University of Alberta

Economics of Carbon Sequestration and Sawmill Sizing in Moose Factory, Ontario

by

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Abstract

This study investigates how both carbon management incentives and forest management will affect the Moose Cree First Nation in Moose Factory, Ontario. This is a two-part case study looking at both carbon incentives and sawmill sizing in areas of the Moose Cree First Nation's traditional territory. A linear programming model was developed to analyze the timber supply available from the forest and then carbon yields were added to capture the level of carbon available. Carbon yields were developed using the Canadian Forest Service's Carbon Budget Model. A mixed integer programming model was also developed to determine an appropriate sawmill size for the area considering the timber supply available and other factors such as costs and revenues. The conclusions drawn from the study will contribute to the decision making process that the Moose Cree First Nation are currently engaged in regarding land use planning in their traditional territory.

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Chapter 1 : Introduction

The Moose Cree First Nation has a unique opportunity in Canada. They have access to an area of forest that has never been harvested and can decide what types of management activities they would like to implement, if any, to encourage economic development in their region. They are interested in both timber and non-timber benefits as well as maintaining traditional lands and their uses. In an attempt to help inform the choices available to the Moose Cree First Nation, this study will address three types of activities that could occur. The first is basic forest management: the economic feasibility of harvesting timber is explored. The second examination is the potential for the incorporation of carbon sequestration into a forest management framework. Lastly, the feasibility of constructing a sawmill in Moose Factory is examined. While the focus of this study is the Moose Factory region, the issues examined in this thesis are relevant to a number of communities in Canada who are facing the challenge of assessing tradeoffs between economic development and traditional uses of land in a world affected by climate change.

1.1 General Problem

Climate change has become an important issue not only in academic circles but to the public as a whole. Although there is little doubt that climate change is occurring and that it is likely caused by human activities, there is not yet a global consensus on how to address the issue (IPCC, 2007). Canada's forests have been seen as a potential means of reducing greenhouse gases through carbon sequestration (IPCC, 2007). Trees have the ability to act both as carbon sinks and carbon sources throughout their lifecycles (Kurz *et* *al.* 2002). Some forest management activities can increase the size of carbon sinks while others can delay the timing of the carbon source (Apps *et al.* 1999). Because forest management can enhance carbon sequestration, various incentive strategies could be used to promote carbon management in the forestry sector (Sun and Sohngen 2006). Incentive systems can have effects on the structure of the forest by altering rotation times and can affect markets through the increases or decreases in the supply of wood (Hoen and Solberg, 1997). Many studies have shown that incorporating carbon sequestration into forest management results in longer rotations and the complete cessation of timber harvesting with high enough incentives (van Kooten *et al.* 1995, Creedy and Wurzbacher 2001, Murray 2000, Hoen and Solberg 1997; Plantinga and Birdsey 1994). Several studies have examined the costs of sequestration and incentive programs, but few have examined the effects that carbon sequestration has at the operational scale or in a First Nation Community[1].

The policy situation regarding forests and carbon markets is somewhat ambiguous. The current government has begun to implement a new climate change strategy, but it is unclear what role, if any, forests will play in this strategy (Government of Canada, 2006). Recently, the province of Ontario has been implementing its own climate change initiatives which could include a carbon credit trading system which could potentially include forests (Ontario Office of the Premier, 2007).

[1] The exceptions to this is McCarney's (2007) who analysed the effects of carbon sequestration on a representative Boreal forest and Krcmar and van Kooten (2005) who studied the potential benefits from a carbon sequestration program for the Little Red River Cree in Northern Alberta.

Turning to the second area of investigation, most of Canada's forest are fully allocated therefore very few new mills have been built and there is very little discussion of optimal sawmill sizing in agricultural economics literature. The literature, however, does discuss optimal equipment sizing. Thus, the study on optimal sawmill sizing is based on the framework outlined in agricultural economics literature (Brown and Schoney, 1985). The decision to build a sawmill is a function of several factors including costs, timber prices, and wood supply. The Moose Cree First Nation are in the process of creating a Land Use Plan for their traditional territories. A part of the discussion is whether or not to build a sawmill to support some forest harvesting (Personal communication with John Turner). This thesis explores the optimal sawmill size and the sensitivity of this decision to various price and cost factors.

1.2 Research Objectives

The purpose of this research is to provide insight into two aspects of forest management in remote areas of Canada's boreal forest – the assessment of carbon management as an option in forest management as well as sawmill sizing decisions. This information is expected to be useful to the Moose Cree First Nation in regards to their decisions on carbon management and the potential for the construction of a sawmill in their community. The research can also provide information to industry and government regarding the feasibility of implementing a carbon management program at the community level which has not had much attention in the literature (the exception being Krcmar and van Kooten, 2005). In addition to providing information required in the decision to build a sawmill this research will also try to determine which size of sawmill is appropriate given the available timber and market conditions. The specific objectives of this study are as follows:

1. Develop a linear programming framework of forest management in the Moose Factory area that incorporates: harvesting, regeneration, consideration of traditional values and carbon stocks.

2. Determine the effect that incorporating carbon and traditional values has on the optimal forest management plan. In particular, what effects will managing for carbon and traditional values have on harvest levels and rotations?

3. Develop a mixed integer programming framework to determine the optimal sawmill size given the forest area, and allow for the possibility that the optimal solution may be not to build a sawmill.

4. Examine the sensitivity of the mixed integer programming framework to various parameters, in particular: prices, interest rates, down payments, costs and consideration of traditional values.

5. Describe how various forest regulations, such as regeneration regulations and even flow constraints, affect carbon supply and the decisions to construct a sawmill.

1.3 Thesis Structure

The thesis is structured as a "two-paper thesis". Chapter 2 discusses: background information and literature on carbon dynamics, the economics of carbon management, traditional land use and values and the study area. Chapter 3 outlines the model formulation used in analyzing the effects of carbon incentives on forest management as well as the framework used to determine the optimal mill size. Chapter 4 details the results of the carbon management model. Chapter 5 presents the results from the sawmill sizing model. In addition Chapter 5 outlines the results of sensitivity analysis. Chapter 6 concludes the thesis with some discussion of the results of both models and some of the policy implications as well as the limitations of the study and suggestions for future research.

Chapter 2 : Background

This chapter presents the background information that will be needed to investigate the potential for carbon management and forest management in Moose Factory, Ontario. The first section will explore carbon management in Canada with emphasis on: the biology, the policy frameworks in Canada, the economics and issues surrounding the implementation of carbon markets. The next section outlines the study area in Northern Ontario and reveals the structure of the forest area that is being studied. The last section addresses the traditional land use values in the study area and concerns that the Moose Cree First Nation have in regards to forest and carbon management.

