn from experience, need to be considered and adopted. Further studies need to examine the potential impact on local economy and social conflicts.

6.3 Conclusions

The main objective of this thesis was to analyze the role of landscape and land-use planning as tools for adapting to climate change. This work has aided in understanding of the links between land-use, landscape planning and climate change. Land-use has been described as the management regime humans impose to the land (Dale, 1997). Climate change and land-use change have been described as important drivers[29] of global change, so the understanding of the relationship between climate change and land-use becomes relevant in planning (Bloomfield and Pearson, 2000; Dale, 1997; IPCC, 2000). Land-use and landscape planning should consider climate warming and global change issues. Having this in mind, sets the foundation for using land-use and landscape planning as adaptation tools to climate change.

[29] Drivers are the forces that cause observed landscape changes (Bùrgi et al., 2004).

There was a counter intuitive increase in softwood over hardwood species during the simulations. Increase in fires promoted a jack pine increase. Species composition resulted also from the application of regeneration rules, simulating planting after harvesting.

Climate change will negatively affect the forestry sector in the Thunder Bay region in the medium term. Results and discussion in this thesis show a potential situation in a specific area of Ontario, nevertheless the approach used here can be used to analyze potential situations in other similar areas in the province and beyond.

Climate change will impact volume of timber available and the time when shortages will occur. This stress that can generate conflict among stakeholders, as production goals are likely to be affected. Information from this thesis is valuable for planning for the medium term and avoiding or mitigating potential land-use conflicts. Methodologies like those presented here can generate scenarios showing diverse alternatives, and can help to plan future forest management and land-use. Scenarios help in showing all stakeholders the potential situation. Promoting participative exercises with the scenarios generated such as those in this thesis, will help to generate more comprehensive plans that include the industry, society, and protection of the environment, thus helping to assure long-term sustainability.

Results for the modeling of this study suggest that current harvesting rates will impact timber availability in the near future under all scenarios used including the baseline. Alternative forest practices can be proposed to counteract potential shortages that can affect the industry and the community. Information from this thesis is relevant to help making an informed change in the use of the forests in the area if there is a sustainable vision that drives harvesting in north western Ontario. A universally young forest is not a healthy forest. Condition in forests that preserve essential ecological processes should be included in planning objectives and management. Healthy forests assure good business, employment, and conservation (May, 1998). Conserving healthy forests in the long term will assure business, employment and conservation in the long term as well.

Results indicate harvesting at the current rates will have more impact than climate change in the medium term.

It has been demonstrated how a managed landscape like the one analyzed here can change what is expected with climate change impacts at least in the medium term (e.g. species composition). If a forest is planned and managed in the light of climate change impacts knowledge from studies like this, land-use can be used to adapt (or mitigate) to those impacts.

6.4 Study contributions

The main contributions of this thesis are the following:

c) The application of BFOLDS in climate change impact studies.

d) The harvesting simulation applied jointly with BFOLDS, can be used as a reference to improve the model and could also be used with other models.

e) The algorithm named "Density Analysis" in this project offers an alternative and improved way to select stands for harvest during landscape simulations and to visualize where useful timber is located. It also has potential to be improved upon by including other variables (Access, mill location etc.) that could generate more realistic situations.

f) This study provides quantitative data to strategic planning in forest management and land-use, showing that boreal timber shortages may be exacerbated and hastened during global warming.

6.5 Some methodological issues

Weather data availability. Unfortunately there is not enough weather data (long- term, complete set of variables, and resolution) available for the study area. Even when using weather generators, weather variables (temperature, precipitation, wind, and humidity) and resolution (daily) needed by BFOLDS were difficult to generate. There is a need in funding for weather monitoring to generate reliable climate databases.

The climate database used in this exercise had daily information from 1963 to 2004 from April to October on average. Information from November to March was not available. Such situation could not represent the whole picture in longer simulations.

Due to time and resource constraint it was impossible to run more and longer simulations, or to conduct sensitivity analysis.

6.6 Planning recommendations

1) Include climate change impacts in forestry planning. This thesis has provided a basis to raise awareness of the issue of climate change on forestry, and the direct and indirect impacts on society and the natural environment.

2) Regional land use planning should bring together different stakeholders during the planning process in order to generate better future options. There never will be final responses to issues like the impact of climate change, so there should be social responsibility in making decisions about planning and management of ecosystems considering uncertainty. Different interests are in the game, so the more points of view are considered in the planning process the better plans will result.

3) Uncertainty is inherent to the issue analyzed in this thesis, but it should not be a pretext to wait until having better information to do planning. Planning should be informed by works like this thesis and other sources to tackle potential environmental degradation. This is the nature of adaptive planning.

6.7 Where do we go from here?

This thesis has provided a source of information to inform planning related to the impacts of climate change on forestry. The focus and scope are limited due to the lack of time and resources. The following aspects can be considered in future research:

a) Increase the length of simulation periods. This study offers several insights about the impacts of climate change and harvesting on forests in the region. Nevertheless, longer simulation can offer more information that can help to extrapolate findings to other areas with more certainty.

b) Consider other factors related to harvesting. As indicated before, the logging applied in this work included the location and yield per cell. Aspects like access or distance to the mill were not considered. A more complete picture can be generated if those aspects are included. Cost-benefit analysis can provide more realistic and useful information on the economic impacts of climate change.

c) Complete simulations in areas with different land-uses. For example, simulations that include both protected and managed areas would help us to better understand long-term dynamics in landscape change.

d) Consider human land-use factors. As indicated, BFOLDS does not include harvesting or other human-induced processes inside its functioning. The approach used in this thesis can help in developing a harvesting module to improve the model.

e) Incorporate landscape metrics into climate change/ land –use analysis. Landscape metrics can be used to determine broader changes in landscape pattern, as a result of climate change and human-induced processes. This analysis can help in physical planning and landscape restoration efforts.

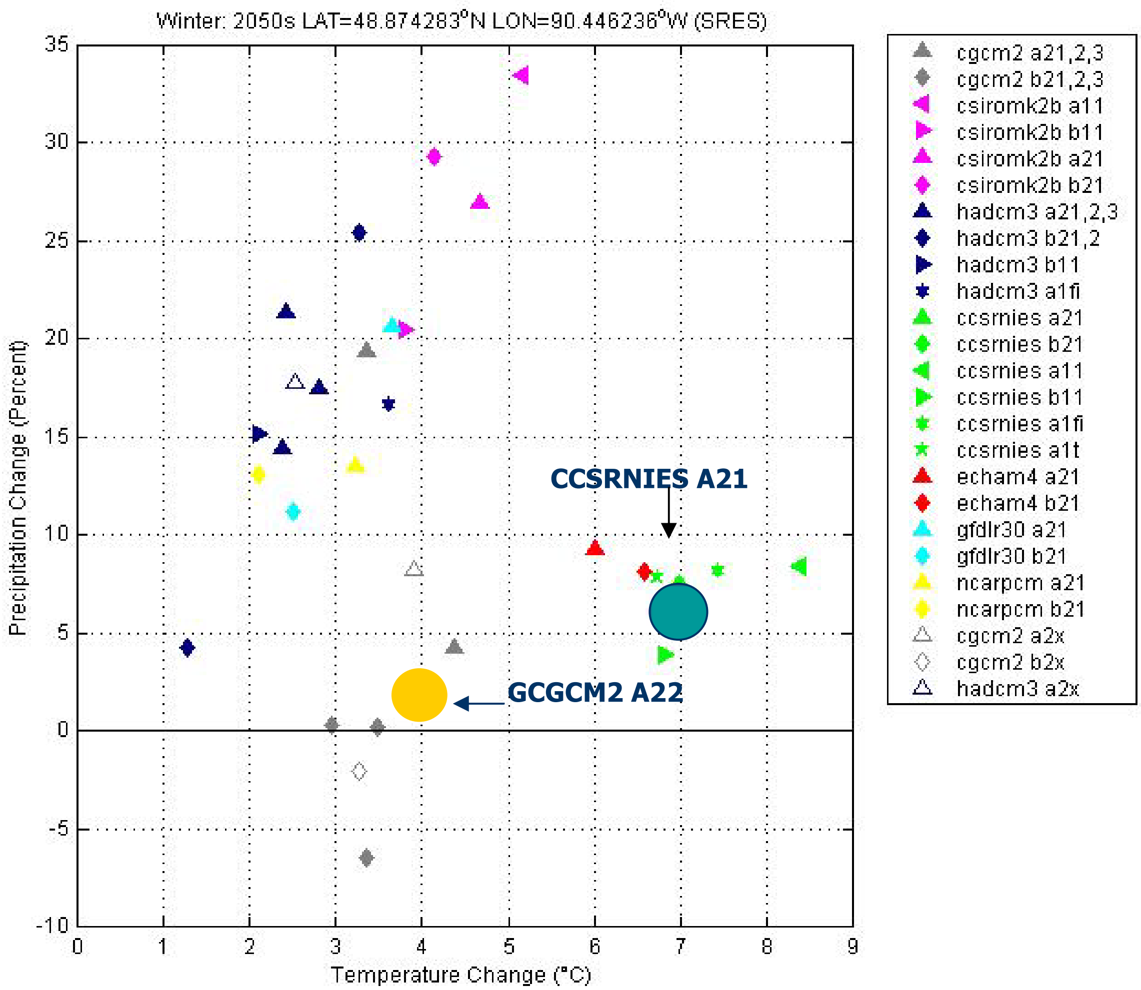
f) Generate scenarios with different harvesting and regeneration rules to get indications of more sustainable management regimes in the area and beyond.

g) The original thesis concept was to include adaptation workshops in the community of Thunder Bay. Result from this thesis would be used to show stakeholders in the area potential impacts of climate change. This would help in identifying sources of conflicts and synergies and to identify adaptation measures that the whole community might embrace. Due to insufficient funding and time, this thesis ended with the analysis and results of impacts of climate change in the area. Nevertheless it can be a starting point to develop those workshops in the future.

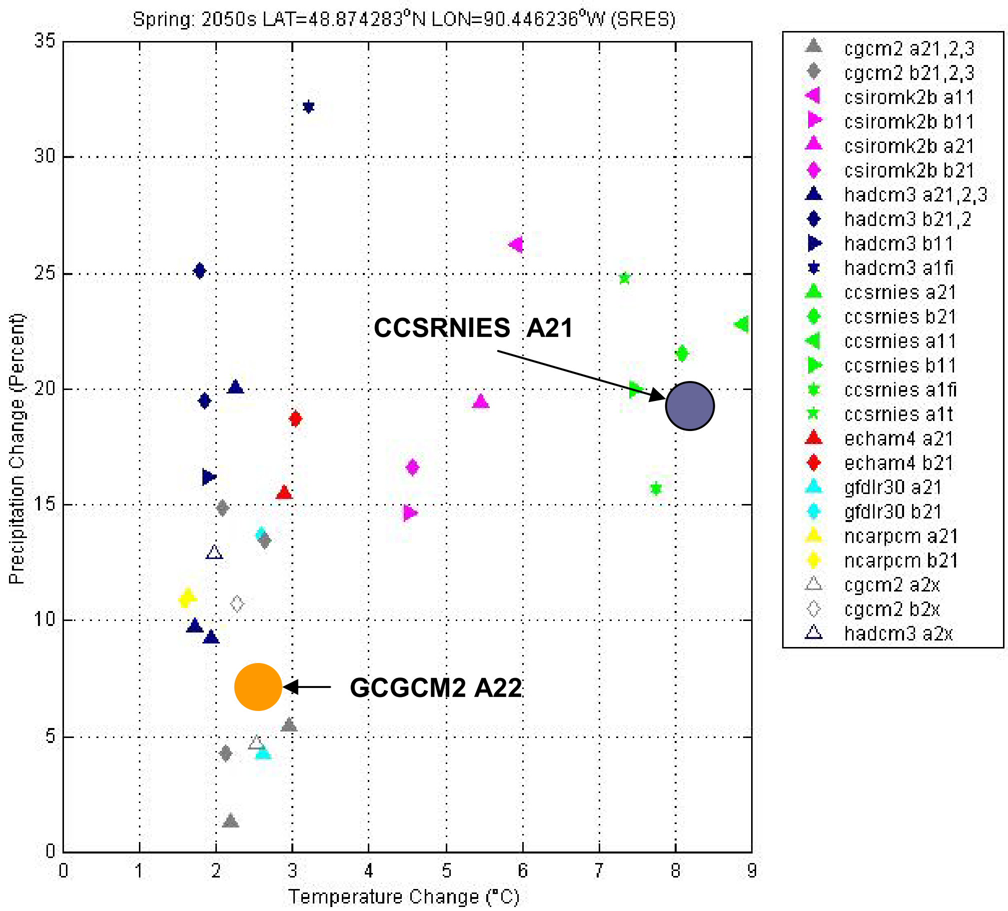
h) Add fire control to the simulations.

Appendix 1: Climate Change Scenarios Selection

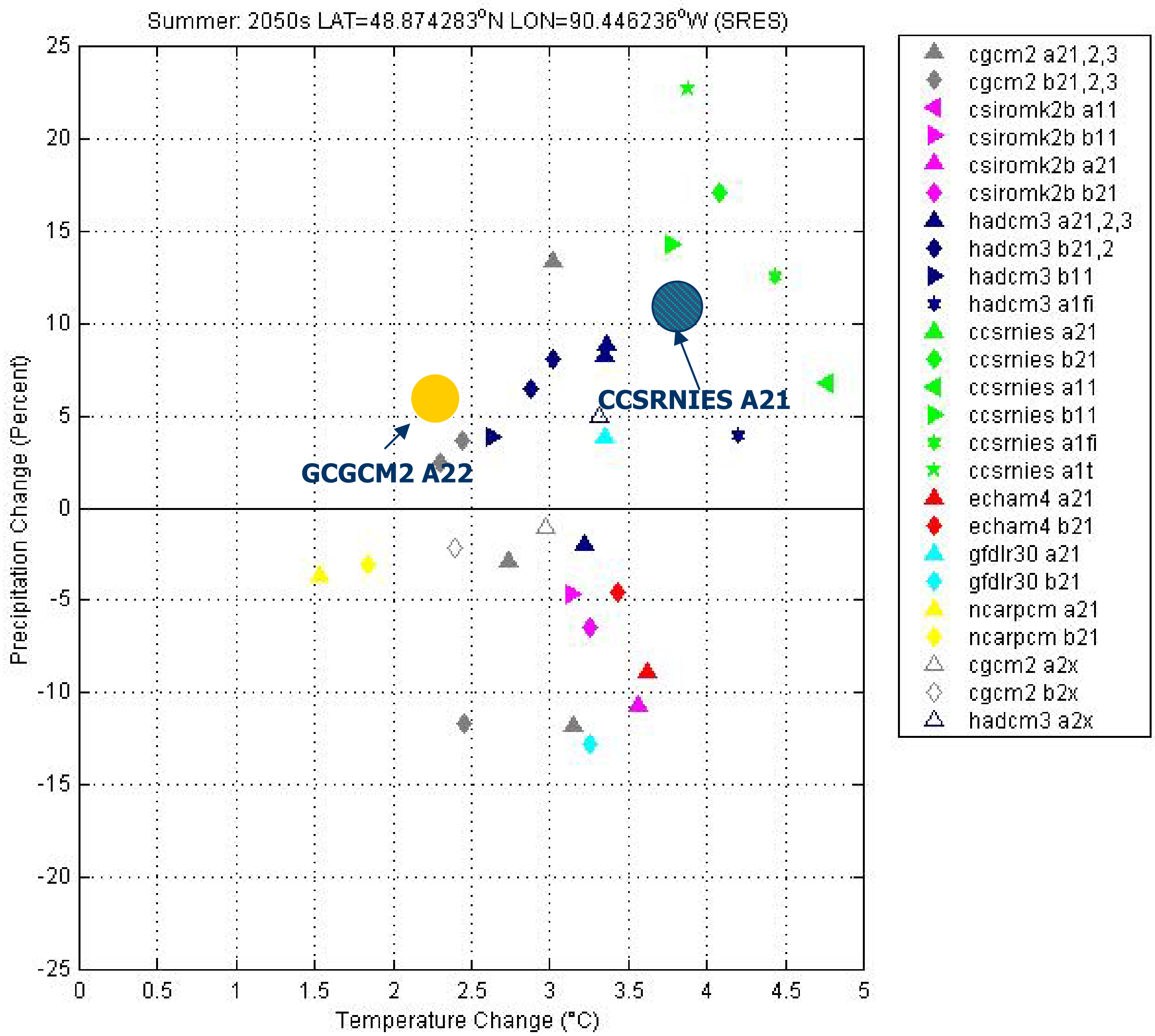
Climate change scenarios selection was based on the scatter plots available in the Canadian Climate Impact Scenarios web from the Canadian Institute for Climate Studies (Canadian Institute for Climate Studies, 2003). From there two scenarios (the CCSRNIES A21, and the GCGC A22) which were the more consistency in all four seasons of the year 2050 were chosen.



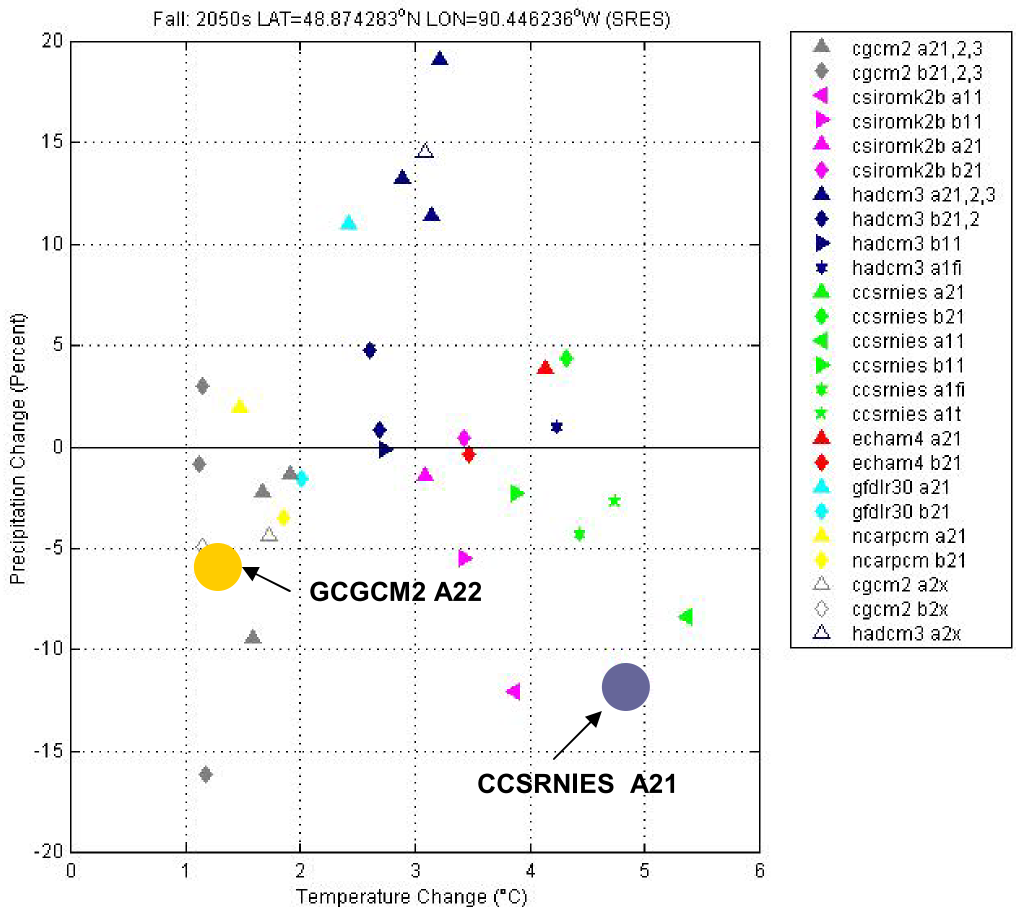
Winter 2050: diverse scenarios. Note how the GCGCM2 A22 is nearer the origin meaning less change, whereas the CCSRNIES A21 has one of the most pronounced changes in temperature and precipitation. (after Canadian Institute of Climate Studies, 2003).



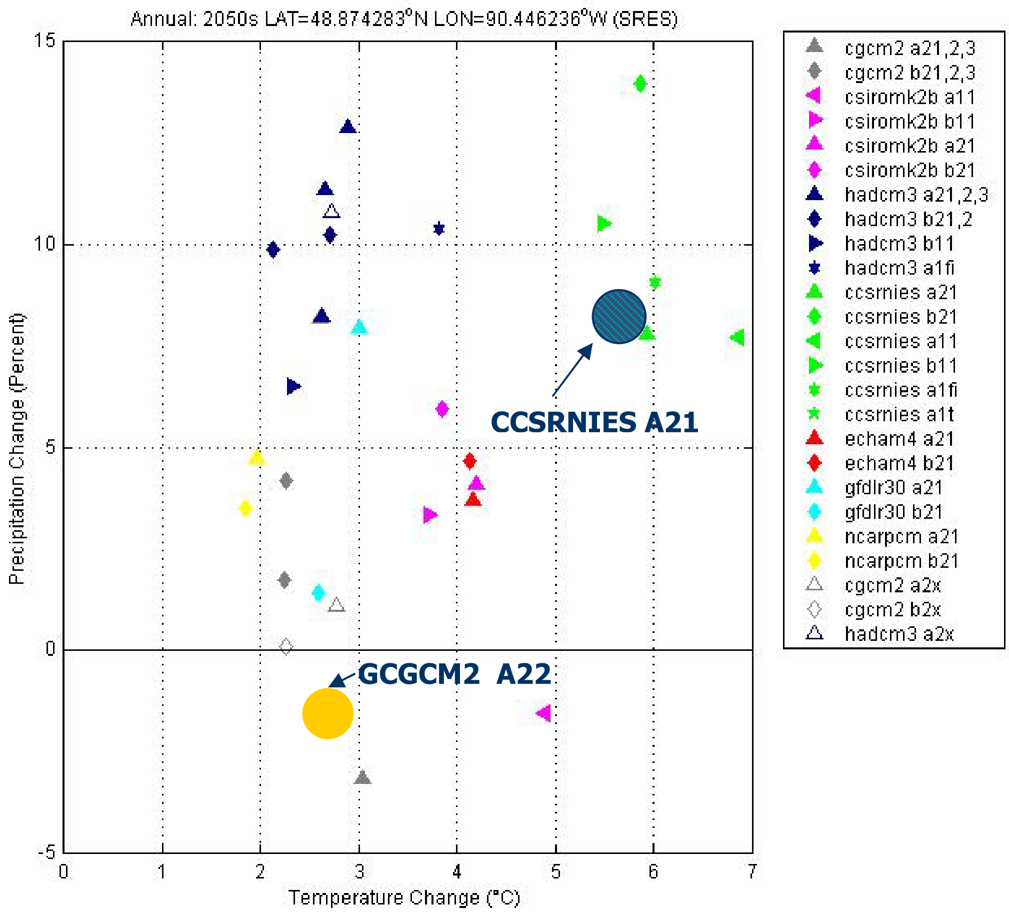
Spring 2050: diverse GCM experiments. Note how the GCGCM2 A22 is neaerr the origin, it means less change whereas the CCSRNIES A21 has one of the most pronounced changes in temperature and precipitation (after Canadian Institute of Climate Studies, 2003).



Summer 2050: diverse GCM experiments. Note how the GCGCM2 A22 is nearer the origin, it means less change whereas the CCSRNIES A21 has one of the most pronounced changes in temperature and precipitation (after Canadian Institute of Climate Studies, 2003).



Fall 2050: diverse GCM experiments. Note how the GCGCM2 A22 is nearer the origin, it means less change whereas the CCSRNIES A21 has one of the most pronounced changes in temperature and precipitation (after Canadian Institute of Climate Studies, 2003).



Year 2050: diverse GCM experiments. Note how the GCGCM2 A22 is nearer the origin, it means less change whereas the CCSRNIES A21 has one of the most pronounced changes in temperature and precipitation (after Canadian Institute of Climate Studies, 2003).

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Appendix 2. Equations used to calculate available timber

Equations derived to obtain Gross Merchantable Volume (m^3/ha), based on the Normal Yield Tables (Plonski, 1974)..

Species, Working Group (WG), and Low Operability Limit (LOL)	Site Class	Equation (y= Gross Merchantable Volume [m^3/ha]; x=Age [Years])	R^2 (between m3/ha and Age)
Species / *WG* / *LOL*: Poplar / PO / 55; Balsam poplar / PB / 55	0	$y = -0.0726x^2 + 13.398x - 217.09$	$R^2 = 0.999$
	1	$y = -0.0726x^2 + 13.398x - 217.09$	$R^2 = 0.999$
	2	$y = -0.065x^2 + 12.226x - 228.21$	$R^2 = 0.9956$
	3	$y = -0.0012x^3 + 0.181x^2 - 3.6455x + 0.7291$	$R^2 = 0.9924$
	4	$y = -0.0012x^3 + 0.181x^2 - 3.6455x + 0.7291$	$R^2 = 0.9924$
Species / *WG* / *LOL*: White Birch / BW / 60; Grey Birch / BG / 60	0	$y = -0.0408x^2 + 7.5032x - 139.1$	$R^2 = 0.9981$
	1	$y = -0.0408x^2 + 7.5032x - 139.1$	$R^2 = 0.9981$
	2	$y = -0.0005x^3 + 0.0497x^2 + 1.3531x - 49.975$	$R^2 = 0.9951$
	3	$y = -0.0005x^3 + 0.0656x^2 - 0.5395x - 17.341$	$R^2 = 0.9898$
	4	$y = -0.0005x^3 + 0.0656x^2 - 0.5395x - 17.341$	$R^2 = 0.9898$

Equations derived to obtain Gross Merchantable Volume (m^3/ha), based on the Normal Yield Tables (Plonski, 1974)..

Species, Working Group (WG), and Low Operability Limit (LOL)	Site Class	Equation (y= Gross Merchantable Volume [m^3/ha]; x=Age [Years])	R^2 (between m3/ha and Age)
Species* / *WG* / *LOL Hemlock / HE / 55 Ash / A / 55 Hard Maple / MH / 55 Yellow Birch / BY / 55 Red Oak / OR / 90 White Oak / OR / 90 Other. Hardwood / OH / 55	0	$y = -0.0125x^2 + 4.3248x - 81.445$	$R^2 = 0.9988$
	1	$y = -0.0125x^2 + 4.3248x - 81.445$	$R^2 = 0.9988$
	2	$y = -0.0099x^2 + 3.5056x - 77.618$	$R^2 = 0.9979$
	3	$y = -0.0085x^2 + 3.1534x - 94.16$	$R^2 = 0.9981$
	4	$y = -0.0085x^2 + 3.1534x - 94.16$	$R^2 = 0.9981$
Species* / *WG* / *LOL White Pine / PW / 60	0	$y = -0.0291x^2 + 9.3929x - 168.29$	$R^2 = 0.9912$
	1	$y = -0.0291x^2 + 9.3929x - 168.29$	$R^2 = 0.9912$
	2	$y = -0.0218x^2 + 7.3037x - 176.56$	$R^2 = 0.9964$
	3	$y = -0.0147x^2 + 5.1236x - 181.66$	$R^2 = 0.9993$
	4	$y = -0.0147x^2 + 5.1236x - 181.66$	$R^2 = 0.9993$

Equations derived to obtain Gross Merchantable Volume (m^3/ha), based on the Normal Yield Tables (Plonski, 1974).

Species, Working Group (WG), and Low Operability Limit (LOL)	Site Class	Equation (y= Gross Merchantable Volume [m^3/ha]; x=Age [Years])	R^2 (between m3/ha and Age)
Species / ***WG*** / ***LOL***: Red Pine / PR / 60	0	$y = 0.0003x^3 - 0.1084x^2 + 13.914x - 177.3$	$R^2 = 0.9981$
	1	$y = 0.0003x^3 - 0.1084x^2 + 13.914x - 177.3$	$R^2 = 0.9981$
	2	$y = 0.0003x^3 - 0.1015x^2 + 13.072x - 232.03$	$R^2 = 0.9938$
	3	$y = -0.0198x^2 + 5.3871x - 107.71$	$R^2 = 0.9894$
	4	$y = -0.0198x^2 + 5.3871x - 107.71$	$R^2 = 0.9894$

Appendix 3. Extensions and Avenue codes used to process harvesting and apply regeneration rules after logging in ArcView©.

1. Creates new fields in table (1)[30]

```
'*****************************************************************
'*Script to add a fields, Yield, WG, Age to the grid attribute table*
'*Rafael Munoz Marquez                                             *
'*May 17, 2004                                                     *
'*****************************************************************
theVTab = av.GetActiveDoc.GetVTab
  theVTab.SetEditable(true)
  theField = Field.Make("WG", #FIELD_DECIMAL, 3, 0)
  theVTab.addFields((Hobbs and Norton))
theField = Field.Make("Yield", #FIELD_DECIMAL, 12, 5)
  theVTab.addFields({theField})
theField = Field.Make("m3/ha", #FIELD_DECIMAL, 10, 10)
  theVTab.addFields({theField})
theField = Field.Make("Age", #FIELD_DECIMAL, 4, 0)
  theVTab.addFields({theField})
theField = Field.Make("Pr", #FIELD_DECIMAL, 2, 0)
  theVTab.addFields({theField})

theVTab.Calculate("Number.MakeRandom (0,10)", theVTab.FindField("Pr"))

'Clear selection
theBitmap = theVTab.GetSelection
  theVtab.UpdateSelection
  theVtab = theBitmap.ClearAll
```

2. Creates new fields in table (2)

```
'********************************************************************
'*Script to add a fields, "NWG", and "Nage" to the grid attribute table*
'*Rafael Munoz Marquez                                                *
'*May 23, 2004                                                        *
'********************************************************************

theVTab = av.GetActiveDoc.GetVTab
  theVTab.SetEditable(true)
  theField = Field.Make("NWG", #FIELD_DECIMAL, 3, 0)
  theVTab.addFields({theField})
theField = Field.Make("Nage", #FIELD_DECIMAL, 4, 0)
  theVTab.addFields({theField})
  theVTab.SetEditable(false)

'Clear selection
theBitmap = theVTab.GetSelection
  theVtab.UpdateSelection
  theVtab = theBitmap.ClearAll
```

3. Calculates yield both for hardwood and softwood

[30] Scripts that have the name of the author of this thesis when written by him; the other scripts were taken from other authors which are indicated. They are available also at http://arcscripts.esri.com/.

```
'***************************************************************************
'Rafael Munoz-Marquez
'March 2004
'Avenue script to calculate yield both for Softwood and hardwood (querying tables)
'****************************************************************************
'The following script unselect any record off the table

theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
theVtab.UpdateSelection
theVtab = theBitmap.ClearAll

'G 1
'SB,65,Sc0-------------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 11) and ([Age] >= 65) and ([Age] <= 150) and ([Sc]=0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate ("(((-0.0332*([Age]^2))+(9.1924*[Age])-195.32)* [Count])",
theVTab.FindField("Yield"))
End



'SB,65,Sc1
expr = "(([Wg] = 11) and ([Age] >= 65) and ([Age] <= 150) and ([Sc]=1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate ("(((-0.0172*([Age]^2))+(5.6928*[Age])- 162.5)* [Count])",
theVTab.FindField("Yield"))
End


'SB,65,Sc2
expr = "(([Wg] = 11) and ([Age] >= 65) and ([Age] <= 150) and ([Sc]=2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0194*([Age]^2))+(6.3018*[Age])- 290.11)* [Count])", theVTab.FindField("Yield"))
End

'SB,75,Sc3
expr = "(([Wg] = 11) and ([Age]>=75) and ([Age] <= 150) and ([Sc]=3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0191*([Age]^2))+(6.0889*[Age])- 343.65)*[Count])", theVTab.FindField("Yield"))
End

'SB,75,Sc4
expr = "(([Wg] = 11) and ([Age]>=75) and ([Age] <= 150) and ([Sc]=4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0191*([Age]^2))+(6.0889*[Age])- 343.65)* [Count])", theVTab.FindField("Yield"))
End



'SW,65,Sc0-------------------------------------------------------
expr = "(([Wg] = 10) and ([Age] >= 65) and ([Age] <= 150) and ([Sc]=0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
```

```
theVTab.Calculate ("(((-0.0332*([Age]^2))+(9.1924*[Age])- 195.32 *[Count])",
theVTab.FindField("Yield"))
End


'SW,65,Sc1
expr = "(([Wg] = 10) and ([Age] >= 65) and ([Age] <= 150) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0172*([Age]^2))+(5.6928*[Age])- 162.5)*[Count])", theVTab.FindField("Yield"))
End


'SW,65,Sc2
expr = "(([Wg] = 10) and ([Age] >= 65) and ([Age] <= 150) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0194*([Age]^2))+(6.3018*[Age])- 290.11)* [Count])", theVTab.FindField("Yield"))
End

'SW,75,Sc3
expr = "(([Wg] = 10) and ([Age]>=75) and ([Age] <= 150) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0191*([Age]^2))+(6.0889*[Age])-343.65)*[Count])", theVTab.FindField("Yield"))
End

'SW,75,Sc4
expr = "(([Wg] = 10) and ([Age]>=75) and ([Age] <= 150) and ([Sc]=4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0191*([Age]^2))+(6.0889*[Age])-343.65)*[Count])", theVTab.FindField("Yield"))
End


'BF,45,Sc0------------------------------------------------------
expr = "(([Wg] = 1) and ([Age] >= 45) and ([Age] <= 150) and ([Sc]=0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate ("(((-0.0332*([Age]^2))+(9.1924*[Age])-195.32)*[Count])",
theVTab.FindField("Yield"))
End


'BF,45,Sc1
expr = "(([Wg] = 1) and ([Age] >= 45) and ([Age] <= 150) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0172*([Age]^2))+(5.6928*[Age])-162.5)*[Count])", theVTab.FindField("Yield"))
End

'BF,60,Sc2
expr = "(([Wg] = 1) and ([Age] >= 60) and ([Age] <= 150) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0194*([Age]^2))+(6.3018*[Age])-290.11)*[Count])", theVTab.FindField("Yield"))
End
```

```
'BF,75,Sc3
expr = "(([Wg] = 1) and ([Age] >= 75) and ([Age] <= 150) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0191*([Age]^2))+(6.0889*[Age])-343.65)*[Count])", theVTab.FindField("Yield"))
End

'BF,75,Sc4
expr = "(([Wg] = 1) and ([Age] >=75) and ([Age] <= 150) and ([Sc]=4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0191*([Age]^2))+(6.0889*[Age])-343.65)*[Count])", theVTab.FindField("Yield"))
End


'CE, HE,90,Sc0
expr = "(([Wg] = 15) and ([Age] >= 75) and ([Age] <= 150) and ([Sc]=0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate ("(((-0.0332*([Age]^2))+(9.1924*[Age])-195.32)*[Count])",
theVTab.FindField("Yield"))
End


'CE,HE, 90,Sc1
expr = "(([Wg] = 15) and ([Age] >= 75) and ([Age] <= 150) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0172*([Age]^2))+(5.6928*[Age])-162.5)*[Count])", theVTab.FindField("Yield"))
End

'CE,HE, 90,Sc2
expr = "(([Wg] = 15) and ([Age] >= 75) and ([Age] <= 150) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate ("(((-0.0194*([Age]^2))+(6.3018*[Age])-290.11)*[Count])",
theVTab.FindField("Yield"))
End

'CE,HE,Sc3
expr = "(([Wg] = 15) and ([Age] >= 75) and ([Age] <= 150) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0191*([Age]^2))+(6.0889*[Age])-343.65)*[Count])", theVTab.FindField("Yield"))
End

'CE,HE,Sc4
expr = "(([Wg] = 15) and ([Age] >= 75) and ([Age] <= 150) and ([Sc]=4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection

if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0191*([Age]^2))+(6.0889*[Age])-343.65)*[Count])", theVTab.FindField("Yield"))
End



'LA,90,Sc0
expr = "(([Wg] = 6) and ([Age] >= 90) and ([Age] <= 150) and ([Sc]=0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
```

```
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate ("(((-0.0332*([Age]^2))+(9.1924*[Age])-195.32)*[Count])",
theVTab.FindField("Yield"))
End


'LA,90,Sc1
expr = "(([Wg] = 6) and ([Age] >= 90) and ([Age] <= 150) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0172*([Age]^2))+(5.6928*[Age])-162.5)*[Count])", theVTab.FindField("Yield"))
End

'LA,90,Sc2
expr = "(([Wg] = 6) and ([Age] >= 90) and ([Age] <= 150) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0194*([Age]^2))+(6.3018*[Age])-290.11)*[Count])", theVTab.FindField("Yield"))
End

'LA,90,Sc3
expr = "(([Wg] = 6) and ([Age] >= 90) and ([Age] <= 150) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0191*([Age]^2))+(6.0889*[Age])-343.65)*[Count])", theVTab.FindField("Yield"))
End


'LA,90,Sc4
expr = "(([Wg] = 6) and ([Age] >= 90) and ([Age] <= 150) and ([Sc]=4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0191*([Age]^2))+(6.0889*[Age])-343.65)*[Count])", theVTab.FindField("Yield"))
End



'G2
'PJ,65,Sc0
expr = "(([Wg] = 8) and ([Age] >=65) and ([Age]<= 100) and ([Sc] = 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0573*([Age]^2))+(9.5927*[Age])-146.54)*[Count])", theVTab.FindField("Yield"))

End



'PJ,65,Sc1
expr = "(([Wg] = 8) and ([Age] >=65) and ([Age]<= 100) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0573*([Age]^2))+(9.5927*[Age])-146.54)*[Count])", theVTab.FindField("Yield"))
End


'PJ,65,Sc2
expr = "(([Wg] = 8) and ([Age] >=65) and ([Age]<= 100) and ([Sc] = 2))"
```

```
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0372*([Age]^2))+(7.0448*[Age])-129.55)*[Count])", theVTab.FindField("Yield"))
End

'PJ,65,Sc3
expr = "(([Wg] = 8) and ([Age] >=65) and ([Age]<= 100) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0254*([Age]^2))+(5.3293*[Age])-125.31)*[Count])", theVTab.FindField("Yield"))
End


'PJ,65,Sc4
expr = "(([Wg] = 8) and ([Age] >=65) and ([Age]<= 100) and ([Sc] = 4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0254*([Age]^2))+(5.3293*[Age])-125.31)*[Count])", theVTab.FindField("Yield"))
End



'G6

'PW,60,Sc0-------
expr = "(( [Wg] = 13) and ([Age] >=60) and ([Age] <= 190) and ([Sc] = 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0291*([Age]^2))+(9.3929*[Age])-168.29)*[Count])", theVTab.FindField("Yield"))
End


'PW,60,Sc1-------
expr = "(( [Wg] = 13) and ([Age] >=60) and ([Age] <= 190) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0291*([Age]^2))+(9.3929*[Age])-168.29)*[Count])", theVTab.FindField("Yield"))
End


'PW,60,Sc2
expr = "(( [Wg] = 13) and ([Age] >=60) and ([Age] <= 190) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0218*([Age]^2))+(7.3037*[Age])-176.56)*[Count])", theVTab.FindField("Yield"))
End


'PW,60,Sc3
expr = "(( [Wg] = 13) and ([Age] >=60) and ([Age] <= 190) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0147*([Age]^2))+(5.1236*[Age])-181.66)*[Count])", theVTab.FindField("Yield"))
End

'PW,60,Sc4
expr = "(( [Wg] = 13) and ([Age] >=60) and ([Age] <= 190) and ([Sc] = 4))"
```

```
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0147*([Age]^2))+(5.1236*[Age])-181.66)*[Count])", theVTab.FindField("Yield"))
End

'G7
'PR,60,Sc0-------
expr = "(([Wg] = 12) and ([Age]>=60) and ([Age] <= 190) and ([Sc] = 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((0.0003*([Age]^3))-(0.1084*([Age]^2))+(13.914*[Age])-177.3)*[Count])",
theVTab.FindField("Yield"))
End


'PR,60,Sc1-------
expr = "(([Wg] = 12) and ([Age]>=60) and ([Age] <= 190) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((0.0003*([Age]^3))-(0.1084*([Age]^2))+(13.914*[Age])-177.3)*[Count])",
theVTab.FindField("Yield"))
End



'PR,60,Sc2
expr = "(([Wg] = 12) and ([Age]>=60) and ([Age] <= 190) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((0.0003*([Age]^3))-(0.1015*([Age]^2))+(13.072*[Age])-232.03)*[Count])",
theVTab.FindField("Yield"))
End


'PR,60,Sc3
expr = "(([Wg] = 12) and ([Age] >=60) and ([Age] <= 190) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0198*([Age]^2))+(5.3871*[Age])-107.71)*[Count])", theVTab.FindField("Yield"))
End

'PR,60,Sc4
expr = "(([Wg] = 12) and ([Age] >=60) and ([Age] <= 190) and ([Sc] = 4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0198*([Age]^2))+(5.3871*[Age])-107.71)*[Count])", theVTab.FindField("Yield"))
End


'G3
'PO,55,Sc0-------
expr = "(([Wg] = 14) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0726*([Age]^2))+(13.398*[Age])-217.09)*[Count])", theVTab.FindField("Yield"))
End
```

```
'PO,55,Sc1
expr = "(([Wg] = 14) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0726*([Age]^2))+(13.398*[Age])-217.09)*[Count])", theVTab.FindField("Yield"))
End


'PO,55,Sc2
expr = "(([Wg] = 14) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.065*([Age]^2))+(12.226*[Age])-228.21)*[Count])", theVTab.FindField("Yield"))
End

'PO,55,Sc3
expr = "(([Wg] = 14) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0012*([Age]^3))+(0.181*([Age]^2))-(3.6455*[Age])+0.7291)*[Count])",
theVTab.FindField("Yield"))
End

'PO,55,Sc4
expr = "(([Wg] = 14) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0012*([Age]^3))+(0.181*([Age]^2))-(3.6455*[Age])+0.7291)*[Count])",
theVTab.FindField("Yield"))
End


'PB,55,Sc0
expr = "(([Wg] = 9) and ([Age] >=55) and ([Age] <= 100) ([Sc] = 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0726*([Age]^2))+(13.398*[Age])-217.09)*[Count])", theVTab.FindField("Yield"))
End


'PB,55,Sc1-------
expr = "(([Wg] = 9) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0726*([Age]^2))+(13.398*[Age])-217.09)*[Count])", theVTab.FindField("Yield"))
End


'PB,55,Sc2
expr = "(([Wg] = 9) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.065*([Age]^2))+(12.226*[Age])-228.21)*[Count])", theVTab.FindField("Yield"))
End

'PB,55,Sc3
expr = "(([Wg] = 9) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 3))"
```

```
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("((-0.0012*([Age]^3))+(0.181*([Age]^2))-(3.6455*[Age])+0.7291)*[Count])",
theVTab.FindField("Yield"))
End

'PB,55,Sc4
expr = "(([Wg] = 9) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0012*([Age]^3))+(0.181*([Age]^2))-(3.6455*[Age])+0.7291)*[Count])",
theVTab.FindField("Yield"))
End


'G4
'AH,55,Sc0-------
expr = "(([Wg] = 5) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0125*([Age]^2))+(4.3248*[Age])-81.445)*[Count])", theVTab.FindField("Yield"))
End


'AH,55,Sc1-------
expr = "(([Wg] = 5) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0125*([Age]^2))+(4.3248*[Age])-81.445)*[Count])", theVTab.FindField("Yield"))
End


'AH,55,Sc2
expr = "(([Wg] = 5) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0099*([Age]^2))+(3.5056*[Age])-77.618)*[Count])", theVTab.FindField("Yield"))
End

'AH,55,Sc3
expr = "(([Wg] = 5) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0085*([Age]^2))+(3.1534*[Age])-94.16)*[Count])", theVTab.FindField("Yield"))
End


'AH,55,Sc4
expr = "(([Wg] = 5) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0085*([Age]^2))+(3.1534*[Age])-94.16)*[Count])", theVTab.FindField("Yield"))
End

'MH,55,Sc0-------
expr = "(([Wg] = 2) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
```

```
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0125*([Age]^2))+(4.3248*[Age])-81.445)*[Count])", theVTab.FindField("Yield"))
End

'MH,55,Sc1-------
expr = "(([Wg] = 2) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0125*([Age]^2))+(4.3248*[Age])-81.445)*[Count])", theVTab.FindField("Yield"))
End

'MH,55,Sc2
expr = "(([Wg] = 2) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0099*([Age]^2))+(3.5056*[Age])-77.618)*[Count])", theVTab.FindField("Yield"))
End

'MH,55,Sc3
expr = "(([Wg] = 2) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0085*([Age]^2))+(3.1534*[Age])-94.16)*[Count])", theVTab.FindField("Yield"))
End

'MH,55,Sc4
expr = "(([Wg] = 2) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0085*([Age]^2))+(3.1534*[Age])-94.16)*[Count])", theVTab.FindField("Yield"))
End


'BY,55,Sc0-------
expr = "(([Wg] = 3) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0125*([Age]^2))+(4.3248*[Age])-81.445)*[Count])", theVTab.FindField("Yield"))
End


'BY,55,Sc1-------
expr = "(([Wg] = 3) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0125*([Age]^2))+(4.3248*[Age])-81.445)*[Count])", theVTab.FindField("Yield"))
End


'BY,55,Sc2
expr = "(([Wg] = 3) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0099*([Age]^2))+(3.5056*[Age])-77.618)*[Count])", theVTab.FindField("Yield"))
End
```

```
'BY,55,Sc3
expr = "(([Wg] = 3) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0085*([Age]^2))+(3.1534*[Age])-94.16)*[Count])", theVTab.FindField("Yield"))
End


'BY,55,Sc4
expr = "(([Wg] = 3) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0085*([Age]^2))+(3.1534*[Age])-94.16)*[Count])", theVTab.FindField("Yield"))
End


'BW,60,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg]= 3 ) and ([Age]>=60) and ([Age] <= 90) and ([Sc]=0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0408*([Age]^2))+(7.5032*[Age])-139.1)*[Ha])", theVTab.FindField("Yield"))
End

'BW,60,Sc1-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg]= 3) and ([Age]>=60) and ([Age] <= 90) and ([Sc]=1))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0408*([Age]^2))+(7.5032*[Age])-139.1)*[Ha])", theVTab.FindField("Yield"))
End


'BW,60,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg]= 3) and ([Age] >=60) and ([Age] <= 90) and ([Age] <=90) and ([Sc]=2))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0005*([Age]^3))+(0.0497*([Age]^2)+(1.3531*[Age])-49.975)*[Ha])",
theVTab.FindField("Yield"))
End

'BW,65,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 3) and ([Age] >= 65) and ([Age] <= 90) and ([Age] <= 110) and ([Sc] = 3))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0005*([Age]^3))+(0.0656*([Age]^2))-(0.5395*[Age])-17.341)*[Ha])",
theVTab.FindField("Yield"))
End

'BW,65,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
```

```
expr = "(([Wg] = 3) and ([Age] >= 65) and ([Age] <= 90) and ([Age] <= 110) and ([Sc] = 4))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_NEW)
theVTab.UpdateSelection
if (thevtab.GetNumSelRecords > 0) Then
theVTab.Calculate
("(((-0.0005*([Age]^3))+(0.0656*([Age]^2))-(0.5395*[Age])-17.341)*[Ha])",
theVTab.FindField("Yield"))
End

'The following code updates m3/ha
theVTab.Calculate("[Yield] / [Count]", theVTab.FindField("m3/ha"))
```