2.1 Carbon Management

2.1.1 Carbon Dynamics

Forests have a unique role to play in the exchange of carbon dioxide (CO_2) with the atmosphere. They emit CO_2 through the natural processes of respiration and decomposition and can store carbon (C) through photosynthesis. Though trees and forests are long-lived, the carbon that is stored as a result of photosynthesis is not permanent. It will decrease as the forest ages and eventually will release CO_2 as the stand decomposes after its death. Disturbances to the forest can also increase or decrease the amount of CO_2 released from forests and stored in forests. Natural disturbances such as wildfires and insects can increase the CO_2 release into the atmosphere through both direct emissions from combustion and increases in decomposition from mortality. Human disturbances such as harvesting and deforestation can also increase the CO_2 release into the atmosphere. Conversely, reforestation efforts can increase the carbon storage in the forest. As a result, individual stands can act as sinks or sources for carbon depending on factors such as age and disturbance history (Kurz *et al.* 2002).

Carbon in forest stands is often described as two stocks: biomass and dead organic matter. Biomass includes the tree itself and all its foliage as well as the below ground biomass which includes fine and coarse roots. The dead organic matter stock includes all of the detritus material from the tree including litter fall and snags (Kurz and Apps 1999, Kull *et al.* 2006). Although the history and disturbances to the biomass stocks determine the amount of carbon stored in the forest, it is the dead organic matter that makes up the largest proportion of carbon in the forested stand. Kurz and Apps (1999) showed that 83% of Canada's stored carbon was in the form of dead organic matter.

Dead organic matter dynamics significantly complicate the accounting for carbon in forests. In the Canadian Forest Service's Carbon Budget Model (CBM-CFS3), dead organic matter stocks are stratified into 4 different pools as they decompose: slow, medium, fast and very fast (Kurz and Apps 1999, Kull *et al.* 2006). Each pool has different rates of decomposition and releases CO_2 accordingly into the atmosphere at different rates. In the case of a softwood species, the foliage and fine roots would go into the very fast pool while the stem wood would go into the medium pool. The rate at which the various pools decompose the organic matter is based on mean annual temperatures and geographical location (Kurz and Apps, 1999, Kurz *et al.* 2002). Figure

2-1 illustrates the carbon dynamics of a medium black spruce stand in northern Ontario after a clear-cut harvest at age 100 and reforestation following harvest. The biomass pools drop to zero after a clear-cut, as expected, but the dead organic matter stocks actually increase immediately following harvest. This is because clear cut harvests generally leave slash on the ground and the root systems intact. The slash and the root systems will decompose slowly which leads to an increase in carbon storage immediately following harvest. Some time after the harvest, as the slash and roots start to decompose, the carbon storage levels will drop for a time and then eventually increase as the stands start to regenerate and new biomass is grown and slower decomposition rates occur (Kurz and Apps, 1999).

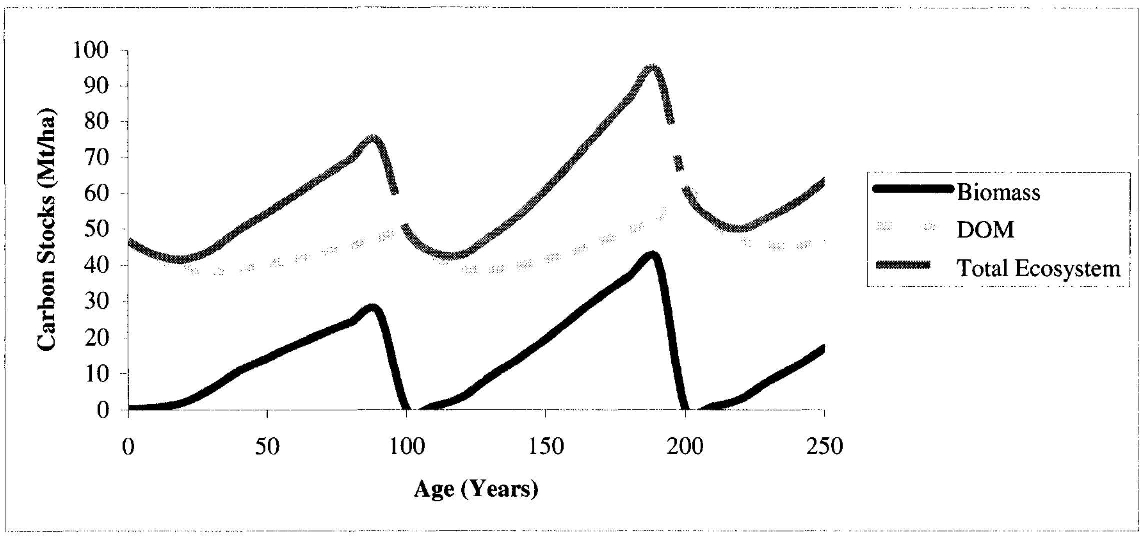

Figure 2-1: Carbon stocks of a 1 ha medium black spruce stand with a 100 year rotation. (Source: figure generated with the Canadian Forest Services Carbon Budget Model (CBM-CFS3) using Moose Factory inventory data obtained from Rob Arnup)

Another key factor in carbon dynamics and accounting is disturbance and its effects on the initial conditions of the stand. Disturbances that alter the stand age distribution are events that will dramatically alter the carbon storage of the stand. In the boreal forest, natural disturbances such as wildfire and insect defoliation can cause mortality, but in general wildfire will cause widespread mortality that will alter the age class distribution of the forest (Bhatti *et al.* 2002). It is important to know the disturbance regime and stand initiating events to correctly model carbon dynamics. A forest stand with fire as a stand initiating event will have very different C levels than one that did not. Wildfire eliminates most of the biomass and resets the age class distribution whereas a stand that has not burned will have an older age class distribution and likely a larger dead organic matter pool (Bhatti *et al.* 2002).

Carbon dynamics are largely influenced by events affecting the biomass stocks as well as the disturbance regime of the region. Modelling programs such as CBM-CFS3 take into account these factors in simulating carbon dynamics in various stands across the country.

2.1.2 Policy Framework for Carbon Management in Canada

The Intergovernmental Panel on Climate Change (IPCC) released its 4th report in 2007 which states that there is significant scientific evidence that the climate is changing and that it is most likely changing due to human activities (IPCC, 2007). Furthermore, greenhouse gas emissions (GHG) have risen 70% between 1970 and 2004 and of that 70%, 40% was as a result of land use, land use change and forestry (LULUCF) (IPCC, 2007). Much of the increase in GHG as a result of LULUCF is attributed to deforestation. In the IPCC summary report, forestry and forests are listed as having mitigation technologies. For example they project by 2030; forest management will be able to increase forest carbon sequestration through species improvement and increases in biomass productivity. Carbon management or sequestration has a role to play in reducing the growth of the world's GHG emission (IPCC, 2007).