4. Applies regeneration rules after logging

```
'**********************************************************************
'*This script changes field value after BFOLDS run to simple and      *
'complex succession rules                                             *
'*Rafael Munoz Marquez                                                *
'*May 23, 2004                                                        *
'**********************************************************************


'WG4
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 4))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("4", theVtab.findfield("NWG"))
end

'PO
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 14))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("14", theVtab.findfield("NWG"))
end


'PB
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 9))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("9", theVtab.findfield("NWG"))
end


'HE
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 15))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("15", theVtab.findfield("NWG"))
end

'AH
theVtab = av.GetActiveDoc.GetVtab
```

```
theBitmap = theVtab.GetSelection
expr = "(([WG] = 5))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("5", theVtab.findfield("NWG"))
end


'MH
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 2))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("2", theVtab.findfield("NWG"))
end

'BY
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 3))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("3", theVtab.findfield("NWG"))
end

'SW
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 10))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("10", theVtab.findfield("NWG"))
end

'LA
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 6))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("6", theVtab.findfield("NWG"))
end

'This script changes field
'value after BFOLDS run to complex succession rules

theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 12))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("12", theVtab.findfield("NWG"))
end



'PR2
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 12) and ([Pr] <= 5))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("13", theVtab.findfield("NWG"))
```

```
end

'PW1
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 13))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("13", theVtab.findfield("NWG"))
end

'PW2
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 13) and ([Pr] >=6))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("12", theVtab.findfield("NWG"))
end

'BW1
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 3))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("3", theVtab.findfield("NWG"))
end


'BW2
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 3) and ([Pr] <= 5) and ([Edaphic8] = 2))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("8", theVtab.findfield("NWG"))
end


'BW3
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 3) and ([Pr] >=6) and ([Edaphic8] = 2))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("12", theVtab.findfield("NWG"))
end

'BW4
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 3) and ([edaphic8] = 1))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("10", theVtab.findfield("NWG"))
end



'CE1
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 15))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
```

```
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("15", theVtab.findfield("NWG"))
end


'CE1
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 15) and ([Moisture8] <> 5))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("1", theVtab.findfield("NWG"))
end



'CE2
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 15) and ([Edaphic8]= 4) and ([Moisture8] = 5))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("11", theVtab.findfield("NWG"))
end


'BF1
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 1))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("1", theVtab.findfield("NWG"))
end



'BF2
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 1) and (([Moisture8]= 1) or ([Moisture8] = 2)))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("14", theVtab.findfield("NWG"))
end


'BF3
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 1) and (([Moisture8]= 3) or ([Moisture8] = 4)))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("14", theVtab.findfield("NWG"))
end


'SB1
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 11))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("11", theVtab.findfield("NWG"))
```

```
end



'SB2
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 11) and (([Moisture8] = 1) or ([Moisture8] = 2)))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("8", theVtab.findfield("NWG"))
end



'SB3
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 11) and (([Moisture8] = 2) or ([Moisture8] = 3)) and ([Pr] <= 5))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("8", theVtab.findfield("NWG"))
end


'SB4
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 11) and (([Moisture8] = 2) or ([Mositure8] = 3)) and ([Pr] >= 6))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("11", theVtab.findfield("NWG"))
end


'PJ1
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 8))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("8", theVtab.findfield("NWG"))
end



'PJ2
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 8) and (([Moisture8] = 3) or ([Moisture8] = 4)))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("11", theVtab.findfield("NWG"))
end



'PJ3
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 8) and (([Moisture8] = 2) or ([Moisture8] = 3)) and ([Pr] >= 6))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("11", theVtab.findfield("NWG"))
end
```

```
'Brush/alder
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 31))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("31", theVtab.findfield("NWG"))
end

'SpruceBog
theVtab = av.GetActiveDoc.GetVtab
theBitmap = theVtab.GetSelection
expr = "(([WG] = 32))"
theVtab.Query(expr,theBitmap,#VTAB_SELTYPE_NEW)
theVtab.UpdateSelection
if(theVtab.GetNumSelRecords > 0) then
theVtab.Calculate ("32", theVtab.findfield("NWG"))
end
```

5. Selects Hardwoods to be potentially allocated

```
'*****************************************************************************
'*Rafael Muñoz-Márquez                                                       *
'*This Script selects all HARDWOODS allocated to be harvested                *
'*March 21, 2004                                                             *
******************************************************************************

'The following script unselect any record off the table

theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
theVtab.UpdateSelection
theVtab = theBitmap.ClearAll

'Selects stands Hardwood


'HardWood (G3, G4, G5)
'G3
'PO,55,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 14) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PO,55,Sc1------------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 14) and ([Age] >= 55) and ([Age] <= 100) and ([Sc]=1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PO,55,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 14) and ([Age] >= 55) and ([Age] <= 100) and ([Sc]=2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'PO,55,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 14) and ([Age]>=55) and ([Age] <= 100) and ([Sc]=3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'PO,55,Sc4
```

```
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 14) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PB,55,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 9) and ([Age] >=55) and and ([Age] <= 100) ([Sc] = 0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'PB,55,Sc1-----------------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 9) and ([Age] >= 55) and ([Age] <= 100) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PB,55,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 9) and ([Age] >= 55) and ([Age] <= 100) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PB,55,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 9) and ([Age]>=55) and ([Age] <= 100) and ([Sc] = 3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PB,55,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 9) and ([Age] >=55) and ([Age] <= 100) and ([Sc] = 4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'BW,60,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg]=""BW"") and ([Age]>=60) and ([Age] <= 90) and ([Sc]=0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'BW,60,Sc1-----------------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""BW"") and ([Age] >= 60) and ([Age] <= 90) and ([Sc] = 1) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'BW,60,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""BW"") and ([Age] >= 60) and ([Age] <= 90) and ([Sc]=2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'BW,60,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""BW"") and ([Age] >= 60) and ([Age] <= 90) and ([Sc] = 3) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'BW,60,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""BW"") and ([Age] >= 60) and ([Age] <= 90) and ([Sc] = 4) and ([Yield] >
0))"
```

```
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'AH,55,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 5) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'AH,55,Sc1-----------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 5) and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'AH,55,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 5) and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'AH,90,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 5) and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'AH,55,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 5) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'MH,55,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 2) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'MH,55,Sc1-----------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 2) and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'MH,55,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 2) and ([Age] >= 5) and ([Age] <= 190) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'MH,55,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 2) and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'MH,55,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 2) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'BY,55,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 3) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 0) and ([Yield] > 0))"
```

```
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'BY,55,Sc1-------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 3) and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'BY,55,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 3) and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'BY,55,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 3) and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'BY,55,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 3) and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'OR,90,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""OR"") and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 0) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'OR,90,Sc1-------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""OR"") and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 1) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'OR,90,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""OR"") and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 2) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'OR,90,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""OR"") and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 3) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)



'OR,90,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""OR"") and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 4) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'OH,55,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
```

```
expr = "(([Wg] = ""OH"") and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 0) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'OH,55,Sc1------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""OH"") and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 1) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'OH,55,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""OH"") and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 2) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'OH,55,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""OH"") and ([Age] >= 55) and ([Age] <= 190) and ([Sc] = 3) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'OH,55,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = ""OH"") and ([Age] >=55) and ([Age] <= 190) and ([Sc] = 4) and ([Yield] >
0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


theVTab.UpdateSelection
```

6. Selects Softwoods to be potenltially allocated

```
'*****************************************************************************
'*Rafael Muñoz-Márquez                                                        *
'*This Script selects all SOFTWOODS stands allocated to be potentially harvested
*
'*March 21, 2004                                                              *
******************************************************************************

'The following script unselect any record of the table

theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
theVtab.UpdateSelection
theVtab = theBitmap.ClearAll


'Selects stands from groups of softwood

'SoftWood (G1, G2, G6, G7)
'G 1
'SB,65,Sc0-------------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 11) and ([Age] >= 65) and ([Age] <= 150) and ([Sc]=0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'SB,65,Sc1-------------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
```

```
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 11) and ([Age] >= 65) and ([Age] <= 150) and ([Sc]=1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'SB,65,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 11) and ([Age] >= 65) and ([Age] <= 150) and ([Sc]=2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'SB,75,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 11) and ([Age]>=75) and ([Age] <= 150) and ([Sc]=3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'SB,75,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 11) and ([Age]>=75) and ([Age] <= 150) and ([Sc]=4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'SW,65,Sc0-----------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 10) and ([Age] >= 65) and ([Age] <= 150) and ([Sc]=0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'SW,65,Sc1-------------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 10) and ([Age] >= 65) and ([Age] <= 150) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'SW,65,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 10) and ([Age] >= 65) and ([Age] <= 150) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'SW,75,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 10) and ([Age]>=75) and ([Age] <= 150) and ([Sc] = 3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'SW,75,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 10) and ([Age]>=75) and ([age] <= 150) and ([Sc]=4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)



'BF,45,Sc0-----------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 1) and ([Age] >= 45) and ([Age] <= 150) and ([Sc]=0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'BF,45,Sc1-------------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 1) and ([Age] >= 45) and ([Age] <= 150) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'BF,60,Sc2
```

```
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 1) and ([Age] >= 60) and ([Age] <= 150) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'BF,75,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 1) and ([Age] >= 75) and ([Age] <= 150) and ([Sc]=3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'BF,75,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 1) and ([Age] >=75) and ([Age] <= 150) and ([Sc]=4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'CE,90,Sc0-----------------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 15) and ([Age] >= 75) and ([Age] <= 150) and ([Sc]=0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'CE,90,Sc1----------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 15) and ([Age] >= 75) and ([Age] <= 150) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'CE,90,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 15) and ([Age] >= 75) and ([Age] <= 150) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'CE,90,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 15) and ([Age] >= 75) and ([Age] <= 150) and ([Sc] = 3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'CE,90,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 15) and ([Age] >= 75) and ([Age] <= 150) and ([Sc]=4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'LA,90,Sc0-----------------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 6) and ([Age] >= 90) and ([Age] <= 150) and ([Sc]=0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'LA,90,Sc1----------------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 6) and ([Age] >= 90) and ([Age] <= 150) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'La,90,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 6) and ([Age] >= 90) and ([Age] <= 150) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'LA,90,Sc3
```

```
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 6) and ([Age] >= 90) and ([Age] <= 150) and ([Sc] = 3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'LA,90,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 6) and ([Age] >= 90) and ([Age] <= 150) and ([Sc]=4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PJ,65,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 8) and ([Age] >=65) and ([Age]<= 100) and ([Sc] = 0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'PJ,65,Sc1-----------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 8) and ([Age] >= 65) and ([Age]<= 100) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PJ,65,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 8) and ([Age] >= 65) and ([Age]<= 100) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'PJ,65,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 8) and ([Age] >= 65) and ([Age]<= 100) and ([Sc] = 3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'PJ,65,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 8) and ([Age] >=65) and ([Age]<= 100) and ([Sc] = 4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PW,60,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(( [Wg] = 13) and ([Age] >=60) and ([Age] <= 190) and ([Sc] = 0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PW,60,Sc1-----------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 13) and ([Age] >= 60) and ([Age] <= 190) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PW,60,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 13) and ([Age] >= 60) and ([Age] <= 190) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'PW,60,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 13) and ([Age] >= 60) and ([Age] <= 190) and ([Sc] = 3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'PW,60,Sc4
```

```
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(( [Wg] = 13) and ([Age] >=60) and ([Age] <= 190) and ([Sc] = 4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PR,60,Sc0-------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 12) and ([Age]>=60) and ([Age] <= 190) and ([Sc] = 0) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'PR,60,Sc1-----------------------------------------------
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 12) and ([Age] >= 60) and ([Age] <= 190) and ([Sc] = 1) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PR,60,Sc2
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 12) and ([Age] >= 60) and ([Age] <= 190) and ([Sc] = 2) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

'PR,60,Sc3
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 12) and ([Age] >= 60) aand ([Age] <= 190) and ([Sc] = 3) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)


'PR,60,Sc4
theVTab = av.GetActiveDoc.GetVTab
theBitmap = theVTab.GetSelection
expr = "(([Wg] = 12) and ([Age] >=60) and ([Age] <= 190) and ([Sc] = 4) and ([Yield] > 0))"
theVTab.Query(expr,TheBitMap,#VTAB_SELTYPE_OR)

theVTab.UpdateSelection
```

*

7. Aggregates value in selected field.

Author: Daniel Schwandt
Year: 2000
Name: "Table.Sum_Column_Aggregated. "
Avalable at http://arcscripts.esri.com/details.asp?dbid=10194
Date accesed: June 19, 2004

```
' Name:    Table.Sum_Column_aggregated
'
' Title:  Summarizes all values in a column (the active field) from the table, adds a new
field with the
'         aggregated sum
'
' Topics: Tables
'
' Description:  Computes the sum of all values in a column, writes the aggregated sum in a new
field
'               ActiveField"_Sum(aggregated)"
'               DO NOT SORT THE TABLE BEFORE OR AFTER YOU RUN THE AGGREGATED SUM !!!
'
' Requires: A table must be the active document, a field must be active(selected).
```

```
'
' Author:   Daniel Schwandt, September 2000
'
' Self:
'
' Returns:
'
theTable = av.GetActiveDoc
theVTab = theTable.GetVTab
theField = theTable.GetActiveField

thePrecision = "d.dddddddddd"
theFieldPrecision = theField.GetPrecision
Script.The.SetNumberFormat( thePrecision.Left( theFieldPrecision + 2 ) )

'add a new field ActiveField_Sum(aggregated)
fieldname = theField.GetAlias + "_Sum(aggregated)"
sum = Field.Make (fieldname, #FIELD_DECIMAL , 32, theFieldPrecision )
theVTab.SetEditable(true)

if (theVTab.IsEditable) then

  if(theVTab.CanAddFields )then
    theVTab.AddFields( {sum} )
   else
   MsgBox.Info("Unable to add a field.", "Problem")
  end

 sum = theVTab.findfield(fieldname)


'aggregated sum over all values of a selected (active) field
  summe = 0

  for each record in theVTab
     v = theVTab.ReturnValue(theField, record)
       if ((v.is(number)).not) then
        MsgBox.Info ("You can summarize only NUMBERS", "Error")
        theVTab.RemoveFields({sum})
        theVTab.SetEditable(FALSE)
        return nil
       end
     summe = summe + v
     theVTab.SetValueNumber( sum, record, summe )
  end

end
theVTab.SetEditable(FALSE)
```

8. Clip grids

Author: Jenness, J.
Year 2004
Name: "Grid tools v.1.1"
Available at: http://www.esri.com/software/arcview/extensions/dialog/index.html
Date accessed: June 19, 2004

```
' grid_tools_jen.RunClipGrid

theView = av.GetActiveDoc
theDisplay = theView.GetDisplay
```

```
theThemes = theView.GetThemes
thePrj = theView.GetProjection

thePolyThemes = {}
for each aTheme in theThemes
  if (aTheme.Is(FTheme)) then
    thePolyThemes.Add(aTheme)
  end
end
theGraphics = theView.GetGraphics.GetSelected

theParameters = av.FindDialog("grid_tools_jen.GridClipDialog").Open
if (theParameters = nil) then return nil end

theGThemes = theParameters.Get(0)
theOption = theParameters.Get(1)
SelectOutside = theParameters.Get(2)

if (theOption = "Features") then

  thePolyTheme = msgBox.List(thePolyThemes, "Please select theme to use to clip/extract
grid...", "Select Theme:")
  if (thePolyTheme = nil) then return nil end
  theFTab = thePolyTheme.GetFTab

elseif (theOption = "Theme") then

  theTheme = msgBox.List(theThemes, "Please select theme to use to clip/extract grid...",
"Select Theme:")
  if (theTheme = nil) then return nil end
  theExtent = theTheme.ReturnExtent

end

for each aGTheme in theGThemes
  theGrid = aGTheme.GetGrid
  Grid.SetAnalysisCellSize(#GRID_ENVTYPE_VALUE, theGrid.GetCellSize)

  if (theOption = "Display") then

    if (SelectOutside) then
      Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, aGTheme.ReturnExtent)
      theClipBoundary = theDisplay.ReturnVisExtent
      theNewGrid = theGrid.ExtractByRect (theClipBoundary, Prj.MakeNull, True)
    else
      Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, theDisplay.ReturnVisExtent)
      theNewGrid = theGrid*1
    end

  elseif (theOption = "Graphics") then

    theGraphics = theView.GetGraphics.GetSelected
    theExtent = theView.GetGraphics.ReturnSelectedExtent

    thePolys = {}
    theLines = {}
    thePoints = {}

    theFileNames = {}

    for each aGraphic in theGraphics
      if ((aGraphic.GetShape.Is(Circle)) or (aGraphic.GetShape.Is(Polygon)) or
(aGraphic.GetShape.Is(Rect))
           or (aGraphic.GetShape.Is(Oval)) or (aGraphic.GetShape.Is(Ellipse))) then
        thePolys.Add(aGraphic.GetShape.AsPolygon)
      elseif ((aGraphic.GetShape.Is(Polyline)) or (aGraphic.GetShape.Is(PolylineM)) or
          (aGraphic.GetShape.Is(PolylineZ))) then
        theLines.Add(aGraphic.GetShape.AsPolyline)
      elseif ((aGraphic.GetShape.Is(Point)) or (aGraphic.GetShape.Is(PointZ)) or
(aGraphic.GetShape.Is(PointM))) then
        thePoints.Add(aGraphic.GetShape)
```

```
  end
end

theMergeList = {}

if (thePolys.Count > 0) then
  thePolyFilename = Filename.GetCWD.MakeTmp("poly", "shp")
  theFilenames.Add(thePolyFilename)
  thePolyFTab = FTab.MakeNew(thePolyFilename, Polygon)
  thePolyFTab.AddFields({Field.Make("id", #FIELD_LOGICAL, 2, 0)})
  for each aPoly in thePolys
    theRecord = thePolyFTab.AddRecord
    thePolyFTab.SetValue(thePolyFTab.FindField("Shape"), theRecord, aPoly)
  end
  thePolyFTab.SetEditable(False)
  theMergeList.Add(thePolyFTab)
else
  thePolyFTab = nil
end

if (theLines.Count > 0) then
  theLineFilename = Filename.GetCWD.MakeTmp("line", "shp")
  theFilenames.Add(theLineFilename)
  theLineFTab = FTab.MakeNew(theLineFilename, Polyline)
  theLineFTab.AddFields({Field.Make("id", #FIELD_LOGICAL, 2, 0)})
  for each aLine in theLines
    theRecord = theLineFTab.AddRecord
    theLineFTab.SetValue(theLineFTab.FindField("Shape"), theRecord, aLine)
  end
  theLineFTab.SetEditable(False)
  theMergeList.Add(theLineFTab)
else
  theLineFTab = nil
end

if (thePoints.Count > 0) then
  thePointFilename = Filename.GetCWD.MakeTmp("line", "shp")
  theFilenames.Add(thePointFilename)
  thePointFTab = FTab.MakeNew(thePointFilename, Point)
  thePointFTab.AddFields({Field.Make("id", #FIELD_LOGICAL, 2, 0)})
  for each aPoint in thePoints
    theRecord = thePointFTab.AddRecord
    thePointFTab.SetValue(thePointFTab.FindField("Shape"), theRecord, aPoint)
  end
  thePointFTab.SetEditable(False)
  theMergeList.Add(thePointFTab)
else
  thePointFTab = nil
end

theGridList = {}

for each anFTab in theMergeList

  if (SelectOutside) then
    Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, aGTheme.ReturnExtent)
    theTempGrid = Grid.MakeFromFTab(anFTab, Prj.MakeNull, nil, nil)
    theFlipGrid = (theTempGrid.IsNull).Con(0.AsGrid, 1.AsGrid)
    theGridList.Add(theFlipGrid)
  else
    Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, theExtent)
    theTempGrid = Grid.MakeFromFTab(anFTab, Prj.MakeNull, nil, nil)
    theTempGrid = theTempGrid*theGrid
    theGridList.Add(theTempGrid)
  end
end

if (SelectOutside) then
  if (theGridList.Count>1) then
    theZeroGrid = Grid.MakeFromNumb(0)
    for each aSubGrid in theGridList
```

```
        theZeroGrid = theZeroGrid+aSubGrid
      end
    else
      theZeroGrid = theGridList.Get(0)
    end
    theTemp2Grid = (theZeroGrid > 0.AsGrid).SetNull(1.AsGrid)
    theNewGrid = theTemp2Grid*theGrid

  else
    if (theGridList.Count >1) then
      theStartGrid = theGridList.Get(0)
      theGridList.Remove(0)
      theNewGrid = theStartGrid.Merge(theGridList)
    else
      theNewGrid = theGridList.Get(0)
    end
  end

  thePolyFTab = nil
  thePointFTab = nil
  theLineFTab = nil
  thePolys = nil
  theLines = nil
  thePoints = nil
  theRecord = nil
  av.PurgeObjects

  for each aFilename in theFilenames
    File.Delete(aFilename)
  end

elseif (theOption = "Features") then

  if (SelectOutside) then
    Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, aGTheme.ReturnExtent)
    theTempGrid = Grid.MakeFromFTab(theFTab, thePrj, nil, nil)
    theFlipGrid = (theTempGrid.IsNull).Con(0.AsGrid, 1.AsGrid)
    theTemp2Grid = (theFlipGrid > 0.AsGrid).SetNull(1.AsGrid)
    theNewgrid = theGrid*theTemp2Grid
  else
    if (theFTab.GetNumSelRecords = 0) then
      Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, thePolyTheme.ReturnExtent)
    else
      Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, thePolyTheme.GetSelectedExtent)
    end
    theTempGrid = Grid.MakeFromFTab(theFTab, thePrj, nil, nil)
    theNewGrid = theGrid*theTempGrid
  end

elseif (theOption = "Theme") then

  if (SelectOutside) then
    Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, aGTheme.ReturnExtent)
    theNewGrid = theGrid.ExtractByRect (theExtent, Prj.MakeNull, True)
  else
    Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, theExtent)
    theNewGrid = theGrid*1
  end

elseif (theOption = "Selection") then
  Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, aGTheme.ReturnExtent)

  if (SelectOutside) then
    theTempGrid = theGrid.ExtractSelection
    theTemp2Grid = (theTempGrid.IsNull).Con(0.AsGrid, 1.AsGrid)
    theTemp3Grid = (theTemp2Grid = 1.AsGrid).SetNull(1.AsGrid)
    theNewGrid = theGrid*theTemp3Grid
  else
    theNewGrid = theGrid.ExtractSelection
  end
```

```
  end

  theThemeName = aGTheme.GetName+"_clip"
  theCounter = 0
  While (theView.FindTheme(theThemeName) <> nil)
    theCounter = theCounter+1
    theThemeName = aGTHeme.GetName+"_clip"+theCounter.AsString
  end
  theGTheme = GTheme.Make(theNewGrid)
  theGTheme.SetName(theThemeName)
  theView.AddTheme(theGTheme)
end
```

9. Combine grids

Author: Jenness, J.
Year 2004
Name: "Grid tools v.1.1"
Available at: http://www.esri.com/software/arcview/extensions/dialog/index.html
Date accessed: June 19, 2004

```
' grid_tools_jen.CombineGrids

theView = av.GetActiveDoc
theThemes = theView.GetThemes
theGThemes = {}
for each aTheme in theThemes
  if (aTheme.Is(GTheme)) then
    if (aTheme.GetGrid.IsInteger) then
      theGThemes.Add(aTheme)
    end
  end
end

theCombineList = msgBox.MultiList(theGThemes, "Please select the grid themes to combine...",
  "Please Select Themes:")
if ((theCombineList = nil) or (theCombineList.Count = 0)) then return nil end

IsFirst = True
theRest = {}
for each aGTheme in theCombineList
  if (IsFirst) then
    theFirstGrid = aGTheme.GetGrid
    IsFirst = False
  else
    theRest.Add(aGTheme.GetGrid)
  end
end

theNewGrid = theFirstGrid.Combine(theRest)

theNewGTheme = GTheme.Make(theNewGrid)

theName = "Combine_1"
theBaseName = "Combine_"
theCounter = 1

while ((theView.FindTheme(theName) = nil).Not)
  theCounter = theCounter+1
  theName = theBaseName+theCounter.AsString
end
```

```
theNewGTheme.SetName(theName)
theView.AddTheme(theNewGTheme)
```

10. Marks records selected with "1"

```
'*********************************************************************
'*Script to mark selected records with "1"                          *
'*Rafael Munoz Marquez                                               *
'*May 23, 2004                                                       *
'*********************************************************************


theVTab = av.GetActiveDoc.GetVTab
  theVTab.SetEditable(true)
  theField = Field.Make("Mark", #FIELD_DECIMAL, 2, 0)
  theVTab.addFields({theField})
  if (thevtab.GetNumSelRecords > 0) Then
  theVTab.Calculate("1", theVTab.FindField("Mark"))
End
```

11. Merge grids

Author: Jenness, J.
Year 2004
Name: "Grid tools v.1.1"
Available at: http://www.esri.com/software/arcview/extensions/dialog/index.html
Date accessed: June 19, 2004

```
' grid_tools_jen.MergeGrids

theView = av.GetActiveDoc
theGThemes = {}
for each aTheme in theView.GetThemes
  if (aTheme.Is(GTheme)) then theGThemes.Add(aTheme) end
end

theMergeDialog = av.FindDialog("grid_tools_jen.AddToListDialog")
theMergeDialog.SetObjectTag(theGThemes)
theMergeList = theMergeDialog.Open

if (theMergeList = nil) then return nil end

IsFirst = True
theRest = {}
for each aGTheme in theMergeList
  if (IsFirst) then
    theFirstGrid = aGTheme.GetGrid
    IsFirst = False
  else
    theRest.Add(aGTheme.GetGrid)
  end
end

theNewGrid = theFirstGrid.Merge(theRest)

theNewGTheme = GTheme.Make(theNewGrid)

theName = "Merge_1"
theBaseName = "Merge_"
theCounter = 1

while ((theView.FindTheme(theName) = nil).Not)
  theCounter = theCounter+1
```

```
  theName = theBaseName+theCounter.AsString
end

theNewGTheme.SetName(theName)
theView.AddTheme(theNewGTheme)
```

12. Sort table

Author: Mark Cedelholm
Year: 2000
Name: "Sort Table by Multiple Columns"
Available at: http://arcscripts.esri.com/details.asp?dbid=11300
Date accessed: June 19, 2004

```
' SortTab.ave
' Sorts a Table document based on multiple fields

' If the sorted table is not to be exported to a new file, the
' underlying VTab must be editable because the script adds a temporary
' sort field

' Dependencies: "TmpField" = Temporary Field Name Generator

theTable = av.GetActiveDoc
theVTab = theTable.GetVTab
theTitle = "Table Sort"

'**** get list of sortable fields

unsupported = {"SHAPELINE","SHAPEMULTIPOINT","SHAPEPOINT","SHAPEPOLY",
               "UNSUPPORTED","BLOB"}
fl = List.Make
for each f in theVTab.GetFields
   ft = f.GetType.AsString.AsTokens("_").Get(1)
   if (unsupported.FindByValue(ft) = -1) then
      fl.Add(f)
   end
end

'**** get sort field name(s) and option(s)

flist = list.make
slist = list.make
addfield = true
sl = {"Ascending","Descending"}
theMsg = ""
while (addfield)
   f = MsgBox.Choice(fl,"Select sort field:",theTitle)
   if (f = nil) then
      return nil
   elseif (flist.Find(f) > -1) then
      MsgBox.Info("Field already selected",theTitle)
   else
      result = MsgBox.ChoiceAsString(sl,"Sort order:",theTitle)
      if (result = nil) then return nil end
      IsAscending = (result = "Ascending")
      flist.Add(f)
      slist.Add(IsAscending)
   end
```

```
   addfield = MsgBox.MiniYesNo("Add another field?",false)
end
ExportSorted = MsgBox.MiniYesNo("Export to a new file?",false)
if (ExportSorted) then
   out_fn = FileName.GetCWD.MakeTmp("table","dbf")
   out_fn = FileDialog.Put(out_fn,"*.dbf","Output File")
   if (out_fn = nil) then
      return nil
   end
else
   if (theVTab.CanEdit.Not) then
      MsgBox.Error("The table cannot be edited.","Sort")
      return nil
   end
end

'**** generate VTabSort object and export to new file

vs = VTabSort.Make(theVTab,flist,slist,false,true)
if (ExportSorted) then
   vs.Export(out_fn,dBASE)
   return nil
end

'**** otherwise, add temporary sort item to theVTab

sort_it = av.Run("TmpField",{theVTab,"xx",""})
w = theVTab.GetNumRecords.AsString.Count
sfwidth = w max 11
sf = Field.Make(sort_it,#FIELD_DECIMAL,sfwidth,0)
theVTab.SetEditable(true)
theVTab.AddFields({sf.Clone})
sf = theVTab.FindField(sort_it)

'**** populate temporary sort field

val = 0
for each r in theVTab
   sr = vs.GetRec(r)
   theVTab.SetValue(sf,sr,val)
   val = val + 1
end

'**** now sort the table on the temporary field

theTable.Sort(sf,false)

'**** remove the sort field

theVTab.RemoveFields({sf})
theVTab.SetEditable(false)
av.PurgeObjects
return nil
```

Appendix 4. GIS analysis sequence to apply harvesting to BFOLDS's output

The following are the steps to be applied to an output in BFOLDS's using ArcView©3x, and Spatial Analyst.

1 Open ArcView©3x.

2 Load the "Grid Tools" and "Spatial Tools" extensions (Available at http://arcscripts.esri.com/).

3 Load the following grids: Edaphic8[31], Moisture8[32], Sc (Site Class), Sp, and Age (both come as output from BFOLDS).

4 From the "Grid Tools" menu select "Combine Grids". Select all available grids from the selector box, and click OK. It creates a new grid with an attribute table that contains fields from all component grids plus the "*Value*" and "*Count*" fields. Rename this grid according to the following convention:

"BScen(0 to 2)y(10 to 70)rep(1 to 10)(1 to 180)"

Bscen1y20rep10(2)→ "B" stands for "Baseline"; "y20" stands for "year 20"; "rep10 sands for "replication # 10; and "2" Stands for its number in the general report (See annex).

2. Create the new fields: "**WG**", "**Yield**", "**m3/ha**", "**Age**", and "**Pr**". (Scrip 1 can be used here[33]). With the "Field Calculator" calculate the following: "WG" has the same value of the grid "Sp" from BFOLDS; "Age" has the same value as the grid "Ac" as well from BFOLDS.

---

[31] Code used in BFOLDS.
[32] Code used in BFOLDS.
[33] All scripts indicated can be located in Appendix 3. Extensions and Avenue codes used to process harvesting and apply regeneration rules after logging in ArcView©..

3. Using the scrip for calculating yield for hardwood and softwood (Script 3), calculate the timber availability both for hardwoods and softwoods. Results are collected in the field "**Yield**". It also calculates the field "**m3/ha**".

   Note: the field "Yield" reflects available timer only at this stage of the project with the quantification the software makes for grids (e.g. the software groups cells with the same characteristics. Yield is calculated with the field "Count", so it can change as grouping changes as well. In this context "m3/ha" = yield per each cell is the governing field). As the rest of the process entails sorting and changing the order of the fields it yield has to be updated when indicated.

   -------------From step (5) to the end, the process is done twice, first for hardwoods and then for softwoods. ---

4. Calculate timber for the selected Hardwood or Softwood using script 5 and/or 6. This only allocates cells that fulfill requirements for harvesting it is those with age within the operability limits. All selected cells might be harvested in the process.

5. Make the view active again. Go to the "Grid Tools" menu and go to the "Clip" option (also available in Script 8). Select the ***Base Grid*** (which should contain the selected cells from step [5]); then select "**Selected Grid Cells**", "**Inside/Intersection Region**", and the O.K. This process creates a grid with the selected cells only. Rename it with the following convention: "**AvHardwood(number)**"**.** "Av" stands for Available, "number" corresponds to the sequential number of the repetition in the whole experiment. When working with Softwood, write "Softwood" instead of "Hardwood".

Sometimes the process creates a grid with all the fields in the attribute table of the *Base Grid*. If that does not happen (it happens when the "Open Theme Table" button is dimmed), then with the view active go to the "Analysis" menu and select the Map Calculator. Once there, select the Av grid created in this step and click "Evaluate". It creates another grid with the same cells and ids. Rename it as the former. If this procedure is followed, delete the first grid.

6. With the View active, and the last grid active, go to the "**Transformation**" menu, and select "**Grid to Point**". The program asks where to locate the new shapefile (.shp). Save it in the working folder (the one for the scenario, year and replication). Name this shapefile just "**pnthardw"** or "**pntsoftwd"**. Be sure to save it in the adequate folder! This process creates a point shapefile with an attribute table with three fields: "**Shape**", "**Pointid**", and "**Grid_Code**". Join this table with the ***Base Grid*** using the fields "**Grid Code**" for the shapefile, and "**Value**" for the grid. This will add needed fields for the next step[34].

7. If the map calculator is applied, then one must join the attribute table of the created grid to the one from the baseline grid table. Do it using the "**Value**" field, and the "**Grid Code**" field for the point.shp.

8. Go to the Analysis menu, and select "Calculate Density". Set parameters based on the existing grids (CellSize = 100) [**Be very careful here as parameters must be equal to the base grid or BFOLDS grids, not to the point .shp)**. Select as the population field "**m3/ha**". Leave the following drop down menus as default and click OK. A grid of density is created.

9. Go to the Analysis menu again and select "**Reclassify**". Once there, click "**OK"**. It generates another gird with 9 values. The interpretation of this grid is: the bigger the number of the classification the more dense points are.

10. The reclassified grid should be combined with the AvHardwood or AvSoftwood grids (Script 9 or "Spatial Tools" menu). Select the reclassified grid and the AvHardwood or AvSoftwood grids which have the selected grids (***Do not combine it with the base grid, as this will contain all the study area instead of just the selected cells either for***

[34] Using the field "Count" verify with the "Field Statistics" that the cells number is the same in both grids.

hardwood or softwood). This will generate another grid with four fields. **To check the process is accurate see how many cells the field "Count" has in both grids: these must be the same.** Name the resulting grids "ClassifiedHard" or ClassifiedSoft".

11. Using the "**Calc***[35]**"** field join this table with the *Base Grid* table using the "**Value**" field for the *Base Grid*. This will deliver the classified records according to the density classification (recall the higher the number, the denser).

12. With the table active, select the Avenue script to sort the table according to the fields "**reclass***" and "**m3/ha**" (Script 12). Export the table to a new file (within the working file per scenario, replication and year). Call it either "**HardClass(number of experiment)**" or "**Softclass(number of experiment)".**

13. Add the new table into the document.

14. Update yield. Check yield for softwood or hardwood with the one obtained in the base grid. Totals must be the same for hardwood or softwood.

15. With the table open, make the field "Yield" active and apply Script 7. It will aggregate the value in the table according to that field and creates another field called "**Yield_sum(aggregated)**".

16. With the Query Builder, make a query with the convention indicated in the following table:

[35] "*" stands for all cases in which the first part of the name is repeated.

Group	Querying expression
Hardwoods:	“[Yield_sum(aggregated)] <= 8000000”
Softwoods	“[Yield_sum(aggregated)] <= 12000000”

If not enough timber is available, use the criteria ± 20% from the amounts indicated in the table below:

Group	Percentage	Amount indicated in the Query Builder
For Hardwoods	+ 20%	9600000
	- 20%	6400000
For Softwoods:	+ 20%	14400000
	- 20%	9600000

If no timber is available even applying the criteria of -20%, then take all extant timber.

17. Once the fields are selected, use the avenue code to mark selected records it will mark those selected fields with “1”, this is important for the following steps.
18. Join this table (hardclass/softclass) with the “Combine_1” grid. This will bring back the cells data in the table (hardclass/softclass). It is needed to put the information back to the original BFOLDS grids. Use their fields “Value” to do it.

19. With the table open use the script 2 which will add the fields “NWG” (new working group), and “Nage” (new Age).

20. Use the Script 4 to apply succession rules. This will be reflected in the fields NAGE and NWG.

21. Select records with “1” (can apply Script 10).

22. Make a clip (With the view active). Select the last grid. Choose the option of selected cells and inside (can use Script 8).

23. Using the Map Calculator, create grids for NAGE and NWG. Name them **NageSoft/Hard** (number), or **NWGSoft/Hard** (number).

24. Open a new view and name in “Combination”. Copy the NageSoft and Hard as well as the Nwg Soft and Hard to the new view. Load the very first grids from BFOLDS (“Ac” and “Sp”).

25. Merge grids (Script 11) and choose Nage (soft and hard). Click OK and name the new grids as **Nage(number).**

26. Merge grids (Script 11) and choose NWG (soft and hard). Click OK and name the new grids as**,** and **NWG(number)**.

27. Using the Field Calculator write the following expression:

a. **([revisedgrid].IsNull.Con([original],[revisedgrid])**

(“revised grid” is the one generated; “original” is the one from BFOLDS).

28. Name the resulting grids as NAc, and NSp with the number of replication and scenario.

29. Save them in the “to deliver” folder to be processed by BFOLDS for the subsequent run.

Appendix 5. Raw data

Baseline
year 2010

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	√	√	75,831,555.08	29,145,377.06	7,923,282.31	21,222,094.74	46,686,178.02	11,999,977.16	34,686,200.87	55,908,295.61	19,923,259.47
2	√	√	70,526,583.06	27,855,250.33	7,858,463.98	19,996,786.35	42,671,332.73	11,992,787.35	30,678,545.38	50,675,331.74	19,851,251.32
3	√	√	66,553,442.68	26,488,845.25	7,968,055.13	18,520,790.12	40,064,597.42	11,966,459.29	28,098,138.14	46,618,928.26	19,934,514.42
4	√	√	75,265,595.54	28,825,307.90	7,993,346.97	20,831,960.93	46,440,287.65	11,922,922.82	34,517,364.82	55,349,325.75	19,916,269.79
5	√	√	74,333,864.07	28,370,944.76	7,984,556.34	20,386,388.41	45,962,919.32	11,962,483.09	34,000,436.23	54,386,824.64	19,947,039.43
6	√	√	75,448,641.42	28,916,465.88	7,999,224.31	20,917,241.57	46,532,175.54	11,977,744.98	34,554,430.56	55,471,672.13	19,976,969.29
7	√	√	71,570,271.30	28,031,029.77	7,993,464.77	20,037,565.01	43,539,241.53	11,983,646.83	31,555,594.70	51,593,159.71	19,977,111.60
8	√	√	66,789,220.29	26,753,274.90	7,999,902.40	18,753,372.50	40,035,945.39	11,948,936.48	28,087,008.91	46,840,381.41	19,948,838.88
9	√	√	67,975,198.30	25,900,774.24	7,999,044.12	17,901,730.12	42,074,424.05	11,994,155.69	30,080,268.36	47,981,998.48	19,993,199.81
10	√	√	74,651,274.09	28,644,965.26	7,998,075.40	20,646,889.86	46,006,308.83	11,972,544.02	34,033,764.81	54,680,654.68	19,970,619.41
Mean			71,894,564.58	27,893,223.53	7,971,741.57	19,921,481.96	44,001,341.05	11,972,165.77	32,029,175.28	51,950,657.24	19,943,907.34
Standard Error			1,178,393.12	358,066.97	14,637.79	360,237.86	845,559.64	7,405.82	845,724.42	1,178,727.93	13,011.35
Median			72,952,067.69	28,200,987.26	7,993,405.87	20,211,976.71	44,751,080.42	11,975,144.50	32,778,015.47	52,989,992.18	19,947,939.16
Standard Deviation			3,726,406.23	1,132,307.17	46,288.76	1,139,172.13	2,673,894.34	23,419.25	2,674,415.45	3,727,464.99	41,145.49

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year 2010

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	√	√	61,370,075.31	24,421,940.89	7,939,959.28	16,481,981.61	36,948,134.42	11,961,623.08	24,986,511.34	41,468,492.95	19,901,582.36
2	√	√	73,716,374.27	28,266,641.75	7,994,057.84	20,272,583.91	45,449,732.51	11,959,560.27	33,490,172.25	53,762,756.16	19,953,618.11
3	√	√	74,436,769.08	28,446,598.54	7,974,438.67	20,472,159.87	45,990,170.55	11,912,036.72	34,078,133.83	54,550,293.70	19,886,475.39
4	√	√	75,886,923.36	29,166,072.19	7,983,772.07	21,182,300.12	46,720,851.17	11,951,081.89	34,769,769.29	55,952,069.41	19,934,853.95
5	√	√	74,873,809.65	28,585,397.36	7,950,211.48	20,635,185.88	46,288,412.29	11,999,109.30	34,289,302.99	54,924,488.87	19,949,320.77
6	√	√	75,411,465.67	29,056,528.06	7,999,881.76	21,056,646.30	46,354,937.62	11,991,851.33	34,363,086.29	55,419,732.58	19,991,733.09
7	√	√	73,945,511.77	28,686,945.76	7,999,847.92	20,687,097.84	45,258,566.01	11,724,104.64	33,534,461.38	54,221,559.21	19,723,952.56
8	√	√	72,127,386.03	27,387,876.01	7,998,739.05	19,389,136.95	44,739,510.03	11,904,472.89	32,835,037.14	52,224,174.09	19,903,211.94
9	√	√	75,402,105.27	28,815,225.18	7,987,761.58	20,827,463.60	46,586,880.09	11,837,957.19	34,748,922.90	55,576,386.50	19,825,718.77
10	√	√	73,795,919.54	28,304,908.70	7,978,311.85	20,326,596.86	45,491,010.84	11,930,663.00	33,560,347.84	53,886,944.70	19,908,974.85
Mean			73,096,634.00	28,113,813.44	7,980,698.15	20,133,115.29	44,982,820.55	11,917,246.03	33,065,574.52	53,198,689.82	19,892,148.05
Standard Error			1,347,668.63	439,271.34	6,609.75	435,263.75	915,080.25	26,062.50	912,749.76	1,341,646.35	24,559.10
Median			74,191,140.43	28,515,997.95	7,985,766.82	20,553,672.88	45,740,590.69	11,940,872.44	33,819,240.83	54,385,926.45	19,906,093.39
Standard Deviation			4,261,702.39	1,389,097.94	20,901.86	1,376,424.85	2,893,737.83	82,416.86	2,886,368.19	4,242,658.27	77,662.69

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year 2010

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	√	√	71,726,977.41	27,157,100.23	7,815,661.44	19,341,438.80	44,569,877.18	11,863,124.01	32,706,753.18	52,048,191.97	19,678,785.44
2	√	√	48,908,167.98	18,196,813.26	7,827,241.33	10,369,571.92	30,711,354.72	11,999,888.91	18,711,465.82	29,081,037.74	19,827,130.24
3	√	√	59,482,326.71	23,275,273.56	7,998,983.03	15,276,290.53	36,207,053.15	11,989,329.75	24,217,723.40	39,494,013.93	19,988,312.78
4	√	√	75,913,160.31	29,280,650.22	7,618,691.28	21,661,958.94	46,632,510.09	11,970,679.61	34,661,830.48	56,323,789.42	19,589,370.89
5	√	√	52,097,710.00	20,122,485.94	7,973,753.65	12,148,732.29	31,975,224.06	11,999,605.55	19,975,618.51	32,124,350.80	19,973,359.20
6	√	√	55,357,566.10	22,230,240.60	7,728,709.41	14,501,531.19	33,127,325.50	11,976,273.40	21,151,052.10	35,652,583.30	19,704,982.81
7	√	√	75,765,259.54	29,031,460.44	7,898,495.40	21,132,965.05	46,733,799.09	11,990,799.62	34,742,999.47	55,875,964.52	19,889,295.02
8	√	√	52,358,055.50	20,661,133.86	7,810,147.17	12,850,986.69	31,696,921.64	11,989,219.25	19,707,702.39	32,558,689.09	19,799,366.42
9	√	√	73,541,085.85	28,555,308.53	7,928,326.98	20,626,981.55	44,985,777.32	11,867,790.50	33,117,986.82	53,744,968.37	19,796,117.48
10	√	√	74,250,293.27	28,846,180.27	7,918,312.22	20,927,868.05	45,404,113.00	11,985,336.46	33,418,776.53	54,346,644.58	19,903,648.68
Mean			63,940,060.27	24,735,664.69	7,851,832.19	16,883,832.50	39,204,395.58	11,963,204.71	27,241,190.87	44,125,023.37	19,815,036.90
Standard Error			3,553,057.54	1,356,096.57	36,837.68	1,360,845.32	2,209,041.36	16,542.20	2,217,215.56	3,565,330.31	40,934.64
Median			65,604,652.06	25,216,186.90	7,862,868.36	17,308,864.66	40,388,465.16	11,987,277.86	28,462,238.29	45,771,102.95	19,813,248.33
Standard Deviation			11,235,754.50	4,288,353.89	116,490.96	4,303,370.74	6,985,602.16	52,311.04	7,011,451.24	11,274,564.38	129,446.71