In 2005, Canada ratified the Kyoto protocol which would mean that Canada would have to decrease its CO_2 emissions 6% below 1990 levels by 2012. Although Canada is bound by this, the Canadian Government has recently determined that it cannot meet these requirements under Kyoto and will therefore develop a "Made in Canada" plan to combat climate change and GHG emissions (Government of Canada, 2006). In the 4th annual report on climate change, the government of Canada introduced an "integrated regulatory approach" which will lead to "significant and long-term reduction in air pollution and GHG emissions from industry, transportation and consumer products" (Government of Canada 2006). They are considering various compliance mechanisms for industries including an emission trading system and credits for companies that reduce their emissions. The target for Canada's industrial sectors is to reduce GHG emissions 45-65% from 2003 levels by 2050. In the report they do not specify what role forests might play in mitigating climate change, specifically if there was a role for a carbon market using Canada's forest. The Government of Canada recognizes that climate change will affect forests and the forest economy in Canada. It points to the recent outbreaks of mountain pine beetle in British Columbia and Alberta as an example of climate change affecting the forest (Government of Canada, 2006).

Like the government of Canada, Ontario does not specifically outline any policies pertaining to carbon sequestration or management and forests. However, there are some indications that Ontario may be emerging with its own plan to tackle climate change. The governments of Ontario and California recently entered into a memorandum of understanding (MOU) on climate change (Ontario Office of the Premier, 2007). In the MOU, Ontario would adopt California's low emissions fuel standard and would work with California to create an international emissions trading system that could conceivably include carbon credits from Ontario's forests.

2.1.3 Economics of Carbon Management

The introduction of carbon markets can have significant impacts on both the forest industry and others (Sedjo, 2001). There are three main areas to examine when considering the effects that carbon sequestration in forests will have on the economy. Firstly, the costs and benefits of C sequestration must be considered. The costs of implementing carbon sequestration programs must be less than the benefits in order for this type of market to be feasible for forestry companies. Secondly, when carbon sequestration is considered a co-benefit of forestry, forest managers will have to change their management regimes to adapt to this new potential source of revenue. Lastly, the creation of carbon markets and the use of carbon credits have the potential to affect the timber market and some associated sectors such as agricultural and wood product substitutes (Sun and Sohngen 2006, Sedjo 2001).

The benefits of carbon sequestration activities are the future damages that will be avoided by reducing the amount of CO_2 in the Earth's atmosphere (Sedjo 2001). The benefits of carbon sequestration programs are rarely quantified because they are very difficult to estimate. Therefore, most of the literature focuses on the costs of such programs and the determination of their feasibility. However, some studies (Sohngen and Mendelsohn 2003) have tried to quantify how many additional hectares of forest could be added to the world's forest supply for carbon sequestration. They found through the use of an optimal control model that approximately 416 to 963 million hectares of forest could be added. Most of these new forests would arise from land use changes, increased forest rotation length and improved forest management activities.

There is substantial discussion in the literature about the costs of carbon sequestration (van Kooten *et al.* 2004; Plantinga *et al.* 1999; Sedjo 2001). The costs of sequestration activities differ significantly depending on the type of program that is analyzed. For example, reforestation programs are considered significantly more costly than conservation programs (van Kooten *et al.* 2004). Furthermore, agro-forestry initiatives and growing trees on marginal farm lands seem to be more costly than conservation or set aside programs (van Kooten *et al.* 2004). The meta-analysis report by van Kooten *et al.* (2004) highlights the vast differences in costs. In an analysis of 55 carbon cost studies, they found that the mean cost of carbon sequestration programs varied from a very small US$1.73/t C to a very large US$1675.36 /t C.

For a sequestration program to operate there must be individuals willing to pay the forests managers for the costs of sequestration. The system outlined in the Kyoto Protocol states that if landowners or managers can increase the level of carbon, above some baseline level, they may be eligible for a carbon credit. This carbon credit can be bought by CO_2 emitters in order to offset their own emissions (Watson *et al.* 2000). In order for carbon sequestration programs to be feasible for forest managers, the price of a carbon credit must be greater than the cost of sequestering the equivalent level of carbon. Other systems include giving subsidies to forest companies for accumulating forest biomass or for delaying harvest (Hoen Solberg 1997, van Kooten *et al.* 1995). Additionally, such subsidy systems would also have to tax forest companies at the time of harvest to complete the incentive. Lastly, Sun and Sohngen (2006) propose that if the price of carbon in a carbon market were high enough, landowners and managers could be persuaded to set aside their forest indefinitely from harvests.

Carbon sequestration programs that involve forest systems must ultimately consider harvest rotation or the optimal decision of when to harvest the trees. Most studies that analyze the carbon sequestration programs consider optimal rotation times (van Kooten *et al.* 1995, Creedy and Wurzbacher 2001, Murray 2000, Hoen and Solberg 1997; Plantinga and Birdsey 1994). The question of optimal forest rotations has been long-standing in forest management. The Faustmann calculation to determine optimal rotation length is recognized as the earliest solution to this problem (Faustmann 1849 from Murray 2000). The Faustmann calculation only considers the values of the trees and the growth rate of the trees. Later, in 1976, Hartman extended the Faustmann calculation to include other values in determining optimal rotations. Hartman was trying to determine the optimal forest rotation when one considers the benefits from recreational values. Plantinga and Birdsey (1994) were among the first to incorporate carbon values into an optimal rotation calculation. Their study showed that it may be optimal to have infinite rotation lengths in some forests depending on the value that can be derived from sequestering carbon. Subsequent studies that followed Plantinga and Birdsey (1994) have shown similar results. Under the right pricing conditions (high carbon prices), it is possible that the optimal rotation length is infinity, or no harvest. These studies also show that as the price of carbon increases; the rotation length increases. There are many factors that can influence the rotation length. These factors include the price of timber, the discount rate and the price of other non-timber values such as water (Plantinga and Birdsey 1994; van Kooten *et al.* 1995; Creedy and Wurzbacher 2001; Chladna 2006).

An additional issue is the reaction that the timber market will have in response to increasing carbon prices. High carbon prices could result in a decreased supply of timber because forests are being left for sequestration. This decreased supply could result in increased prices of lumber and pulp. Eventually, the increase in lumber prices would in-turn trigger the forest industry to harvest again, moderating the effect of high carbon prices (Hoen and Solberg 1997). Related to the effects that carbon markets may have on timber markets is the problem of leakages. Sohngen and Sun (2006), as well as Sedjo (2001), identify leakages as a problem associated with all carbon sequestration programs. One type of leakage arises when as a result of carbon being sequestered there may be an increase in the production of wood substitutes such as steel and plastics which are more energy intensive to produce than lumber products. This may result in increases in CO_2 emissions. Leakages can reduce carbon sequestration gains by up to 50%, which is a major problem with this type of climate change abatement policy (Sohngen and Sun 2006).