Baseline
year 2020

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	√	√	40,571,950.54	10,281,619.31	7,961,496.43	2,320,122.88	30,290,331.22	11,991,136.06	18,299,195.17	20,619,318.05	19,952,632.49
2	√	√	42,307,169.58	10,636,693.14	7,987,298.62	2,649,394.52	31,670,476.43	11,984,376.42	19,686,100.01	22,335,494.53	19,971,675.04
3	√	√	38,216,050.09	9,659,391.48	7,990,695.41	1,668,696.06	28,556,658.62	11,997,664.22	16,558,994.39	18,227,690.45	19,988,359.64
4	√	√	47,337,846.56	11,763,465.97	7,999,736.41	3,763,729.56	35,574,380.59	11,973,572.12	23,600,808.47	27,364,538.03	19,973,308.53
5	√	√	44,158,352.26	10,841,599.76	7,992,406.65	2,849,193.12	33,316,752.50	11,990,287.15	21,326,465.34	24,175,658.46	19,982,693.80
6	√	√	46,500,263.43	11,383,558.14	7,999,809.16	3,383,748.99	35,116,705.29	11,998,595.83	23,118,109.46	26,501,858.44	19,998,404.98
7	√	√	43,584,534.26	11,107,579.81	7,845,784.39	3,261,795.41	32,476,954.45	11,985,833.07	20,491,121.38	23,752,916.79	19,831,617.46
8	×	√	26,279,781.27	7,308,457.43	7,308,457.43	0.00	18,971,323.84	11,999,933.53	6,971,390.31	6,971,390.31	19,308,390.96
9	√	√	40,514,521.51	9,967,869.64	7,984,463.54	1,983,406.10	30,546,651.87	11,996,450.44	18,550,201.43	20,533,607.52	19,980,913.98
10	√	√	47,022,268.27	11,659,116.65	7,997,370.81	3,661,745.84	35,363,151.62	11,998,172.37	23,364,979.25	27,026,725.09	19,995,543.18
Mean			41,649,273.78	10,460,935.13	7,906,751.89	2,837,981.39	31,188,338.64	11,991,602.12	19,196,736.52	21,750,919.77	19,898,354.01
Standard Error			1,959,850.27	414,102.24	68,076.59	359,987.62	1,548,909.99	2,654.70	1,550,047.59	1,902,505.18	67,324.82
Median			42,945,851.92	10,739,146.45	7,988,997.02	2,749,293.82	32,073,715.44	11,993,793.25	20,088,610.70	23,044,205.66	19,977,111.26
Standard Deviation			6,197,590.74	1,309,506.28	215,277.07	1,138,380.81	4,898,083.46	8,394.89	4,901,680.87	6,016,249.61	212,899.76

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year 2020

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	√	√	33,174,216.46	8,953,389.83	7,998,130.03	955,259.79	24,220,826.64	11,990,841.45	12,229,985.18	13,185,244.98	19,988,971.48
2	√	√	46,328,925.00	11,729,237.83	7,999,509.90	3,729,727.93	34,599,687.17	11,998,349.69	22,601,337.48	26,331,065.41	19,997,859.59
3	√	√	44,024,495.40	11,207,406.65	7,997,867.62	3,209,539.03	32,817,088.74	11,984,644.84	20,832,443.90	24,041,982.94	19,982,512.46
4	√	√	43,170,342.72	10,771,669.64	7,941,350.91	2,830,318.73	32,398,673.08	11,811,337.14	20,587,335.95	23,417,654.67	19,752,688.04
5	√	√	44,633,522.34	11,147,271.00	7,988,514.41	3,158,756.58	33,486,251.34	11,925,147.88	21,561,103.46	24,719,860.04	19,913,662.30
6	√	√	47,622,994.43	11,917,921.42	7,998,299.66	3,919,621.76	35,705,073.02	11,987,699.44	23,717,373.57	27,636,995.33	19,985,999.10
7	√	√	41,841,084.48	10,886,993.77	7,997,474.68	2,889,519.09	30,954,090.71	11,999,777.21	18,954,313.50	21,843,832.59	19,997,251.90
8	√	√	44,790,524.84	11,132,712.87	7,986,638.94	3,146,073.93	33,657,811.97	11,987,320.20	21,670,491.77	24,816,565.70	19,973,959.14
9	√	√	47,206,790.46	11,581,306.52	7,994,695.33	3,586,611.19	35,625,483.94	11,985,987.56	23,639,496.37	27,226,107.57	19,980,682.89
10	√	√	42,612,295.17	10,968,907.46	7,993,935.32	2,974,972.14	31,643,387.71	11,997,802.44	19,645,585.27	22,620,557.41	19,991,737.76
Mean			43,540,519.13	11,029,681.70	7,989,641.68	3,040,040.02	32,510,837.43	11,966,890.79	20,543,946.65	23,583,986.66	19,956,532.47
Standard Error			1,300,519.98	259,064.10	5,537.43	258,614.30	1,046,374.79	18,580.16	1,047,381.34	1,301,176.44	23,916.12
Median			44,329,008.87	11,139,991.93	7,996,085.01	3,152,415.26	33,151,670.04	11,987,509.82	21,196,773.68	24,380,921.49	19,984,255.78
Standard Deviation			4,112,605.29	819,232.63	17,510.88	817,810.23	3,308,927.64	58,755.62	3,312,110.62	4,114,681.20	75,629.42

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year 2020

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	√	√	47,561,688.88	11,706,550.13	7,998,742.43	3,707,807.70	35,855,138.74	11,981,574.02	23,873,564.73	27,581,372.43	19,980,316.45
2	×	√	21,100,928.88	5,422,099.47	5,422,099.47	0.00	15,678,829.41	11,981,332.56	3,697,496.85	3,697,496.85	17,403,432.03
3	√	√	30,911,130.53	8,087,235.90	7,993,500.18	93,735.72	22,823,894.63	11,999,497.59	10,824,397.04	10,918,132.76	19,992,997.77
4	√	√	47,337,846.56	11,763,465.97	7,999,736.41	3,763,729.56	35,574,380.59	11,973,572.12	23,600,808.47	27,364,538.03	19,973,308.53
5	×	√	27,104,350.13	7,115,476.12	7,115,476.12	0.00	19,988,874.01	11,992,744.04	7,996,129.98	7,996,129.98	19,108,220.16
6	×	√	23,589,338.23	6,390,152.28	6,390,152.28	0.00	17,199,185.95	11,969,518.27	5,229,667.68	5,229,667.68	18,359,670.55
7	√	√	39,328,173.57	10,307,092.89	7,923,405.21	2,383,687.68	29,021,080.68	11,965,773.49	17,055,307.18	19,438,994.87	19,889,178.70
8	×	√	26,279,781.27	7,308,457.43	7,308,457.43	0.00	18,971,323.84	11,999,933.53	6,971,390.31	6,971,390.31	19,308,390.96
9	√	√	44,872,610.63	11,354,161.98	7,996,556.53	3,357,605.45	33,518,448.66	11,994,155.55	21,524,293.11	24,881,898.56	19,990,712.07
10	√	√	40,164,768.58	10,614,729.70	7,914,708.75	2,700,020.95	29,550,038.88	11,987,152.67	17,562,886.21	20,262,907.16	19,901,861.42
Mean			34,825,061.73	9,006,942.19	7,406,283.48	2,667,764.51	25,818,119.54	11,984,525.38	13,833,594.16	15,434,252.86	19,390,808.86
Standard Error			3,216,413.72	757,761.03	278,607.62	543,106.25	2,463,788.76	3,865.07	2,464,464.12	2,995,778.78	279,253.96
Median			35,119,652.05	9,197,164.39	7,919,056.98	1,238,711.70	25,922,487.65	11,984,363.35	13,939,852.11	15,178,563.81	19,895,520.06
Standard Deviation			10,171,193.24	2,396,250.78	881,034.65	1,717,452.77	7,791,184.14	12,222.44	7,793,319.83	9,473,484.30	883,078.55

Baseline
year 2030

Rep	Fulfillment: Hardwood	Fulfillment: Softwood	Tot mature timber available (m3)	Mature hardwood (m3): Available	Mature hardwood (m3): Logged	Mature hardwood (m3): Remain	Mature softwood (m3): Available	Mature softwood (m3): Logged	Mature softwood (m3): Remain	Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
1	×	√	26,132,413.21	3,997,594.03	3,997,594.03	0.00	22,134,819.17	11,990,036.48	10,144,782.69	10,144,782.69	15,987,630.51
2	×	√	28,012,020.68	4,298,908.09	4,298,908.09	0.00	23,713,112.58	11,994,738.00	11,718,374.58	11,718,374.58	16,293,646.10
3	×	√	23,220,525.51	3,325,696.69	3,325,696.69	0.00	19,894,828.82	11,872,549.65	8,022,279.18	8,022,279.18	15,198,246.33
4	×	√	31,994,781.56	4,941,941.53	4,941,941.53	0.00	27,052,840.04	11,986,112.26	15,066,727.78	15,066,727.78	16,928,053.78
5	×	√	28,700,533.57	4,393,482.07	4,393,482.07	0.00	24,307,051.50	11,942,862.49	12,364,189.01	12,364,189.01	16,336,344.56
6	×	√	27,211,228.30	4,042,821.10	4,042,821.10	0.00	23,168,407.20	11,931,334.66	11,237,072.54	11,237,072.54	15,974,155.76
7	×	√	27,550,880.35	4,502,237.83	4,502,237.83	0.00	23,048,642.52	11,974,340.96	11,074,301.56	11,074,301.56	16,476,578.78
8	×	×	10,980,796.79	1,582,567.58	1,582,567.58	0.00	9,398,229.21	9,398,229.21	0.00	0.00	10,980,796.79
9	×	√	23,946,107.28	3,418,724.78	3,418,724.78	0.00	20,527,382.50	11,989,219.76	8,538,162.74	8,538,162.74	15,407,944.53
10	×	√	30,838,365.71	4,647,697.89	4,647,697.89	0.00	26,190,667.82	11,998,705.57	14,191,962.25	14,191,962.25	16,646,403.46
Mean			25,858,765.29	3,915,167.16	3,915,167.16	0.00	21,943,598.14	11,707,812.90	10,235,785.23	10,235,785.23	15,622,980.06
Standard Error			1,861,597.52	304,951.76	304,951.76	0.00	1,560,649.07	256,921.90	1,333,267.97	1,333,267.97	542,327.54
Median			27,381,054.32	4,170,864.60	4,170,864.60	0.00	23,108,524.86	11,980,226.61	11,155,687.05	11,155,687.05	16,140,638.30
Standard Deviation			5,886,888.26	964,342.15	964,342.15	0.00	4,935,205.69	812,458.38	4,216,163.53	4,216,163.53	1,714,990.26

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year 2030

Rep	Fulfillment: Hardwood	Fulfillment: Softwood	Tot mature timber available (m3)	Mature hardwood (m3): Available	Mature hardwood (m3): Logged	Mature hardwood (m3): Remain	Mature softwood (m3): Available	Mature softwood (m3): Logged	Mature softwood (m3): Remain	Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
1	×	√	16,943,394.97	2,369,230.07	2,369,230.07	0.00	14,574,164.90	11,993,171.31	2,580,993.59	2,580,993.59	14,362,401.38
2	×	√	29,615,779.65	4,543,892.27	4,543,892.27	0.00	25,071,887.38	11,988,468.13	13,083,419.24	13,083,419.24	16,532,360.41
3	×	√	28,465,944.88	4,323,897.20	4,323,897.20	0.00	24,142,047.67	11,997,624.23	12,144,423.44	12,144,423.44	16,321,521.44
4	×	√	27,713,449.75	4,049,827.54	4,049,827.54	0.00	23,663,622.21	11,999,055.85	11,664,566.36	11,664,566.36	16,048,883.39
5	×	√	28,276,884.46	4,329,388.55	4,329,388.55	0.00	23,947,495.91	11,823,902.14	12,123,593.78	12,123,593.78	16,153,290.68
6	×	√	31,216,942.46	4,753,282.27	4,753,282.27	0.00	26,463,660.19	11,979,412.27	14,484,247.92	14,484,247.92	16,732,694.54
7	×	√	26,426,431.72	4,332,653.48	4,332,653.48	0.00	22,093,778.24	11,999,882.55	10,093,895.69	10,093,895.69	16,332,536.03
8	×	√	30,228,415.18	4,443,432.59	4,443,432.59	0.00	25,784,982.59	11,999,257.45	13,785,725.14	13,785,725.14	16,442,690.05
9	×	√	32,500,977.10	4,774,258.00	4,774,258.00	0.00	27,726,719.10	11,998,957.95	15,727,761.15	15,727,761.15	16,773,215.95
10	×	√	24,320,086.43	3,634,951.89	3,634,951.89	0.00	20,685,134.54	11,997,271.19	8,687,863.36	8,687,863.36	15,632,223.08
Mean			27,570,830.66	4,155,481.39	4,155,481.39	0.00	23,415,349.27	11,977,700.31	11,437,648.97	11,437,648.97	16,133,181.69
Standard Error			1,394,371.64	224,520.09	224,520.09	0.00	1,176,054.91	17,210.07	1,224,604.51	1,224,604.51	223,446.38
Median			28,371,414.67	4,331,021.01	4,331,021.01	0.00	24,044,771.79	11,997,447.71	11,894,080.07	11,894,080.07	16,327,028.73
Standard Deviation			4,409,390.29	709,994.86	709,994.86	0.00	3,719,012.17	54,423.03	3,872,539.49	3,872,539.49	706,599.49

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year 2030

Rep	Fulfillment: Hardwood	Fulfillment: Softwood	Tot mature timber available (m3)	Mature hardwood (m3): Available	Mature hardwood (m3): Logged	Mature hardwood (m3): Remain	Mature softwood (m3): Available	Mature softwood (m3): Logged	Mature softwood (m3): Remain	Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
1	×	√	31,717,106.86	6,405,868.35	6,405,868.35	0.00	25,311,238.51	11,998,772.74	13,312,465.77	13,312,465.77	18,404,641.09
2	×	×	6,430,146.06	1,026,675.12	1,026,675.12	0.00	5,403,470.94	5,403,470.94	0.00	0.00	6,430,146.06
3	×	√	15,075,899.91	1,919,129.51	1,919,129.51	0.00	13,156,770.41	11,992,712.92	1,164,057.48	1,164,057.48	13,911,842.43
4	×	√	32,895,502.32	4,968,739.49	4,968,739.49	0.00	27,926,762.83	11,999,101.74	15,927,661.09	15,927,661.09	16,967,841.23
5	×	√	12,545,232.06	1,844,976.43	1,844,976.43	0.00	10,700,255.63	10,700,255.63	0.00	0.00	12,545,232.06
6	×	×	8,844,667.20	1,383,291.50	1,383,291.50	0.00	7,461,375.70	7,461,375.70	0.00	0.00	8,844,667.20
7	×	√	23,675,271.03	3,526,675.09	3,526,675.09	0.00	20,148,595.95	11,973,199.45	8,175,396.50	8,175,396.50	15,499,874.53
8	×	×	10,833,190.54	1,570,194.07	1,570,194.07	0.00	9,262,996.47	9,262,996.47	0.00	0.00	10,833,190.54
9	×	√	27,583,407.16	4,057,899.31	4,057,899.31	0.00	23,525,507.85	11,956,035.26	11,569,472.59	11,569,472.59	16,013,934.57
10	×	√	24,878,525.79	4,050,479.03	4,050,479.03	0.00	20,828,046.75	11,998,081.98	8,829,964.78	8,829,964.78	16,048,561.01
Mean			19,447,894.89	3,075,392.79	3,075,392.79	0.00	16,372,502.10	10,474,600.28	5,897,901.82	5,897,901.82	13,549,993.07
Standard Error			3,105,166.26	567,387.19	567,387.19	0.00	2,563,561.76	745,565.39	2,008,517.38	2,008,517.38	1,214,353.92
Median			19,375,585.47	2,722,902.30	2,722,902.30	0.00	16,652,683.18	11,964,617.35	4,669,726.99	4,669,726.99	14,705,858.48
Standard Deviation			9,819,397.90	1,794,235.84	1,794,235.84	0.00	8,106,694.10	2,357,684.77	6,351,489.64	6,351,489.64	3,840,124.26

Baseline
year 2040

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	×	√	16,696,412.29	2,662,718.39	2,662,718.39	0.00	14,033,693.90	11,996,081.84	2,037,612.06	2,037,612.06	14,658,800.23
2	×	√	18,891,955.65	2,439,974.69	2,439,974.69	0.00	16,451,980.96	11,995,118.22	4,456,862.74	4,456,862.74	14,435,092.91
3	×	√	17,120,403.23	2,602,271.20	2,602,271.20	0.00	14,518,132.02	11,999,742.39	2,518,389.63	2,518,389.63	14,602,013.60
4	×	√	23,401,608.27	2,667,725.15	2,667,725.15	0.00	20,733,883.12	11,919,791.46	8,814,091.66	8,814,091.66	14,587,516.61
5	×	√	22,147,153.83	2,858,186.37	2,858,186.37	0.00	19,288,967.46	11,999,474.89	7,289,492.58	7,289,492.58	14,857,661.25
6	×	√	19,106,653.37	2,660,321.37	2,660,321.37	0.00	16,446,164.94	11,997,656.33	4,448,508.60	4,448,508.60	14,657,977.70
7	×	√	19,877,494.55	2,531,621.21	2,531,621.21	0.00	17,345,873.34	11,993,078.45	5,352,794.90	5,352,794.90	14,524,699.65
8	×	×	6,356,770.61	1,850,633.51	1,850,633.51	0.00	4,506,137.10	4,506,137.10	0.00	0.00	6,356,770.61
9	×	√	16,702,640.66	2,456,330.60	2,456,330.60	0.00	14,246,310.06	11,984,084.79	2,262,225.28	2,262,225.28	14,440,415.39
10	×	√	24,170,192.03	2,814,938.89	2,814,938.89	0.00	21,355,253.14	11,993,079.98	9,362,173.16	9,362,173.16	14,808,018.87
Mean			18,447,128.45	2,554,472.14	2,554,472.14	0.00	15,892,639.60	11,238,424.54	4,654,215.06	4,654,215.06	13,792,896.68
Standard Error			1,590,648.03	89,241.87	89,241.87	0.00	1,510,157.31	748,070.38	976,246.22	976,246.22	827,389.77
Median			18,999,304.51	2,631,296.29	2,631,296.29	0.00	16,449,072.95	11,994,099.10	4,452,685.67	4,452,685.67	14,594,765.10
Standard Deviation			5,030,070.73	282,207.56	282,207.56	0.00	4,775,536.74	2,365,606.26	3,087,161.62	3,087,161.62	2,616,436.19

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year 2040

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	×	√	9,218,288.53	2,131,237.40	2,131,237.40	0.00	7,087,051.13	7,087,051.13	0.00	0.00	9,218,288.53
2	×	√	16,657,059.13	2,148,483.17	2,148,483.17	0.00	14,508,575.96	11,992,219.44	2,516,356.53	2,516,356.53	14,140,702.61
3	×	√	19,692,352.00	2,676,576.13	2,676,576.13	0.00	17,015,775.88	11,984,176.46	5,031,599.41	5,031,599.41	14,660,752.59
4	×	√	20,836,833.99	2,640,621.86	2,640,621.86	0.00	18,196,212.13	11,998,993.39	6,197,218.73	6,197,218.73	14,639,615.25
5	×	√	19,787,015.76	2,156,597.10	2,156,597.10	0.00	17,630,418.65	11,961,311.13	5,669,107.52	5,669,107.52	14,117,908.24
6	×	√	24,718,543.39	3,021,980.81	3,021,980.81	0.00	21,696,562.58	11,945,968.85	9,750,593.73	9,750,593.73	14,967,949.66
7	×	√	19,375,800.81	2,509,853.67	2,509,853.67	0.00	16,865,947.14	11,993,955.92	4,871,991.22	4,871,991.22	14,503,809.59
8	×	√	24,005,899.99	2,957,182.33	2,957,182.33	0.00	21,048,717.65	11,999,603.08	9,049,114.57	9,049,114.57	14,956,785.41
9	×	√	26,367,337.06	2,940,805.61	2,940,805.61	0.00	23,426,531.44	11,999,597.44	11,426,934.00	11,426,934.00	14,940,403.06
10	×	√	17,453,024.64	2,414,778.16	2,414,778.16	0.00	15,038,246.47	11,970,284.63	3,067,961.84	3,067,961.84	14,385,062.79
Mean			19,811,215.53	2,559,811.63	2,559,811.63	0.00	17,251,403.90	11,493,316.15	5,758,087.76	5,758,087.76	13,559,270.98
Standard Error			1,540,692.62	109,331.50	109,331.50	0.00	1,450,237.06	983,458.84	921,344.13	921,344.13	1,035,801.53
Median			19,739,683.88	2,575,237.77	2,575,237.77	0.00	17,323,097.26	11,988,197.95	5,350,353.47	5,350,353.47	14,571,712.42
Standard Deviation			4,872,097.84	345,736.56	345,736.56	0.00	4,586,052.26	3,109,969.92	2,913,545.97	2,913,545.97	3,275,492.04

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year 2040

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	×	√	22,971,620.42	2,461,563.76	2,461,563.76	0.00	20,510,056.66	11,925,746.94	8,584,309.72	8,584,309.72	14,387,310.70
2	×	×	4,221,899.28	1,365,805.95	1,365,805.95	0.00	2,856,093.33	2,856,093.33	0.00	0.00	4,221,899.28
3	×	×	8,045,016.86	2,366,926.34	2,366,926.34	0.00	5,678,090.53	5,678,090.53	0.00	0.00	8,045,016.86
4	×	√	26,344,494.29	2,984,986.81	2,984,986.81	0.00	23,359,507.48	11,999,849.64	11,359,657.85	11,359,657.85	14,984,836.45
5	×	×	5,005,788.79	1,502,262.79	1,502,262.79	0.00	3,503,526.01	3,503,526.01	0.00	0.00	5,005,788.79
6	×	×	5,019,359.72	1,403,325.66	1,403,325.66	0.00	3,616,034.06	3,616,034.06	0.00	0.00	5,019,359.72
7	×	√	15,068,597.78	2,451,422.81	2,451,422.81	0.00	12,617,174.96	11,999,613.15	617,561.81	617,561.81	14,451,035.96
8	×	×	6,096,518.98	1,750,581.44	1,750,581.44	0.00	4,345,937.54	4,345,937.54	0.00	0.00	6,096,518.98
9	×	√	20,926,001.32	2,781,388.63	2,781,388.63	0.00	18,144,612.69	11,999,182.41	6,145,430.28	6,145,430.28	14,780,571.04
10	×	√	14,817,133.45	2,475,434.12	2,475,434.12	0.00	12,341,699.32	11,998,500.13	343,199.19	343,199.19	14,473,934.25
Mean			12,851,643.09	2,154,369.83	2,154,369.83	0.00	10,697,273.26	7,992,257.37	2,705,015.89	2,705,015.89	10,146,627.20
Standard Error			2,634,291.40	188,211.98	188,211.98	0.00	2,466,183.80	1,350,015.24	1,365,554.72	1,365,554.72	1,523,002.36
Median			11,431,075.15	2,409,174.58	2,409,174.58	0.00	9,009,894.92	8,801,918.73	171,599.60	171,599.60	11,216,163.78
Standard Deviation			8,330,360.83	595,178.52	595,178.52	0.00	7,798,757.95	4,269,123.03	4,318,263.18	4,318,263.18	4,816,156.34