2.1.4 Carbon Baselines

Since neither Canada, nor Ontario, has a regulatory framework for a carbon market the baseline or the reference scenario against which increases or decreases in carbon will be measured is difficult to determine. The Intergovernmental Panel on Climate Change outlines several baselines that may be used under Kyoto (Watson *et al.* 2000). There are three major types of baselines: business as usual (BAU), constant and absence of activity. The BAU scenario pertaining to forestry would mean that only forest management activities currently in place would make up the baseline. For example, if a stand of trees was scheduled to be clear-cut, then that decrease in carbon associated with the harvest would be part of the baseline, and no debits would be accrued. Similarly, if instead of clear cutting that stand the forester decided to conserve it, then the forest company could potentially receive a carbon credit because that stock would not have been there under the BAU scenario. The constant baseline established by Kyoto is quite simplein that the carbon levels present in Canadian forests in 1990 form the baseline (Watson *et al.,* 2000). Any increases or decreases in carbon from that constant level would be debited or credited to the country. The last type of baseline that is described in the IPCC report on LULUCF is a no activity baseline. This would involve measuring stock changes in the absence of active management or going back in time and determining a baseline of carbon when no activity was present.

The choice of a baseline has important consequences for forest companies and forest managers. For example if a constant baseline is chosen and the forest has a naturally declining carbon over time then the forest manager is likely going to be debited for the natural path of their forests. Furthermore, should a natural event such as a wildfire destroy an area of forest, the manager would have to be debited for that loss of carbon (Watson *et al.,* 2000). Whereas, in a BAU scenario, the wildfire would have been incorporated to the baseline and therefore would not affect the country's carbon accounting.

All of the baselines outlined in the IPCC report assume that activity was occurring on the land base prior to 1990. In the case of the Moose Cree First Nation's forest area, there has been no industrial activity. In their case, a BAU baseline would make any industrial activity result in carbon losses or debits. However, if activities such as forest management were planned for the area, then an argument could be made that the BAU scenario would be those plans in which case adjustments could be made to increase the carbon storage on that land base. The lack of industrial activity in the Moose Cree's forested areas poses a unique challenge in determining an appropriate baseline, especially when compounded with the lack of regulatory framework from the Canadian or Ontario governments.

2.1.5 Permanence and Discounting of Carbon Credits

In the case of a forest, there is little debate that once trees are planted and start to grow, they act as carbon sinks and can store carbon for decades. However, a tree does not live forever. Once a carbon credit based on forest management is sold, the forest from which it was created could be harvested, resulting in a loss of carbon and not a gain of carbon. Furthermore, natural events such as wildfires could destroy forests that created credits that were sold. Who would be liable for the loss in credit? The potential for insurance could arise from this lack of permanence. Owners of credits could hold an insurance policy whereby in the case of a default, or the loss of a credit, the insurance company would substitute the credit from another carbon sink (Benitez and van Kooten, 2005, Marland *et al.,* 2001). Creating ton-years is another way of dealing with permanence. In such a system, a credit would be given only when a certain number of tons of carbon were sequestered for a certain number of years. A conversion or equivalency factor would define the specific number of ton-years that would create a permanent credit (Benitez and van Kooten, 2005; Marland *et al.,* 2001). Many have criticized the ton-years system because of the arbitrary choice of the conversion or equivalency factor (Benitez and van Kooten, 2005).

Another system could involve rental markets, where the owner of the credit rents it out and the renter receives the benefit of the asset. However, the credit can revert to a debit at the end of some set term unless the credit remains sequestered and the lease is renewed (Marland *et al.*, 2001; Benitez and van Kooten, 2005). Many other systems and schemes are present in the literature with various benefits and drawbacks, but there is consensus in the literature that carbon increases as a result of forest management cannot be traded one-for-one for emissions credits. The issue of permanence needs to be addressed in some manner (Marland *et al.* 2001; Benitez and van Kooten, 2005).

Discounting can play a significant role in the analysis of carbon markets. Marland *et al.* (1997) show that net present values of future carbon emission reductions vary substantially based on which discount rate is applied. They argue that the discount rate applied to carbon is different than the discount rate applied to financial transactions because the financial discount rate reflects the opportunity cost of money, whereas the carbon discount rate reflects the marginal rate of substitution between damage from CO_2 emissions now and in the future. Because of this difference they argue that the carbon discount rate should be lower than the social rate of time preference (in their paper that was lower than 3%). In their case, higher discount rates resulted in decreased present values of carbon emission reductions. At high discount rates in some situations, particularly short rotations, carbon emission reduction programs would result in net negative present values. Other studies imply that discount rates also have an effect on the optimal rotations of stands when carbon and timber are considered benefits from the forest (Hoen and Solberg 1997; Plantinga and Birdsey 1994). These studies suggest that as discount rates increase, at moderate CO_2 prices, optimal rotation ages decrease. Stands are more valuable now than in the future. All these studies show that the choice of a discount rate for carbon can have significant impacts on the feasibility of carbon emission reduction programs, particularly in forest scenarios, because of their long growing cycles.

2.2 Study Area: Moose Factory, Ontario

Moose Factory is an island community located at the outlet of the Moose River which flows into the southern tip of James Bay (51 degrees North and 80 degrees West). The community is isolated and can only be accessed by plane or train. The community was established in 1693 by the Hudson's Bay Company as a fur trading post (Moose Cree First Nation, 2006). The Moose Cree First Nation negotiated and signed Treaty #9 in 1905, and as a result most of the island of Moose Factory was designated as reserve land for the Moose Cree. The island is 1300 acres in size and has a permanent population of 2,700 residents. The Moose Cree First Nation have a membership of 3,562, of which 1,531 live on the reserve, and 2,031 live off-reserve in the nearby community of Moosonee or in other communities (Moose Cree First Nation, 2006).