Baseline
year 2050

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	×	×	11,192,191.19	3,797,161.33	3,797,161.33	0.00	7,395,029.85	7,395,029.85	0.00	0.00	11,192,191.19
2	×	×	15,333,966.70	4,117,479.30	4,117,479.30	0.00	11,216,487.40	11,216,487.40	0.00	0.00	15,333,966.70
3	×	×	13,786,132.53	4,220,861.53	4,220,861.53	0.00	9,565,271.00	9,565,271.00	0.00	0.00	13,786,132.53
4	×	√	20,557,340.79	4,121,980.46	4,121,980.46	0.00	16,435,360.32	11,997,945.11	4,437,415.21	4,437,415.21	16,119,925.58
5	×	√	19,655,823.29	4,285,658.42	4,285,658.42	0.00	15,370,164.87	11,998,177.20	3,371,987.67	3,371,987.67	16,283,835.62
6	×	×	15,457,401.26	4,101,583.20	4,101,583.20	0.00	11,355,818.07	11,355,818.07	0.00	0.00	15,457,401.26
7	×	×	15,811,911.96	4,082,147.59	4,082,147.59	0.00	11,729,764.37	11,729,764.37	0.00	0.00	15,811,911.96
8	×	×	6,699,706.70	2,579,647.14	2,579,647.14	0.00	4,120,059.56	4,120,059.56	0.00	0.00	6,699,706.70
9	×	×	12,284,104.54	4,052,074.36	4,052,074.36	0.00	8,232,030.18	8,232,030.18	0.00	0.00	12,284,104.54
10	×	√	21,146,915.43	4,563,617.05	4,563,617.05	0.00	16,583,298.38	11,999,386.40	4,583,911.98	4,583,911.98	16,563,003.45
Mean			15,192,549.44	3,992,221.04	3,992,221.04	0.00	11,200,328.40	9,960,996.91	1,239,331.49	1,239,331.49	13,953,217.95
Standard Error			1,426,722.48	168,471.73	168,471.73	0.00	1,291,721.13	836,336.42	638,694.66	638,694.66	986,642.51
Median			15,395,683.98	4,109,531.25	4,109,531.25	0.00	11,286,152.73	11,286,152.73	0.00	0.00	15,395,683.98
Standard Deviation			4,511,692.63	532,754.39	532,754.39	0.00	4,084,780.87	2,644,727.98	2,019,729.86	2,019,729.86	3,120,037.58

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year 2050

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	×	×	7,585,572.61	3,294,471.91	3,294,471.91	0.00	4,291,100.70	4,291,100.70	0.00	0.00	7,585,572.61
2	×	×	10,784,648.53	3,254,782.83	3,254,782.83	0.00	7,529,865.70	7,529,865.70	0.00	0.00	10,784,648.53
3	×	×	14,564,966.16	3,406,821.40	3,406,821.40	0.00	11,158,144.76	11,158,144.76	0.00	0.00	14,564,966.16
4	×	√	17,190,917.27	4,225,812.18	4,225,812.18	0.00	12,965,105.09	11,986,931.72	978,173.37	978,173.37	16,212,743.90
5	×	√	16,935,811.38	4,298,106.79	4,298,106.79	0.00	12,637,704.59	11,993,115.01	644,589.58	644,589.58	16,291,221.80
6	×	√	22,534,634.32	4,450,241.60	4,450,241.60	0.00	18,084,392.72	11,957,895.34	6,126,497.38	6,126,497.38	16,408,136.94
7	×	×	15,872,618.83	4,109,613.12	4,109,613.12	0.00	11,763,005.71	11,763,005.71	0.00	0.00	15,872,618.83
8	×	√	21,586,356.13	4,354,687.68	4,354,687.68	0.00	17,231,668.44	11,999,779.76	5,231,888.68	5,231,888.68	16,354,467.44
9	×	√	23,255,705.81	4,587,877.05	4,587,877.05	0.00	18,667,828.77	11,990,315.90	6,677,512.87	6,677,512.87	16,578,192.94
10	×	×	13,664,691.59	4,091,873.69	4,091,873.69	0.00	9,572,817.89	9,572,817.89	0.00	0.00	13,664,691.59
Mean			16,397,592.26	4,007,428.82	4,007,428.82	0.00	12,390,163.44	10,424,297.25	1,965,866.19	1,965,866.19	14,431,726.07
Standard Error			1,608,308.33	157,722.06	157,722.06	0.00	1,470,945.57	824,883.98	895,803.97	895,803.97	952,735.60
Median			16,404,215.10	4,167,712.65	4,167,712.65	0.00	12,200,355.15	11,860,450.52	322,294.79	322,294.79	16,042,681.36
Standard Deviation			5,085,917.50	498,760.95	498,760.95	0.00	4,651,538.32	2,608,512.17	2,832,780.88	2,832,780.88	3,012,814.52

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year 2050

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	×	√	20,371,930.72	4,503,281.12	4,503,281.12	0.00	15,868,649.61	11,999,067.97	3,869,581.64	3,869,581.64	16,502,349.09
2	×	×	5,328,477.63	2,730,993.88	2,730,993.88	0.00	2,597,483.75	2,597,483.75	0.00	0.00	5,328,477.63
3	×	×	8,003,500.38	3,099,470.28	3,099,470.28	0.00	4,904,030.10	4,904,030.10	0.00	0.00	8,003,500.38
4	×	√	24,312,022.61	4,661,119.19	4,661,119.19	0.00	19,650,903.42	11,994,862.81	7,656,040.61	7,656,040.61	16,655,982.00
5	×	×	5,735,043.09	2,498,122.18	2,498,122.18	0.00	3,236,920.92	3,236,920.92	0.00	0.00	5,735,043.09
6	×	×	6,086,399.30	2,904,888.66	2,904,888.66	0.00	3,181,510.64	3,181,510.64	0.00	0.00	6,086,399.30
7	×	×	9,974,004.96	3,711,009.82	3,711,009.82	0.00	6,262,995.14	6,262,995.14	0.00	0.00	9,974,004.96
8	×	×	6,662,266.54	2,633,142.31	2,633,142.31	0.00	4,029,124.23	4,029,124.23	0.00	0.00	6,662,266.54
9	×	√	17,386,160.19	4,374,354.75	4,374,354.75	0.00	13,011,805.44	11,996,890.74	1,014,914.69	1,014,914.69	16,371,245.50
10	×	×	8,611,004.23	3,217,835.55	3,217,835.55	0.00	5,393,168.68	5,393,168.68	0.00	0.00	8,611,004.23
Mean			11,247,080.97	3,433,421.77	3,433,421.77	0.00	7,813,659.19	6,559,605.50	1,254,053.69	1,254,053.69	9,993,027.27
Standard Error			2,169,997.19	259,491.72	259,491.72	0.00	1,922,636.34	1,235,749.12	808,923.60	808,923.60	1,489,073.66
Median			8,307,252.30	3,158,652.91	3,158,652.91	0.00	5,148,599.39	5,148,599.39	0.00	0.00	8,307,252.30
Standard Deviation			6,862,133.62	820,584.87	820,584.87	0.00	6,079,909.95	3,907,781.83	2,558,041.03	2,558,041.03	4,708,864.37

Baseline
year 2060

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	×	×	6,707,941.29	156,823.45	156,823.45	0.00	6,551,117.84	6,551,117.84	0.00	0.00	6,707,941.29
2	×	×	9,743,304.58	1,730,939.29	1,730,939.29	0.00	8,012,365.29	8,012,365.29	0.00	0.00	9,743,304.58
3	×	×	9,923,110.33	1,810,088.21	1,810,088.21	0.00	8,113,022.12	8,113,022.12	0.00	0.00	9,923,110.33
4	×	√	14,266,533.40	290,494.44	290,494.44	0.00	13,976,038.96	11,995,656.32	1,980,382.64	1,980,382.64	12,286,150.76
5	×	√	13,100,583.17	230,130.36	230,130.36	0.00	12,870,452.81	11,999,414.79	871,038.02	871,038.02	12,229,545.15
6	×	×	7,990,889.32	184,296.41	184,296.41	0.00	7,806,592.91	7,806,592.91	0.00	0.00	7,990,889.32
7	×	×	9,842,318.09	1,752,206.63	1,752,206.63	0.00	8,090,111.46	8,090,111.46	0.00	0.00	9,842,318.09
8	×	×	7,800,123.47	2,593,327.00	2,593,327.00	0.00	5,206,796.48	5,206,796.48	0.00	0.00	7,800,123.47
9	×	×	7,980,904.93	1,119,971.97	1,119,971.97	0.00	6,860,932.96	6,860,932.96	0.00	0.00	7,980,904.93
10	×	√	13,578,621.39	393,785.58	393,785.58	0.00	13,184,835.80	11,997,328.07	1,187,507.73	1,187,507.73	12,391,113.65
Mean			10,093,433.00	1,026,206.33	1,026,206.33	0.00	9,067,226.66	8,663,333.82	403,892.84	403,892.84	9,689,540.16
Standard Error			846,057.54	281,710.23	281,710.23	0.00	978,572.20	780,286.80	222,598.37	222,598.37	656,911.75
Median			9,792,811.33	756,878.78	756,878.78	0.00	8,051,238.37	8,051,238.37	0.00	0.00	9,792,811.33
Standard Deviation			2,675,468.87	890,845.97	890,845.97	0.00	3,094,517.01	2,467,483.53	703,917.85	703,917.85	2,077,337.35

CGCM2 A22
year 2060

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	×	×	7,085,882.86	1,984,149.16	1,984,149.16	0.00	5,101,733.70	5,101,733.70	0.00	0.00	5,961,669.10
2	×	×	5,961,669.10	136,073.83	136,073.83	0.00	5,825,595.26	5,825,595.26	0.00	0.00	7,257,919.62
3	×	×	7,257,919.62	460,642.60	460,642.60	0.00	6,797,277.03	6,797,277.03	0.00	0.00	10,390,704.55
4	×	×	10,390,704.55	726,512.25	726,512.25	0.00	9,664,192.30	9,664,192.30	0.00	0.00	8,788,498.08
5	×	×	8,788,498.08	677,895.15	677,895.15	0.00	8,110,602.93	8,110,602.93	0.00	0.00	12,496,071.24
6	×	√	16,652,291.19	496,823.23	496,823.23	0.00	16,155,467.97	11,999,248.02	4,156,219.95	4,156,219.95	6,405,518.28
7	×	×	6,405,518.28	328,949.28	328,949.28	0.00	6,076,569.00	6,076,569.00	0.00	0.00	12,473,845.42
8	×	√	16,091,000.13	490,350.31	490,350.31	0.00	15,600,649.82	11,983,495.11	3,617,154.71	3,617,154.71	10,786,805.06
9	×	×	10,786,805.06	167,149.74	167,149.74	0.00	10,619,655.31	10,619,655.31	0.00	0.00	8,151,964.99
10	×	×	8,151,964.99	310,708.70	310,708.70	0.00	7,841,256.29	7,841,256.29	0.00	0.00	0.00
Mean			9,757,225.39	577,925.43	577,925.43	0.00	9,179,299.96	8,401,962.49	777,337.47	777,337.47	8,271,299.63
Standard Error			1,209,490.47	167,826.06	167,826.06	0.00	1,239,703.04	804,087.85	519,780.26	519,780.26	1,177,890.47
Median			8,470,231.53	475,496.46	475,496.46	0.00	7,975,929.61	7,975,929.61	0.00	0.00	8,470,231.53
Standard Deviation			3,824,744.68	530,712.60	530,712.60	0.00	3,920,285.23	2,542,749.06	1,643,689.52	1,643,689.52	3,724,816.71

CCSRNIES A21
year 2060

Fulfillment			Tot mature timber available (m3)	Mature hardwood (m3)			Mature softwood (m3)			Tot. Mature Tim remaining (m3)	Tot Mature Tim logged (m3)
Rep	Hardwood	Softwood		Available	Logged	Remain	Available	Logged	Remain		
1	×	×	8,699,937.74	165,012.33	165,012.33	0.00	8,534,925.41	8,534,925.41	0.00	0.00	6,706,556.63
2	×	×	2,722,882.65	520,898.23	520,898.23	0.00	2,201,984.42	2,201,984.42	0.00	0.00	1,514,976.32
3	×	×	6,706,556.63	146,733.02	146,733.02	0.00	6,559,823.61	6,559,823.61	0.00	0.00	5,605,024.10
4	×	√	19,525,239.81	323,411.33	323,411.33	0.00	19,201,828.47	1,191,564.98	18,010,263.49	18,010,263.49	7,154,000.70
5	×	×	5,605,024.10	1,345,350.47	1,345,350.47	0.00	4,259,673.63	4,259,673.63	0.00	0.00	7,210,585.35
6	×	×	7,154,000.70	2,267,667.35	2,267,667.35	0.00	4,886,333.35	4,886,333.35	0.00	0.00	7,159,275.57
7	×	×	7,210,585.35	166,932.90	166,932.90	0.00	7,043,652.45	7,043,652.45	0.00	0.00	11,121,208.55
8	×	×	7,159,275.57	2,679,738.98	2,679,738.98	0.00	4,479,536.59	4,479,536.59	0.00	0.00	6,166,308.13
9	×	×	11,121,208.55	643,124.92	643,124.92	0.00	10,478,083.63	10,478,083.63	0.00	0.00	0.00
10	×	×	6,166,308.13	159,502.70	159,502.70	0.00	6,006,805.43	6,006,805.43	0.00	0.00	7,486,904.04
Mean			8,207,101.92	841,837.22	841,837.22	0.00	7,365,264.70	6,645,066.82	720,197.88	720,197.88	7,093,312.40
Standard Error			1,427,114.82	296,984.70	296,984.70	0.00	1,507,522.83	947,068.83	720,197.88	720,197.88	1,039,722.24
Median			7,156,638.13	422,154.78	422,154.78	0.00	6,283,314.52	6,283,314.52	0.00	0.00	7,156,638.13
Standard Deviation			4,512,933.30	939,148.07	939,148.07	0.00	4,767,205.77	2,994,894.61	2,277,465.68	2,277,465.68	3,287,890.42

Statistics of species composition change over time for hardwood

Baseline — Mean n=10, units ha

	Maple/Oak	Y. Birch	W. Birch	Ash	B. Poplar	Poplar
2010	1009.6	137.5	60401.7	242.6	99.3	147597.1
2020	2262.8	338.8	34886.1	243.7	161.6	118679.2
2030	2435.4	398.4	28909.5	244	220	116200
2040	2713.7	433.9	23112.7	246.1	320.1	111581.1
2050	3023.9	466.9	20065.5	248.2	366	108013.7
2060	3154.5	486	17047.9	250.1	434.4	106024.7

CGCM2A22 — Mean n=10, units ha

	Maple/Oak	Y. Birch	W. Birch	Ash	B. Poplar	Poplar
2010	1008.2	134	60607	242.6	45	146781.2
2020	2262	349.6	35353.9	243.2	96.8	117278.2
2030	2471.7	382	29317.9	243.3	169.4	113612
2040	2752.3	439.8	23347.8	245.3	299.8	110342
2050	2952.1	452.3	20481.4	248.4	333.4	106665.3
2060	3102.2	511.2	17250.9	250.2	442.8	107308.6

CCSRNIESA21 — Mean n=10, units ha

	Maple/Oak	Y. Birch	W. Birch	Ash	B. Poplar	Poplar
2010	945.3	145.5	59961.3	242.7	214.3	151903.1
2020	1978.8	379.2	37374.3	244	414.5	129964.6
2030	2109.9	466.7	32259.7	245.3	501.5	127147.1
2040	2300.1	513	27590.2	247.4	669.4	123792.3
2050	2716	536.5	24011.5	249.1	670.1	118423.2
2060	2840.3	598.4	20626.7	250.1	832.6	117716.4

Baseline — S.E. n=10, units ha

	Maple/Oak	Y. Birch	W. Birch	Ash	B. Poplar	Poplar
2010	24.01722	5.090841	214.4732	0.163299	33.79219	964.8726
2020	59.98718	11.72159	503.1981	0.334996	50.09928	2747.262
2030	82.15232	21.95258	741.6093	0.365148	53.85536	2810.522
2040	94.3311	24.66327	1051.932	0.752034	50.62003	3086.592
2050	48.90045	26.98125	806.0433	0.827312	69.11006	2673.479
2060	55.56023	28.86135	747.4074	1.260071	64.6184	2578.588

CGCM2A22 — S.E. n=10, units ha

	Maple/Oak	Y. Birch	W. Birch	Ash	B. Poplar	Poplar
2010	10.50587	5.696002	81.4285	0.266667	21.64512	1037.278
2020	51.32186	9.999111	212.565	0.38873	23.72378	2057.665
2030	73.06497	10.64268	396.1921	0.395811	38.2414	2421.621
2040	87.12074	20.31846	572.3379	0.517472	76.14501	3568.754
2050	65.63069	22.87359	529.5799	0.541603	80.89653	3431.192
2060	69.56129	41.8733	479.2594	0.663325	84.89272	3424.421

CCSRNIESA21 — S.E. n=10, units ha

	Maple/Oak	Y. Birch	W. Birch	Ash	B. Poplar	Poplar
2010	23.61734	10.23746	299.2493	0.213437	62.68068	2357.808
2020	108.2385	27.89815	1158.016	0.557773	124.7129	4775.956
2030	130.2466	43.06818	1515.215	1.247664	127.1865	5220.958
2040	149.9169	43.03694	2068.753	1.156623	149.3299	5928.866
2050	121.2981	49.53814	1651.354	1.501481	151.112	5520.179
2060	140.4607	67.88621	1580.653	1.566667	189.0119	5661.204

Statistics of species composition change over time for softwood

Baseline — Mean n=10, units ha

	Balsam Fir	Larch	Jack Pine	W. Spruce	B. Spruce	R. Pine	W. Pine	edar/Hemlock
2010	17136.7	1687.6	134659.1	3793.5	328301	577.5	2290	10028.6
2020	29528.9	1214.9	139361.4	6465.2	358068.3	701.3	4841.3	11202.4
2030	35028	966.1	160514.5	6662.4	339713.4	1054.7	5434.8	10176.2
2040	40819.1	787.4	180134	6752	325539.6	1928.7	5372.7	8211.9
2050	45907.1	663.5	191501.6	6046.4	316713.8	3174.2	4928.9	6837
2060	51296.2	500.5	214385.8	4710.4	296208.3	3851.2	4722	4879.3

CGCM2A2 — Mean n=10, units ha

	Balsam Fir	Larch	Jack Pine	W. Spruce	B. Spruce	R. Pine	W. Pine	edar/Hemlock
2010	17272.5	1690.5	132140	3722.6	331399.2	570.6	2316.5	10038.9
2020	30361.4	1215.6	135847.7	6685.7	361410.7	725.5	4853.6	11279.7
2030	35686.2	971.1	154123.3	6826	346842.2	989.4	5595.4	10731.3
2040	41424.5	793.6	174754.3	7107.8	330601.4	1939	5500.8	8406.7
2050	46958.2	676.8	187640.6	6332.3	319843.4	3044.1	5223.4	7103.1
2060	50169.5	507.9	215505.2	4994.1	294227.7	3655.8	4960.7	5060.8

CCSRNIES — Mean n=10, units ha

	Balsam Fir	Larch	Jack Pine	W. Spruce	B. Spruce	R. Pine	W. Pine	edar/Hemlock
2010	15309.5	1641.7	148430.1	3990.8	313139.3	561.1	2035.8	9439.9
2020	25711.3	1187.7	159346.2	6473	330429	735.3	3936.6	9778.5
2030	30796.9	985.6	181624.8	6584.2	311172.8	1172.9	4375.3	8508.9
2040	35593.3	806.1	201493.9	6525.9	295777.4	1994.8	4218.8	6427.7
2050	40264.5	714.3	210159.7	5922.9	291743.8	2851.7	4209.2	5478.3
2060	41865.7	580	233842.3	5004.4	272102.2	3226.6	4071	4390.3

Baseline — S.E. n=10, units ha

	Balsam Fir	Larch	Jack Pine	W. Spruce	B. Spruce	R. Pine	W. Pine	edar/Hemlock
2010	380.5469	3.950246	2636.093	110.3413	2877.847	8.721939	31.89183	50.90191
2020	1147.061	8.451759	6008.883	145.1271	7604.942	23.95415	195.5954	295.4009
2030	1230.16	13.40021	5898.624	133.6959	7513.627	68.35155	256.234	408.6393
2040	1383.934	9.071567	6015.527	174.5375	7833.965	79.903	288.1769	490.3328
2050	1580.104	13.79875	6538.495	211.4046	7790.229	115.5999	223.682	418.0173
2060	1868.098	17.92593	5651.974	198.4921	6566.081	139.8338	184.272	310.2915

CGCM2A2 — S.E. n=10, units ha

	Balsam Fir	Larch	Jack Pine	W. Spruce	B. Spruce	R. Pine	W. Pine	edar/Hemlock
2010	423.771	5.057997	2479.57	53.44596	2939.289	10.64393	24.01585	108.7054
2020	758.8945	6.912469	3481.299	144.4244	4649.172	21.11832	81.79421	190.4819
2030	801.1594	7.817999	3380.72	180.5249	4842.873	48.88153	143.392	301.8397
2040	1706.418	7.961295	5539.933	209.2523	7269.203	98.24799	203.3692	461.6515
2050	1913.217	12.76436	6262.578	210.9666	7576.783	119.9509	209.5295	461.4938
2060	2227.835	16.92562	6472.929	200.5425	7388.907	87.36587	192.6584	412.1332

CCSRNIES — S.E. n=10, units ha

	Balsam Fir	Larch	Jack Pine	W. Spruce	B. Spruce	R. Pine	W. Pine	edar/Hemlock
2010	892.0863	14.82344	6605.573	144.1672	7532.75	13.59612	128.9867	269.5944
2020	1729.548	10.27624	9035.814	160.6013	12153.24	40.55341	371.0898	532.8715
2030	1968.345	18.18253	9211.194	237.6986	12652.73	108.4718	465.2089	743.2971
2040	2647.121	15.79905	10082.36	249.3882	13677.85	71.35931	504.0363	826.9525
2050	3218.197	25.87966	9393.485	153.4668	12038.04	148.1835	345.596	621.2014
2060	4045.488	29.42184	10018.26	151.0244	12259.78	249.643	350.6844	497.0604

Statistics of species composition change over time for other species

Baseline	Mean n=10, units ha	
	Open	*Bush/Alder*
2010	11.2	6614
2020	17.1	6614
2030	15.6	6614
2040	20	6614
2050	16.3	6614
2060	21.7	6614

CGCM2A22	Mean n=10, units ha	
	Open	*Bush/Alder*
2010	4.2	6614
2020	9.4	6614
2030	11.8	6614
2040	17.9	6614
2050	18.2	6614
2060	25.4	6614

CCSRNIESA21	Mean n=10, units ha	
	Open	*Bush/Alder*
2010	12.6	6614
2020	20	6614
2030	21.4	6614
2040	22.7	6614
2050	22.2	6614
2060	26	6614