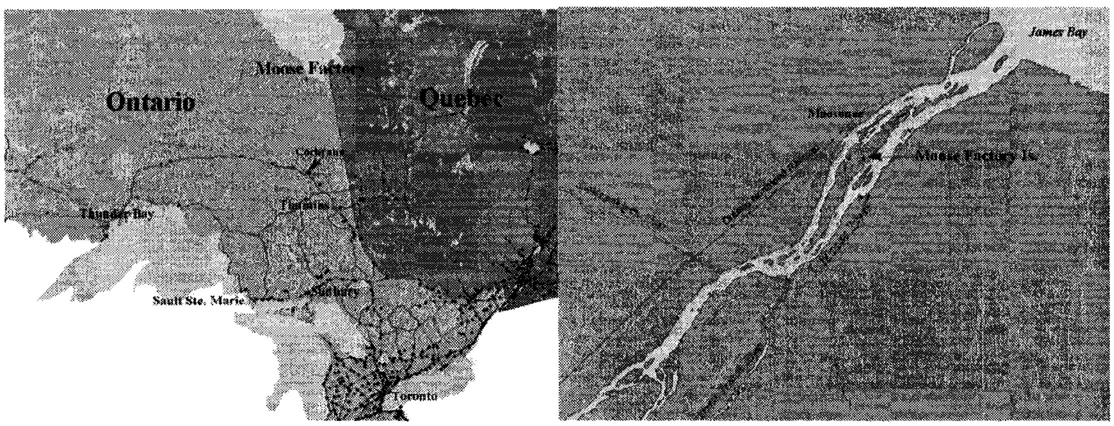

Figure 2-2: Map of Moose Factory Ontario (Moose Cree First Nation, 2007).

2.3.1 Economy of Moose Factory

The economy of Moose Factory has evolved over time since first contact with Europeans in the mid 1600's. Before contact, the Moose Cree engaged in traditional land-based harvesting pursuits which involved hunting, trapping, fishing, and gathering activities (Berkes and Preston, 1993). The Hudson's Bay Company opened its second outpost in Canada at Moose Factory and was the first English-speaking settlement in

Ontario (Marsh, 2007). As a result, new technologies were available to the community, which increased the efficiency of their hunting and trapping (Berkes and Preston, 1993). After the Second World War institutions such as government and religion made a large impact on the economy and the way of life for the Cree of Moose Factory. Before WWII, most of the Cree would still have an annual cycle of living on the land in different locations and would only come to the town site of Moose Factory during the summer to trade with the Hudson's Bay Company. Winter dwelling sites were located near hunting and trapping lines and were usually organized by family group. Each family group would have their traditional hunting territory within the larger territory. Although each family group had their territory, they would coordinate with other groups to "enforce customary rules for exploiting the resource base" and respect the needs of others (Berkes and Preston, 1993). After WWII, with the arrival of religious organizations and government services, this cyclical way of life ceased. Most of the Moose Cree started to live year round in Moose Factory.

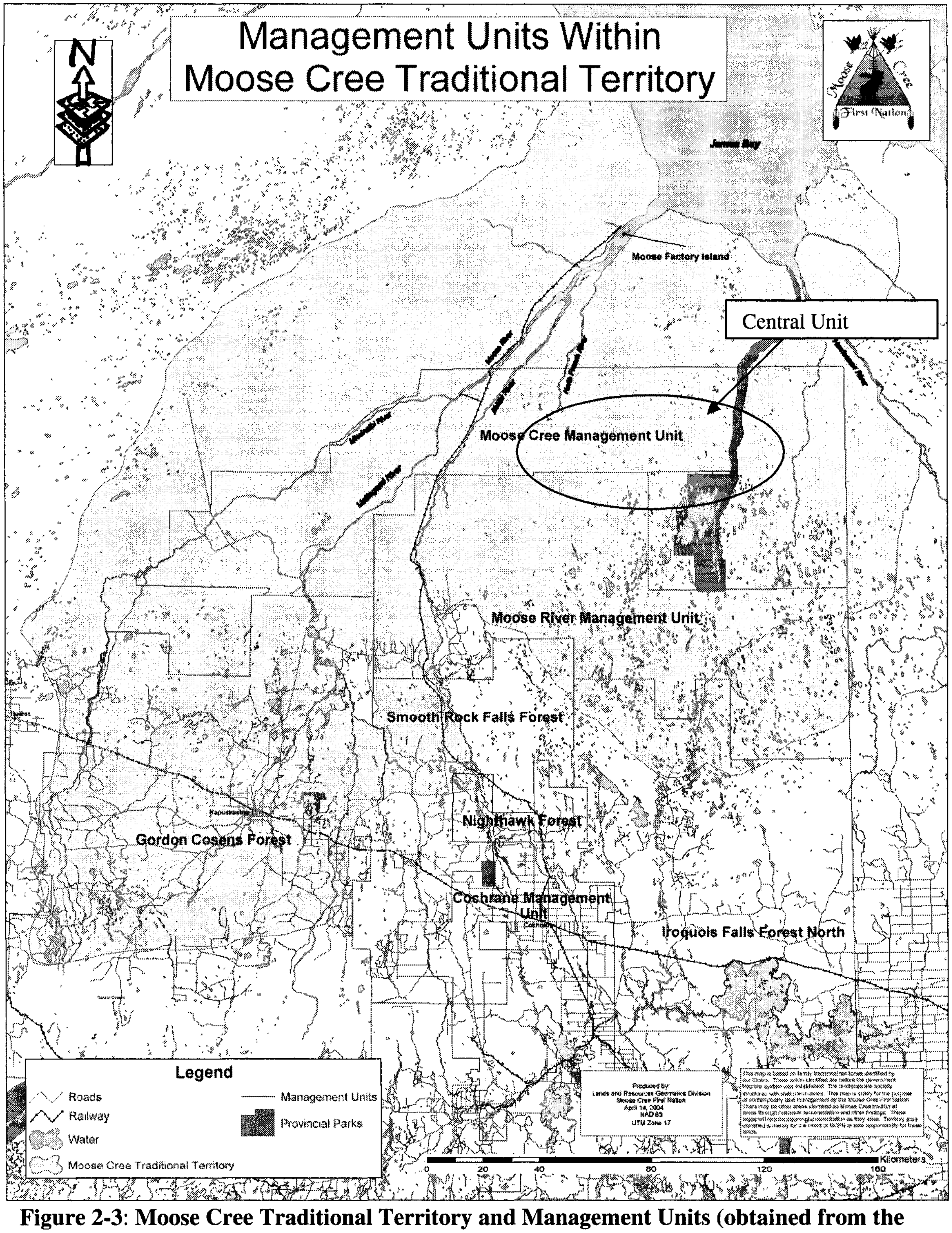

Figure 2-3: Moose Cree Traditional Territory and Management Units (obtained from the Moose Cree First Nation)

Today, economic activity in the area is derived from the service industry. The main employers in the community are the Federal and Provincial governments. A tourism sector is being established; mainly hunting camps and guiding. There is still a "bush economy" in Moose Factory and hunting is still a way of life for many. The community "shuts down" for two weeks in October and families return to their traditional hunting grounds via boat or the train. During this two-week period, the schools and government offices are shut down. The Moose Cree would like to increase the economic activity within their community by exploring the potential for a forest industry in the Central Unit area of the Traditional Territory.