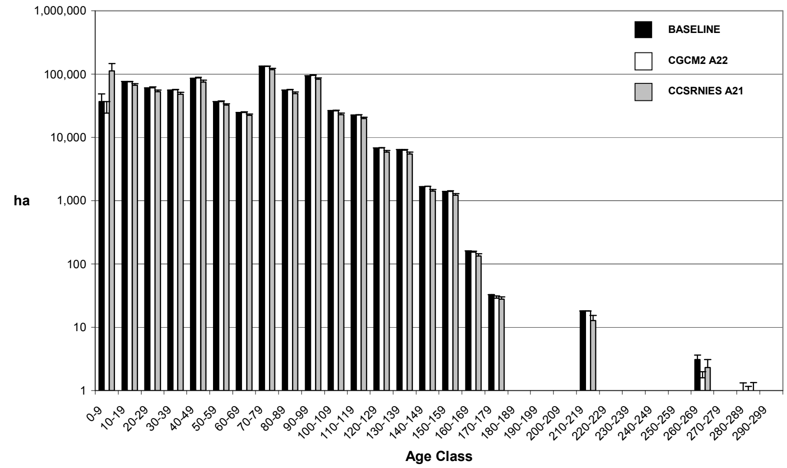
Baseline	S.E.n=10, units ha	
	Open	*Bush/Alder*
2010	3.485844	0
2020	3.274311	0
2030	2.362673	0
2040	3.105551	0
2050	2.599359	0
2060	4.038839	0

CGCM2A22	S.E.n=10, units ha	
	Open	*Bush/Alder*
2010	2.112397	0
2020	2.196968	0
2030	2.080598	0
2040	4.822286	0
2050	4.680456	0
2060	5.168709	0

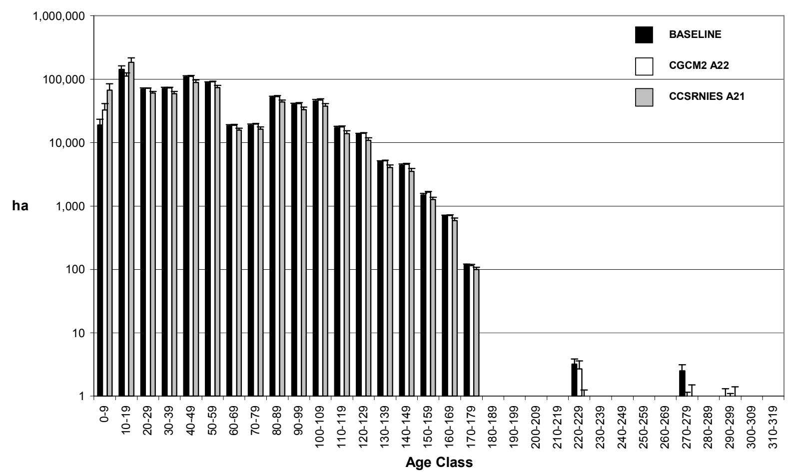
CCSRNIESA21	S.E.n=10, units ha	
	Open	*Bush/Alder*
2010	3.896437	0
2020	4.077036	0
2030	3.190959	0
2040	3.3	0
2050	3.372437	0
2060	5.895384	0

Appendix 6. Stand Age Class Graphs

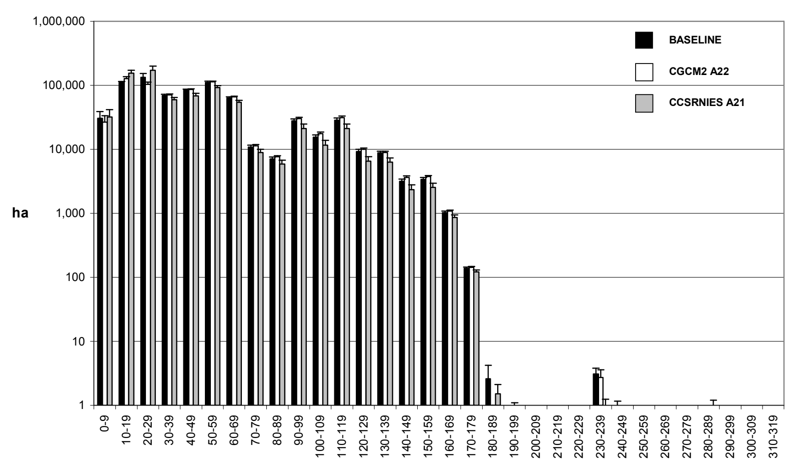
Age Classes Before Harvesting: All Working Groups Year 2010



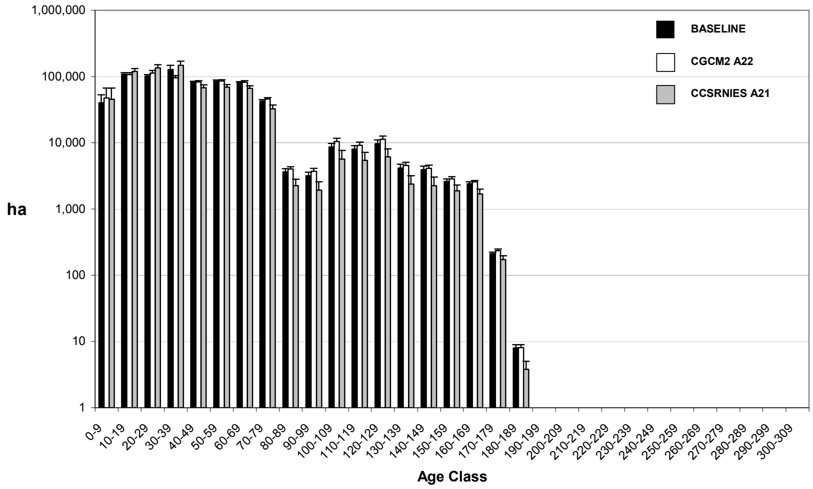
Age Classes Before Harvesting: All Working Groups Year 2020



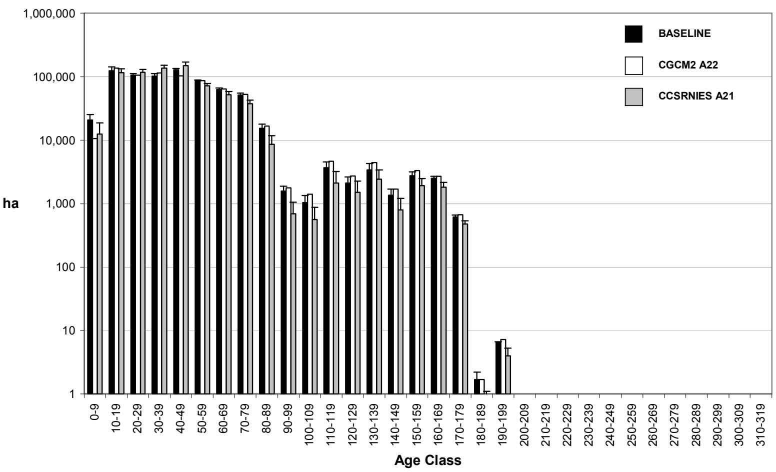
Age Classes Before Harvesting: All Working Groups Year 2030



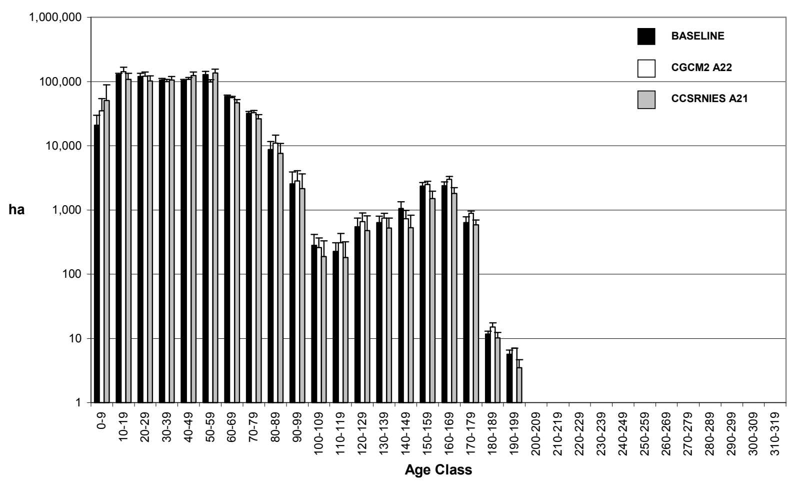
Age Classes Before Harvesting: All Working Groups Year 2040



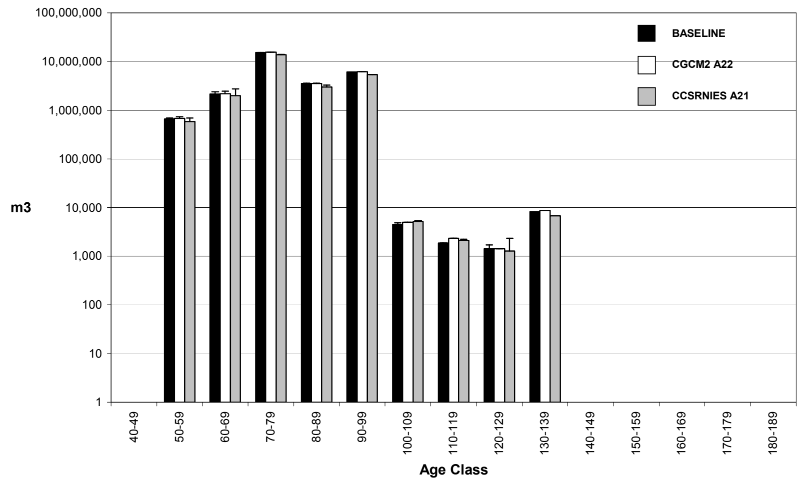
Age Classes Before Harvesting: All Working Groups Year 2050



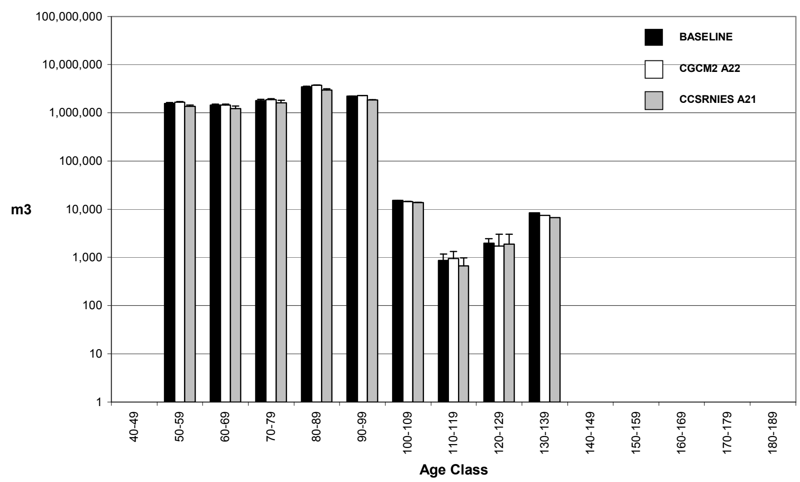
Age Classes Before Harvesting: All Working Groups Year 2060



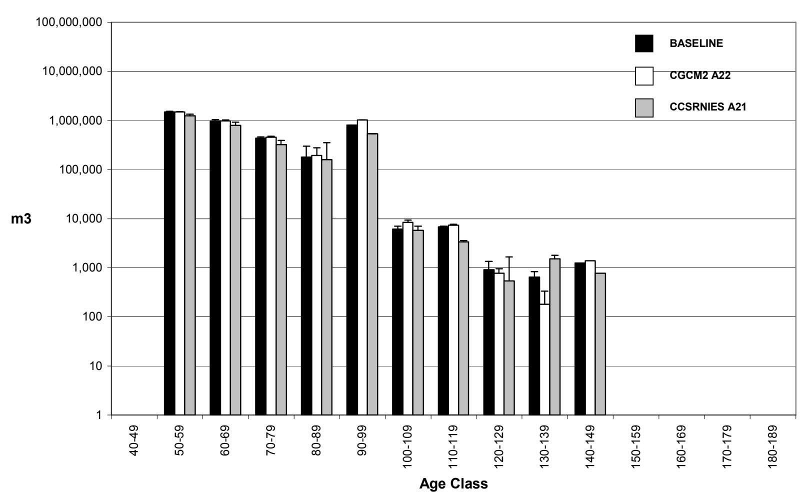
Harvesteable Hardwood Age Classes Year 2010



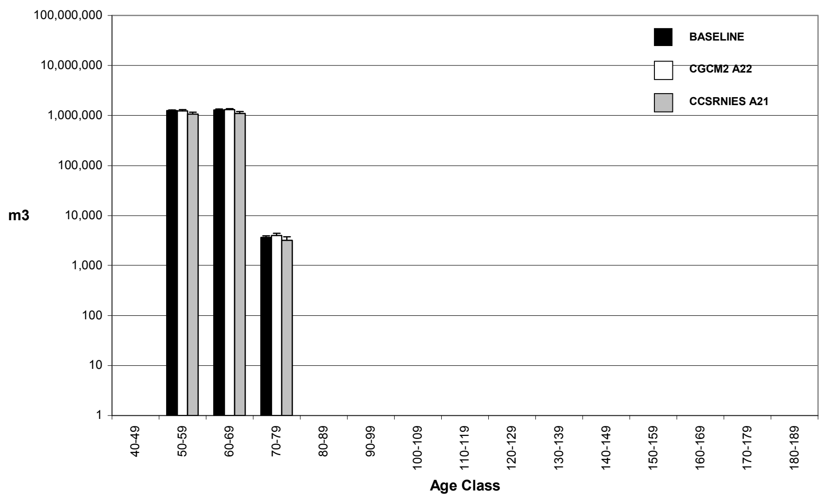
Harvesteable Hardwood Age Classes Year 2020



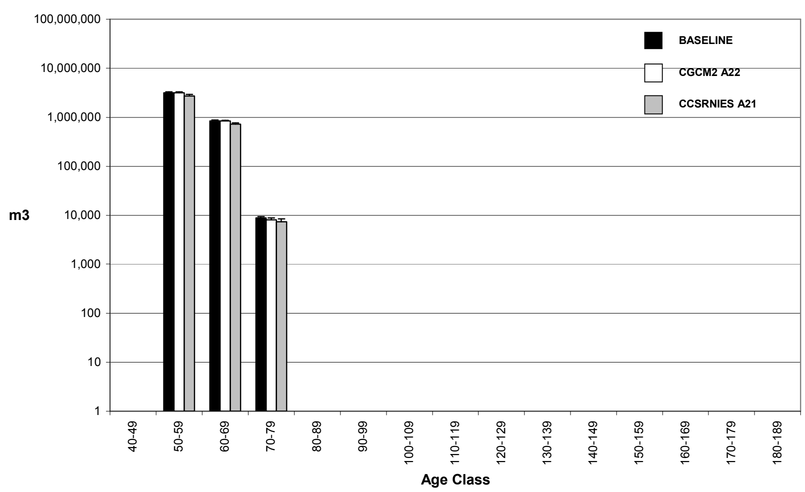
Harvesteable Hardwood Age Classes Year 2030



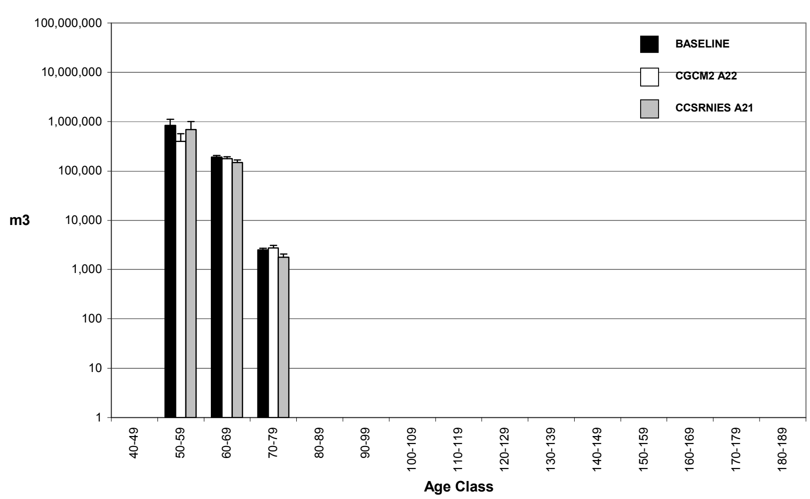
Harvesteable Hardwood Age Classes Year 2040



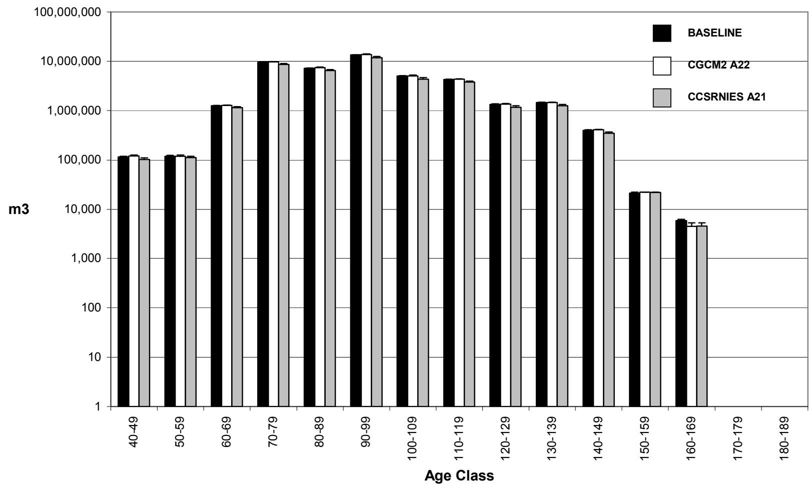
Harvesteable Hardwood Age Classes Year 2050



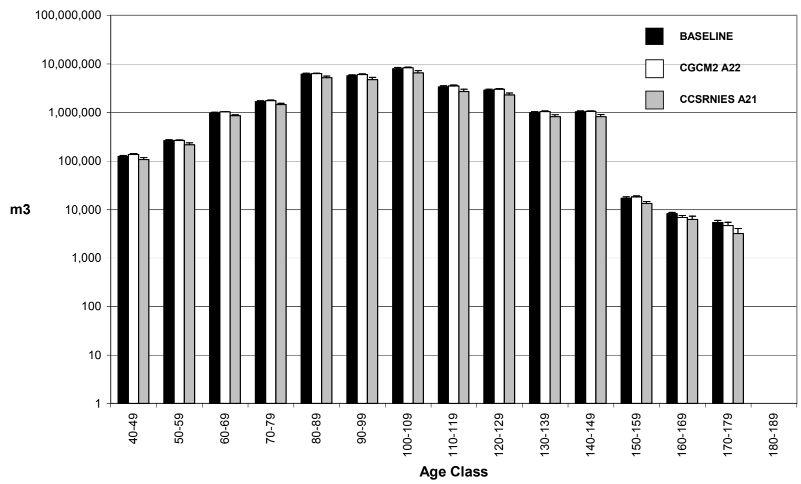
Harvesteable Hardwood Age Classes Year 2060



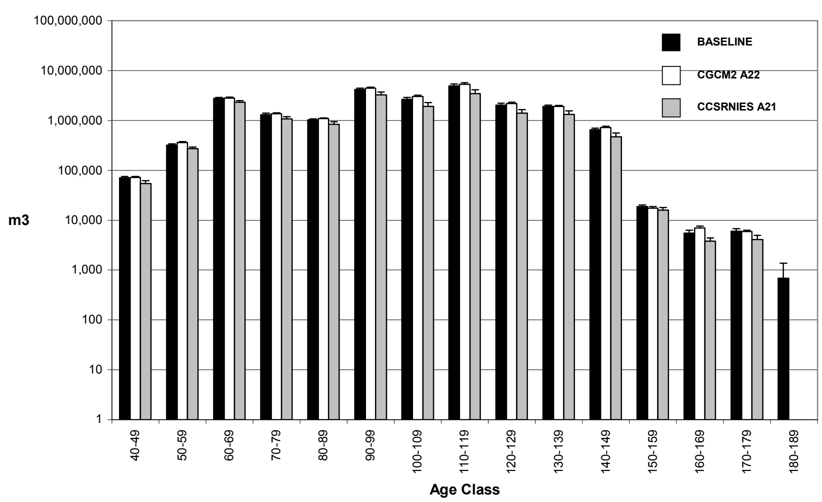
Harvesteable Softwood Age Classes Year 2010



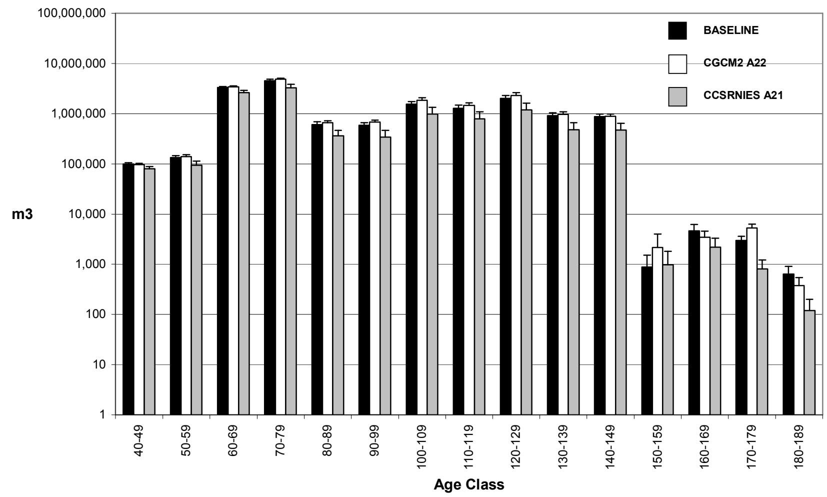
Harvesteable Softwood Age Classes Year 2020



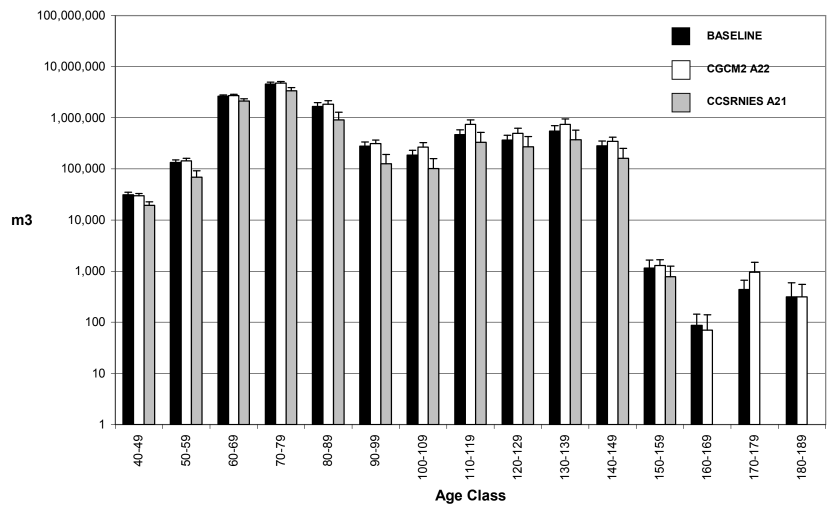
Harvesteable Softwood Age Classes Year 2030