2.3.2 The Central Unit

The traditional territory of the Moose Cree, as depicted in Figure 2-3, is approximately 17,000 square kilometers. The study area is called the Central Unit and has approximately 240,000 hectares of forested land. There are four main species of tree within the area: black spruce (*Picea mariana*), larch or tamarack (*Larix laricina*), cedar (*Thuja spp.*) and jack pine (*Pinus banksiana*). The Central Unit has many small swamps and lakes located within it. The area was inventoried in 2000 and had a fire burn through a large stand of jack pine and black spruce in 1996. As a result, the initial age class distribution of the forest contains a large amount of young forest. Figure 2-4, illustrates the age class distribution of the forest in the central unit. The majority of the forest is middle aged with a few stands that are quite old.

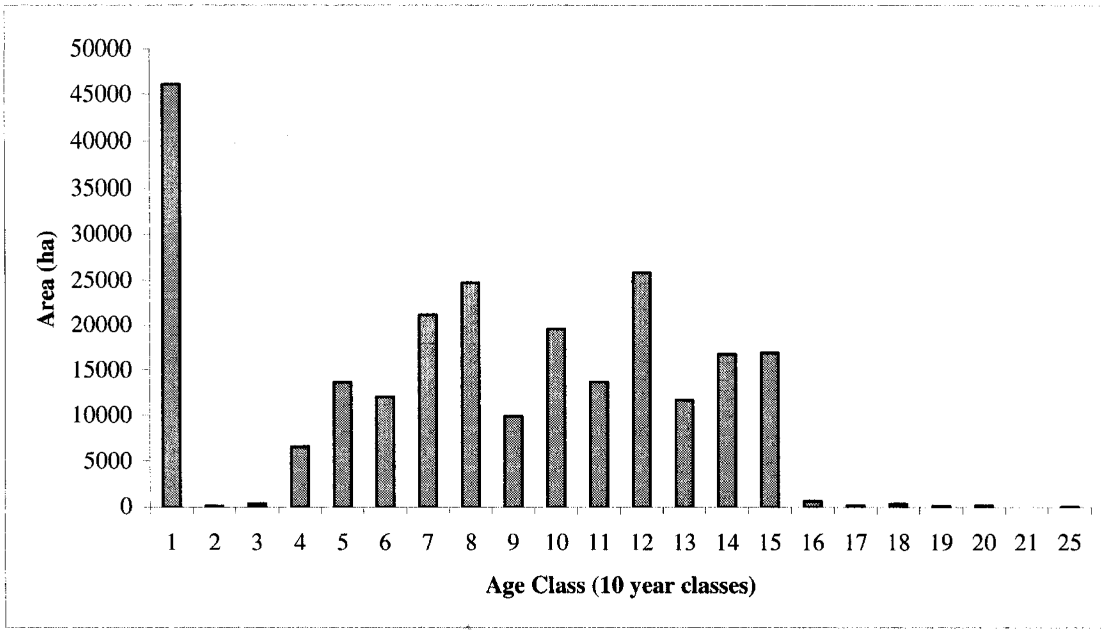

Figure 2-4: Age Class Distribution of Forest within the Study Area (Source: Rob Arnup)

The species were aggregated into 4 species groups according to their prevalence and proximity to each other and their similar site characteristics. Cedar and larch tend to grow together on similar sites. Most cedar leading stands contain a proportion of larch and most larch leading stands contain a proportion of cedar, therefore these two species were aggregated into a larch and cedar mix. Similarly, jack pine and black spruce grow in the same stands. Therefore, these two species were also aggregated. Pure black spruce and jack pine stands are also prevalent. Therefore, these stands were left as their own species group. The inventory data also had information pertaining to the site classification of the stands; high productivity stands or lower productivity stands. The Ontario system uses a scale from X to 4 where X is the highest productivity stand and 4 is the lowest productivity stand (personal communication with Rob Arnup). This Ontario system was used to create three site productivity classifications: high, medium and low. Table 2-1 shows the breakdown of the forest into the various species groups and site classifications.

Table 2-1: Proportion of the total forest area in each species group and site classification

	Site Classification			
Species Group	*High*	*Medium*	*Low*	TOTAL
Black Spruce and Jack Pine Mix	6.7%	26.7%	20.7%	54.1%
Larch and Cedar Mix	0.0%	1.3%	3.7%	5.0%
Black Spruce	3.5%	24.4%	8.8%	36.7%
Jack Pine	0.0%	4.0%	0.1%	4.2%

The majority of forest stands are black spruce and jack pine mixes and the most common site classification is a stand with medium productivity. Figure 2-5 illustrates the age class distribution by species group. Because of the fires in 2000, there is a large area of jack pine and black spruce forest that are in the first age class. The remainder of the forest is nearly evenly divided between the age classes. Since the majority of the forest is comprised of mixed black spruce and jack pine stands, a large area of forest is represented in all of the age classes.

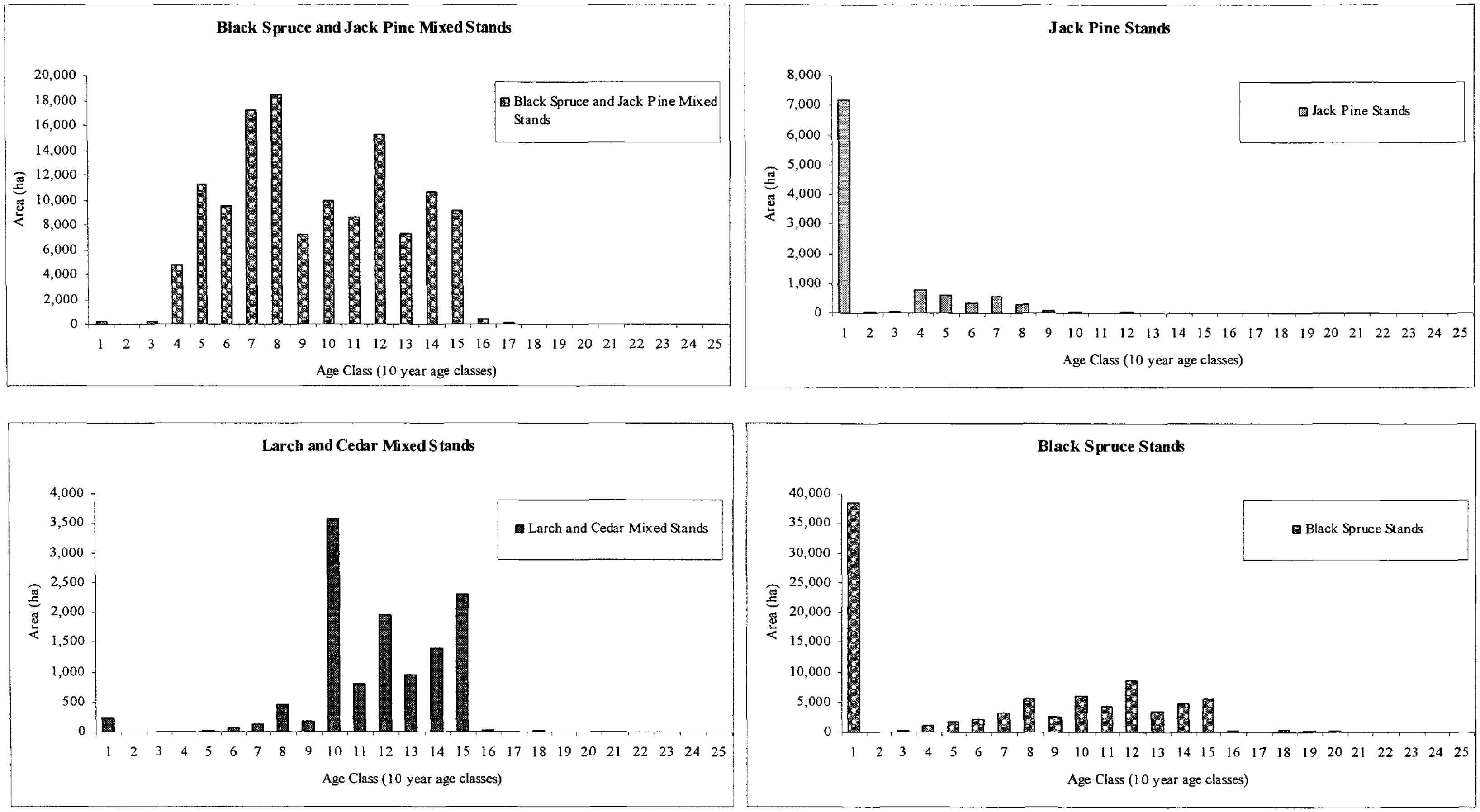

Figure 2-5: Age Class Distribution of the Central Unit Forest by Species Group

2.3 First Nation Traditional Land Use and Economic Development

2.3.1 Traditional Land Use

The Moose Cree First Nation identify three main concerns that need to be addressed in order for the consideration of forestry activities to proceed in their traditional territories. The first is the preservation of traditional hunting grounds and species habitats. The second is the restriction of access to their hunting grounds by "outsiders", and the last is the scale of forestry activities and how it will affect both the preservation of hunting grounds and the forest access.

2.3.1.1 Hunting

The community of Moose Factory continues to live off the land in some form or another. According to a 1994 study, approximately 94% of those interviewed considered themselves hunters (Berkes and Preston, 1993). The hunt in Moose Factory continues to provide substantial food sources for the community. In 1993, the total value of hunting in terms of the cash value of the food that was obtained, was valued at approximately $1.2 million (Berkes and Preston 1993). A further $200,000 was obtained through fuel, wood gathering, berry picking and fur sales (Berkes and Preston, 1993). Moose and caribou provide the largest volume of meat in terms of edible weight. In the study year, 42, 926 kilograms of moose and caribou were harvested from traditional hunting grounds; a further 41,000 kilograms of fish were harvested and 36,000 kilograms of waterfowl. Because of the large amount of moose and caribou that are harvested for consumption, these two species will be the focus of habitat conservation in this study. Furthermore, personal communications with First Nation members indicate that in terms of forest management activities and hunting, they are most concerned about the impact that such activities may have on their ability to hunt moose. Woodland Caribou was not thought of as an important food source, but because it is considered a threatened species under the Species at Risk Act, consideration must be paid to the effects that any forest operations may have on caribou (Environment Canada, 2007). In personal communications with community members, it is apparent that hunting is very important to them, and the continued use of traditional hunting grounds is also a priority.

2.3.1.2 Access

Industrial activities such as forestry will increase the number of roads (access points) for "outsiders", or people from the south, to come into the Moose Cree First Nation traditional territory and hunt. Any forestry activity will have to take this concern into consideration.

2.3.1.3 Scale of Operations

In discussions with the Lands and Resources Secretariat, the officials responsible for industrial developments within the traditional territory, it became evident that they do not think that the community would support large scale forestry operations. Any decisions made by the Lands and Resources Secretariat concerning forestry activities would likely need to be ratified by the band members. The Secretariat's feeling is that the community would likely only support forestry activities on 50% of the traditional territory. Like the habitat conservation and access issues, the scale of forestry activities need to be taken into consideration when analyzing the potential for such activities.

2.3.2 Economic Development

Employment and economic development is a priority for many First Nation Communities and Moose Factory is no different. According to the band website as of September 1, 2006 there were 195 reserve members who were unemployed (Moose Cree First Nation, 2006). The desire of the Moose Cree First Nation and many other First Nations communities to increase employment opportunities is quite common (Anderson, 1997). Often, employment goals are achieved through economic development. Anderson (1997) outlines eight characteristics of First Nation's economic development. Firstly, Nation Economic development involves attaining economic self-sufficiency, capacity building and the improvement of socioeconomic circumstances while preserving and strengthening traditional cultures, values and languages (Anderson 1997). Carbon sequestration programs alone, or in conjunction with forestry, could potentially play a role in achieving this economic self-sufficiency while maintaining traditional values. Timber and carbon markets have the potential to increase employment and revenues in the community. The sale of carbon credits would likely be a positive initiative in this community because the creation of carbon credits would likely mean receiving economic revenue from the conservation of some of their forests. However, it would not likely create direct employment unless it was in conjunction with other forest activities such as harvesting. This thesis aims to determine the economic viability of both forestry and carbon sequestration programs for the Moose Cree First Nation while keeping in mind their traditional land uses.

2.4 Summary

This chapter explored the main issues related to carbon management in northern Ontario. The first section explained carbon dynamics in the forest and how geography and past disturbance affects the carbon levels. The costs and benefits of carbon sequestration and other carbon mitigation schemes were also examined, as well as the issues facing forest managers including baselines, permanence and discount rates. The second section of the chapter addressed the possible impacts of forestry and carbon sequestration activities on traditional land use activities. The key issues addressed in this section were the preservation of hunting grounds, the potential of increased access and the effects that the scale of forestry operations would have on both hunting grounds and access. The last section outlined the study area in Moose Factory, Ontario, and specifically detailed the forest area being studied. The following chapter will incorporate this background information to develop a mechanism for analyzing the potential economic benefits of carbon and forest management for the Moose Cree First Nation.

Chapter 3 : Methodology

Chapter three outlines the methodologies used for both the carbon management and sawmill sizing models. The first section outlines the timber supply modelling that is the basis for both models. Next, the linear programming formulation for the carbon management model is described. Section 3.3 deals with the mixed integer programming formulation, while the last two sections describe the parameters and software packages used to solve both sets of models.