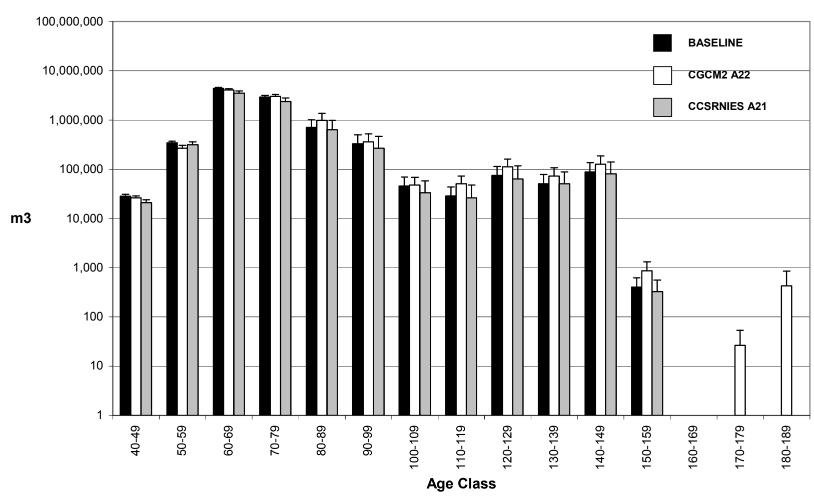
Harvesteable Softwood Age Classes Year 2040



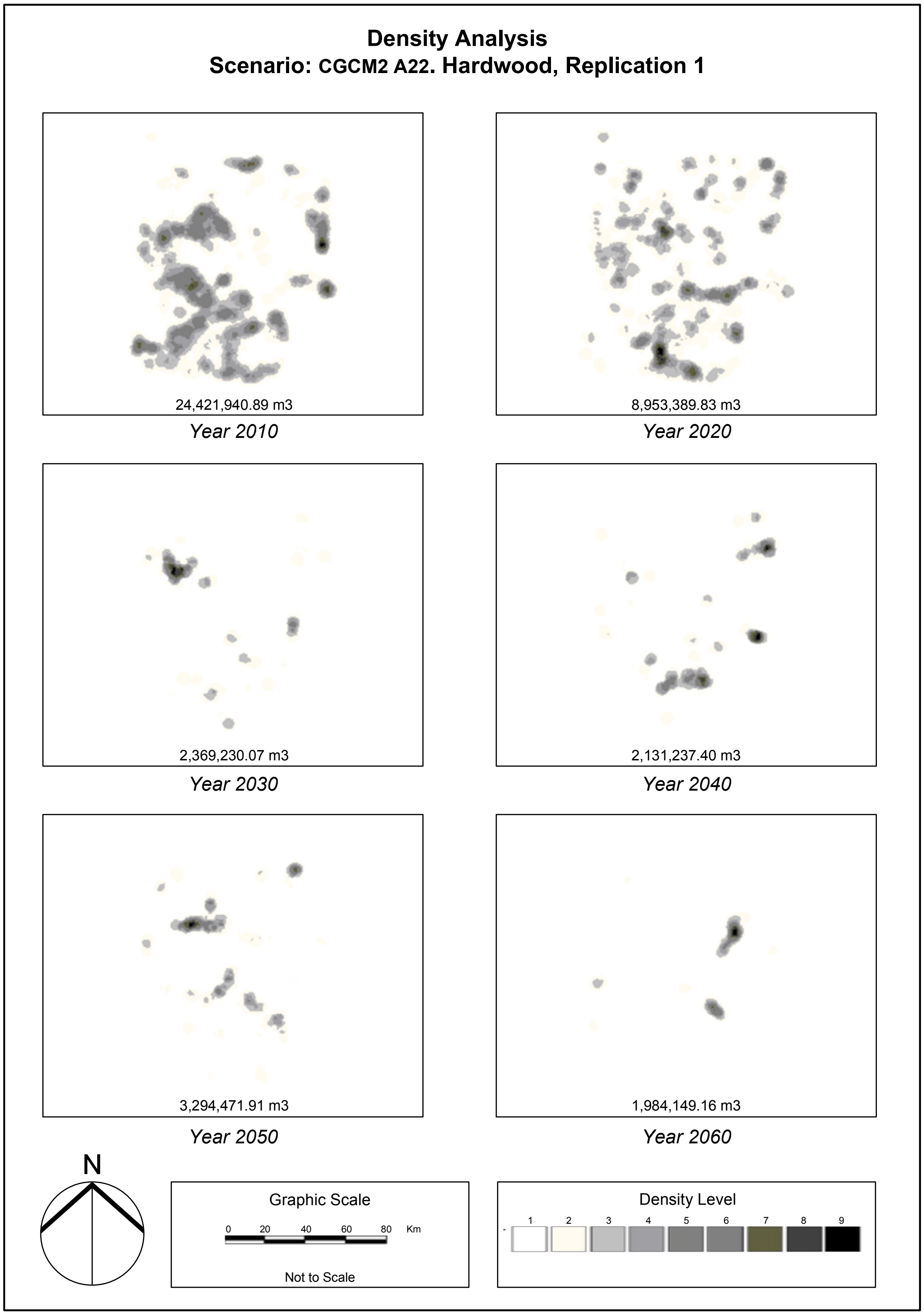
Harvesteable Softwood Age Classes Year 2050



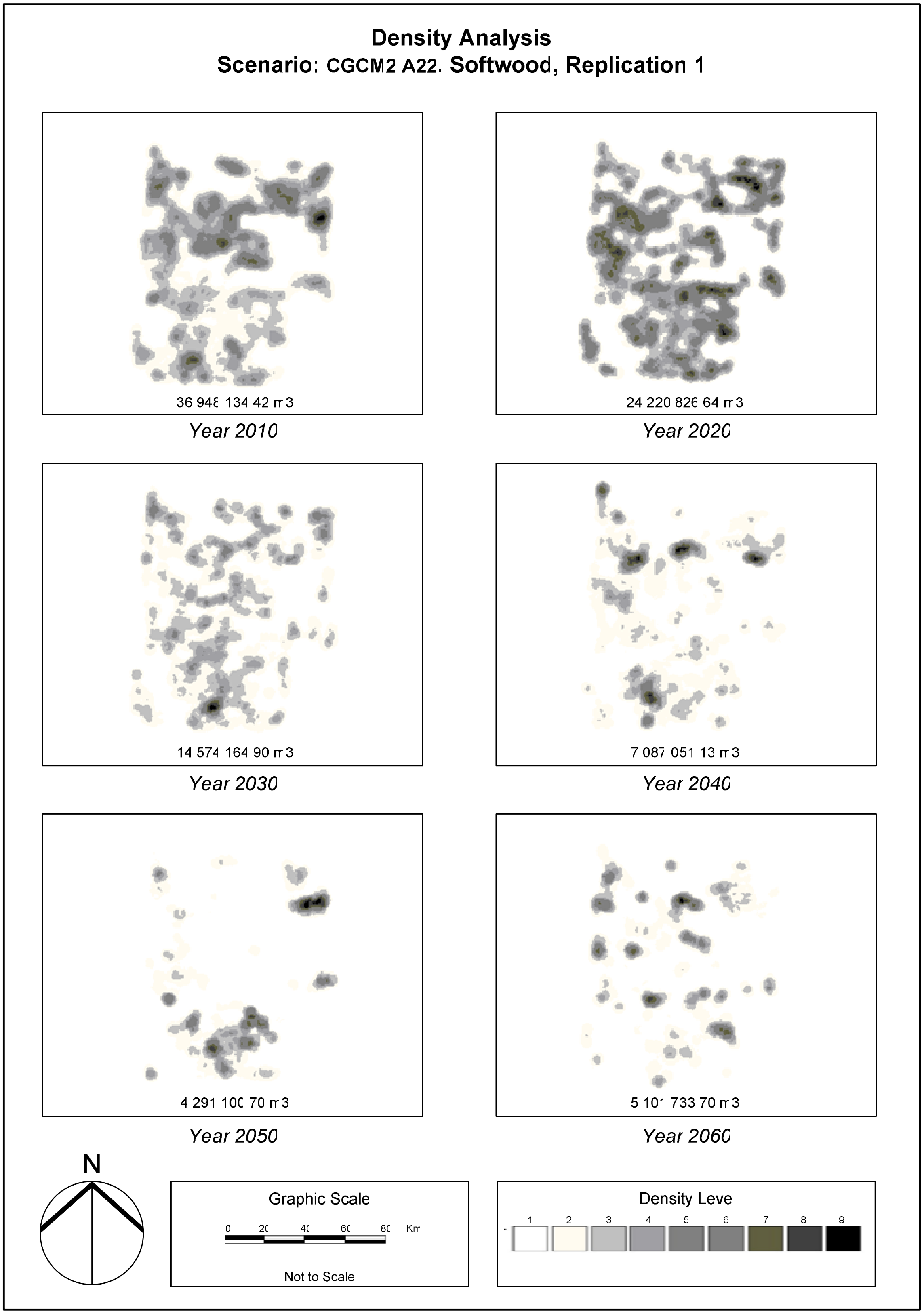
Harvesteable Softwood Age Classes Year 2060



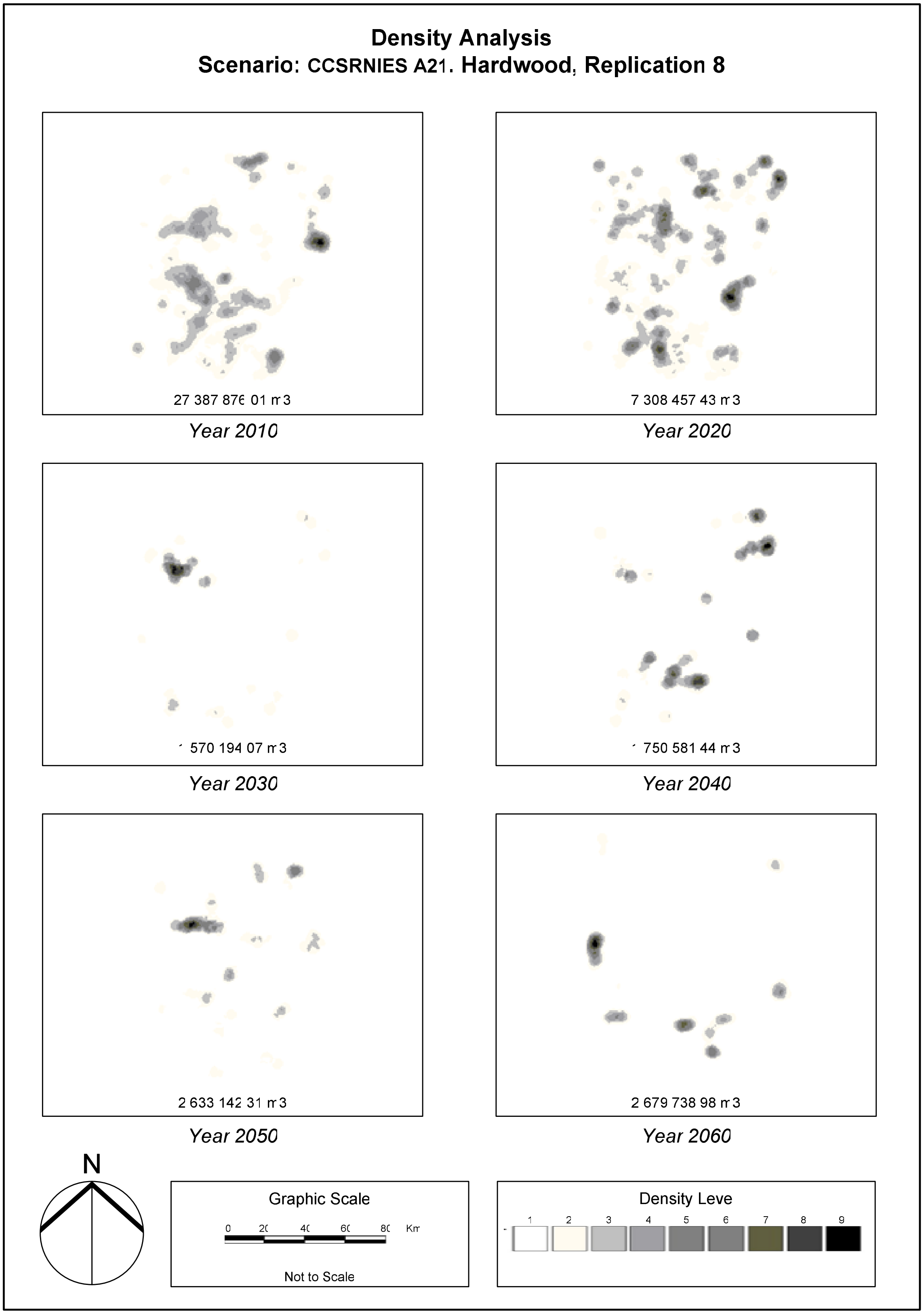
Appendix 7. Density Analysis Maps



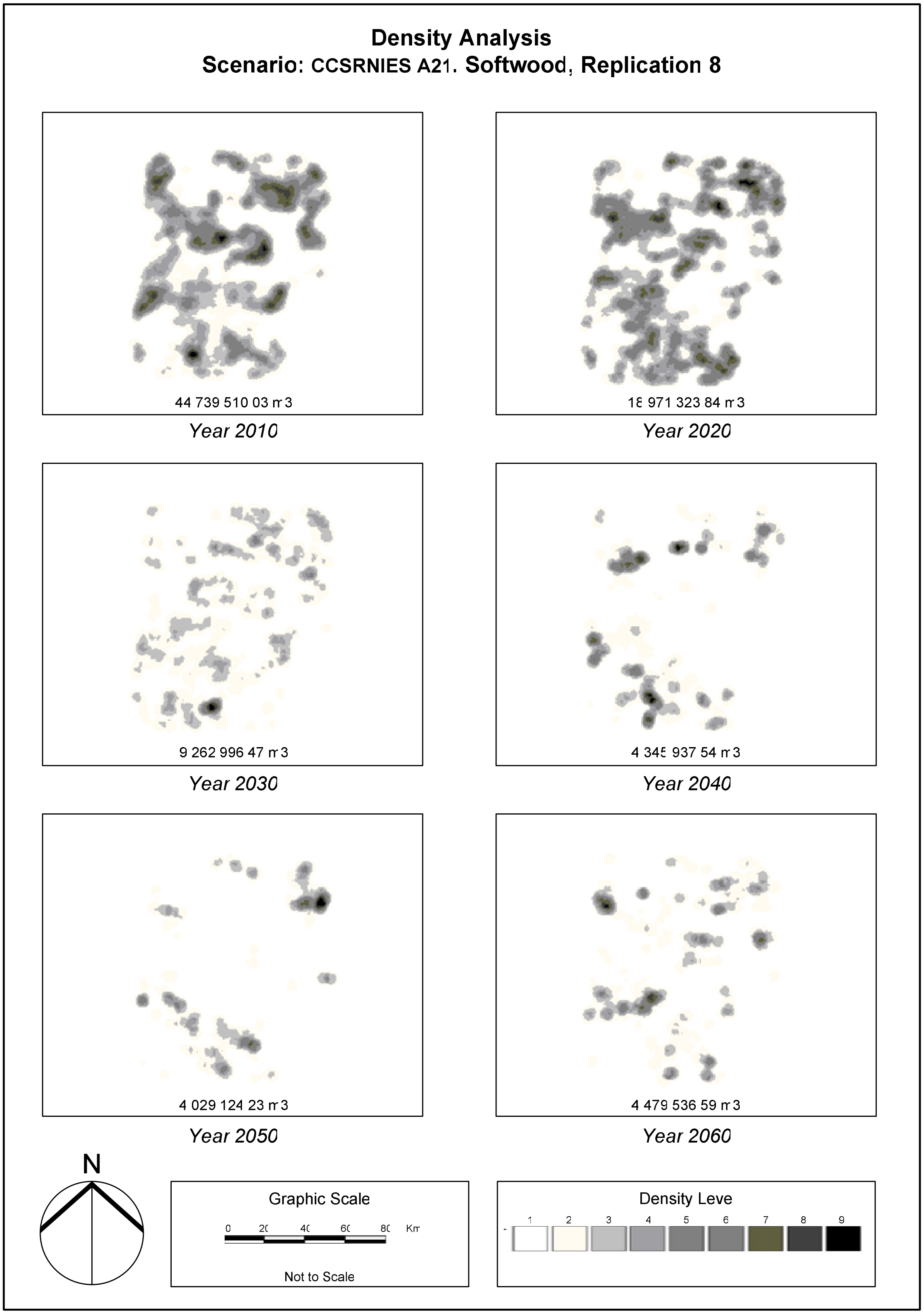
Density analysis sample for hardwood (volume indicated inside each map corresponds to timber available each year).The target for hardwood every 10 year was 8,000,000 m^3 ± 20%.



Density analysis sample for softwood (volume indicated inside each map correspondes to timber available each year).The target for softwood every 10 year was 12,000,000 m^3 ± 20%.



Density analysis sample for hardwood (volume indicated inside each map corresponds to timber available each year).The target for hardwood every 10 year was 8,000,000 m^3 ± 20%.



Density analysis sample for softwood (volume indicated inside each map corresponds to timber available each year).The target for softwood every 10 year was 12,000,000 m^3 ± 20%.

Glossary

Adaptive capacity. † The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Anthropogenic emissions. † Emissions of greenhouse gases, greenhouse gas precursors, and aerosols associated with human activities. These include burning of fossil fuels for energy, deforestation, and land-use changes that result in net increase in emissions.

Anthropogenic.† Resulting from or produced by human beings.

Atmosphere.† The gaseous envelop surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases, such as argon (0.93% volume mixing ratio), helium, and radiatively active greenhouse gases such as carbon dioxide (0.035% volume mixing ratio) and ozone. In addition, the atmosphere contains water vapor, whose amount is highly variable but typically 1% volume mixing ratio. The atmosphere also contains clouds and aerosols.

Available (harvestable) timber.***** Timber that based on age, and other characteristics can be logged.

Baseline.† The baseline (or reference) is any datum against which change is measured. It might be a "current baseline," in which case it represents observable, present-day conditions. It might also be a "future baseline," which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.

Biodiversity.† The numbers and relative abundances of different genes (genetic diversity), species, and ecosystems (communities) in a particular area.

Biomass.† The total mass of living organisms in a given area or volume. In this thesis it only considers biomass contained in mature trees to be logged.

Biota.† All living organisms of an area; the flora and fauna considered as a unit.

Boreal forest.† Forests of pine, spruce, fir, and larch stretching from the east coast of Canada westward to Alaska and continuing from Siberia westward across the entire extent of Russia to the European Plain.

Climate†. Climate in a narrow sense is usually defined as the "average weather" or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change.† Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between "climate change" attributable to human activities altering the atmospheric composition, and "climate variability" attributable to natural causes.

Climate Forcing (in the TAR of the IPCC). † The radiative forcing of the surface-troposphere system due to the perturbation in or the introduction of an agent (say, a change in greenhouse gas concentrations) is the change in net (down minus up) irradiance (solar plus long-wave; in Wm^{-2}) at the tropopause AFTER allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropo-spheric temperatures and state held fixed at the unperturbed values".

Climate scenario.† A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate. A "climate change scenario" is the difference between a climate scenario and the current climate.

Climate variability.† Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). See also climate change.

Crown Lands.* Land vested in Her Majesty in the right of Ontario.

Disturbance regime.† Frequency, intensity, and types of disturbances, such as fires, inspect or pest outbreaks, floods, and droughts.

Equilibrium and transient climate experiment.† An "equilibrium climate experiment" is an experiment in which a climate model is allowed to fully adjust to a change in radiative forcing. Such experiments provide information on the difference between the initial and final states of the model, but not on the time-dependent response. If the forcing is allowed to evolve gradually according to a prescribed emission scenario, the time dependent response of a climate model may be analyzed. Such an experiment is called a "transient climate experiment." See also climate projection.

Extent.*** The size of the area or temporal boundaries of the system under consideration or by the total area sampled.

Forest products.** Any raw material yielded by trees.

Forest Resource Inventory.* An assessment of forest resources, including digitized maps and a database which describes the location and nature of forest cover (including tree size, age, volume and species composition) as well as a description of other forest values such as soils, vegetation and wildlife features.

Grain*** The finest level of resolution, or measurement made in an observation.

Hardwood.** The wood of an angiospermous tree as distinguished from that of a coniferous tree.

Harvesting.** The removal of forest products for utilization, comprising cutting and sometimes initial processing and extraction.

Hierarchy.**** A system if interconections wherein the higher levels constrain the lower levels to various degrees.

Kyoto Protocol.† The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted at the Third Session of the Conference of the Parties to the UNFCCC in 1997 in Kyoto, Japan. It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in Annex B of the Protocol (most countries in the Organization for Economic Cooperation and Development, and countries with economies in transition) agreed to reduce their anthropogenic greenhouse gas emissions (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride) by at least 5% below 1990 levels in the commitment period 2008 to 2012.

Land use.† The total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions). The social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation).

Land-use change.† A change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land-use change may have an impact on the albedo, evapotranspiration, sources, and sinks of greenhouse gases, or other properties of the climate system, and may thus have an impact on climate, locally or globally.

Mitigation.† An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.

Non-linearity.† A process is called "non-linear" when there is no simple proportional relation between cause and effect. The climate system contains many such non-linear processes, resulting in a system with a potentially very complex behavior. Such complexity may lead to rapid climate change.

Operability limit (maximum)[36]***.** Maximum age set to select a species to be logged. If a cell was above this limit, it was not selected for calculations of timber availability. It varied with each species.

Operability limit (minimum).*****. Minimum age set to select a species to be logged. If a cell was below this limit, it was not selected for calculations of timber availability. It varied with each species.

Resilience.† Amount of change a system can undergo without changing state.

Scale.***** Spatial or temporal dimensions of an object or process, characterized by grain and extent.

Scenario.† A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technology change, prices) and relationships. Scenarios are neither predictions nor forecasts and sometimes may be based on a "narrative storyline." Scenarios may be derived from projections, but are often based on additional information from other sources.

Site class.* The measure of the relative productive capacity of a site for a particular crop or stand, generally based on tree height at a given age and expressed as either good, medium, poor or low.

Softwood.** Cone-bearing trees with needles or scale-like leaves belonging to the botanical group Gymnospermae. Also, stands of such trees and the wood produced by them.

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[36] Maximum and minimum operability limits defined a window from where cells with age within those limits were used to make calculations of timber available. Timber calculations considered age, species, and site class. Cell selection for logging was based on yield and location (see sections 4.2.9.1 and 4.2.9.2).

Stand Age Class.** One of the intervals into which the age range of forest stands is divided for classification and use.

Stands.** A community of trees possessing sufficient uniformity in composition, constitution, age, arrangement, or condition to be distinguishable from adjacent communities.

Sustainable development.† Development that meets the needs of the present without compromising the ability of future generations to meet their own needs

Timber available.*** Timber potentially harvested which is equal to the *Gross Merchantable Volume* in m^3/ha indicated in Plonski (1974).

Working group.** An aggregate of stands (cells in this thesis), having the same predominant species, and managed under the same broad silvicultural system.

Yield. ** The actual or estimated harvest of forest products over a given period of time. In this thesis it was considered as the timber available in cubic meters in each cell that had age between operability limits. In this thesis it was considered as the timber available in cubic meters in each cell that had age between operability limits.

† (IPCC, 2001a)

* (Ministry of Forests, 2001)

** (Ontario Ministry of Natural Resources, 1996a)

*** (O'Neill and Smith, 2002)

**** (Turner et al., 2001)

***** Of my own

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