3.1 Timber Supply Modelling

To examine the implications of carbon markets and optimal mill size on forest management, the inventory information from the Central Unit in the Moose Cree Traditional territory was incorporated into a timber supply model for the area. A linear programming model can be used to determine a sustainable timber supply that can satisfy most government regulations and policies. Johnson and Scheurman (1977) developed two strategies to model timber supply in an optimization context. The main difference between the two models is that a Model I formulation follows the life history of a hectare for the entire planning horizon (Davis *et al.*, 2001). Conversely, Model II "detaches the regenerated stands from existing stands and defines unique regenerated stand decision variables with timing and prescription options" (Davis *et al.* 2001). Essentially, in Model II, stands are separated into existing stands, which are those that have not been harvested and managed stands, which are stands that have been harvested; whereas in Model I stands do not have this designation. The timber supply modelling procedure used in this study will follow more closely a Model II type formulation in that when a stand of trees is harvested, it no longer remains part of the existing forest stock and is moved into the managed forest stock where it will be planted.

Yield curves were created in order to describe the growth of the different forest stands as they proceed through the planning horizon. The M.O.S.S.Y. modelling program was used to create the yield curves (Forestry Research Partnership, 2006). M.O.S.S.Y., which stands for Modelling Ontario's Stand Succession and Yield was developed by the Ontario's Forest Research Partnership in conjunction with the Canadian Ecology Centres as a way to develop yield curves for all the forest units in Ontario. The raw data from the central unit inventory were aggregated and compiled in order to be put into M.O.S.S.Y. according to methodologies from several Ontario studies (Stinson *et al.* 2004 and Penner 2005). M.O.S.S.Y. was used to develop three sets of yield curves for each stand type and site classification. The first set of yield curves was developed for the existing forest. The other two sets of yields curves were created to depict stands naturally regenerated and planted stock stands. There were four stand types: black spruce, jack pine, a larch/cedar mix and a black spruce/jack pine mix. Each stand type is stratified into three site classifications: high, medium and low. The appendix contains the yield curve information.

3.2 Carbon Management Model Formulation

This section outlines the linear programming formulation for analyzing the potential for carbon and forest management in Moose Factory. Furthermore, this section explains the carbon modelling system used to create carbon yield curves and will explain the baseline used and the addition of an area constraint to the model.

3.2.1 Linear Programming Formulation

The objective of this model is to maximize the net present value from the Central Unit for the Moose Cree First Nation where both timber and permanent carbon credits are considered.

Objective Function

$$\max_{X_{ijk}} \sum_{i=1}^{I} \sum_{j=-M}^{k-M} \sum_{k=1}^{N} \left[Y_{ijk} X_{ijk} - (C^H_{ijk} + C^R_{ijk}) X^p_{ijk} \right] e^{-10\delta k} + \sum_{k=1}^{N} P^C \left[R_k \right] e^{-10\delta k} \qquad (3.1)$$

Subject to

<u>*Area Constraints:*</u>

$$\sum_{k=1}^{N} X_{ijk} + W_{ij} = A_{ij} \qquad \forall\ i,j \qquad (3.2)$$

$$\sum_{i=k+1}^{N} X_{ikl} + W_{ik} - \sum_{j=-M}^{k-1} X_{ijk} = 0 \qquad \forall\ i,k \qquad (3.3)$$

Where

Y_{ijk} =Revenue ($/ha) for timber from forest type *i* which was born in period *j* and harvested in period *k*

$X_{ijk}(X_{ikl})$ =Area (ha) of forest type *i* which was born in period *j(period k)* and harvested in period *k(period l)*

C^H_{ijk} =Harvesting cost ($/ha) associated with forest type *i* which is born in period *j* and harvested in period *k*.

C^R_i =Regeneration costs ($/ha) associated forest type *i*.

$W_{ij}(W_{ik})$ = Area (ha) of forest type *i* which is born in period *j(period k)* and never harvested within the planning horizon

A_{ij} =area of forest in forest type *i* born in period *j*

δ = Discount rate (%)

N = The number of periods in the planning horizon

M =Age (in periods) of the oldest age class of forest type I that is present at the beginning of the planning horizon (period 0)

p =used to classify the regeneration strategy used, either natural regeneration or planted stock

P^C =Price of carbon ($/tonne)

R_k =The permanent increase or decrease in carbon from the baseline level in period *k* (tonnes)

The objective function (Equation 3.1) maximizes the sum of the net present value of the forest (including both timber and carbon stocks) over the planning horizon. The area constraints (Equations 3.2 and 3.3) ensure that each forest unit is assigned to an action or is left as standing inventory at the end of the planning horizon. Equation 3.2 ensures that the harvest areas do not exceed the existing forest and Equation 3.3 ensures that the harvest area does not exceed the total area of new or managed forest (those forests that were born during the planning horizon).

As most forests in Canada are regulated to some extent, harvest volume constraints (equations 3.4 and 3.5) were added to the model to ensure than an even flow of timber is being harvested each period. In this case, the volume harvested from the preceding period must be the same as the volume harvested in the current period.

Harvest Constraints:

$$H_k = \sum_{i=1}^{I} \sum_{j=-M+1}^{K} V_{ijk} * X_{ijk} \qquad \forall k \qquad (3.4)$$

$$H_k - H_{k+1} = 0 \qquad \forall k \qquad (3.5)$$

Where:

H_k = Volume harvested (m^3) harvested in period *k*
V_{ijk} = Yield for forest type *i,* regenerated in period *j,* and harvested in period *k*

Equation 3.6 constrains the area reforested to be equal to the area harvested. In other words, every hectare that is harvested is reforested through tree planting or natural regeneration. This is consistent with most government regulations concerning reforestation (Ontario Ministry of Natural Resources, 2006).

Regeneration Constraint:

$$\sum_{j=-M}^{k-M} \left[\sum_{p=1}^{P} X^{P}{}_{ijk} - X_{ijk} \right] = 0 \qquad \forall k \qquad (3.6)$$

The issue of permanence in carbon credits was addressed by only counting a carbon credit when there is an increase in the level of carbon from the previous period. An increase in carbon above the baseline does not immediately result in a credit. That increase in carbon from the baseline must be present in the subsequent period in order for it to be permanent credit. If there is a decrease in the carbon level from the baseline, the same applies. It is not counted as a permanent debit unless it is present in the subsequent period. Equations 3.7 and 3.8 describe this accounting method. The use of this permanent carbon credit system introduces a constraint into the model. In the objective function (equation 3.1), the permanent credit is multiplied by the price of carbon.

Therefore, this constraint is only active in the model when the price of carbon is greater than zero. When the price of carbon is zero, this portion of the objective function drops out of the objective function.

Calculation of Permanent Carbon Credit:

$$D_k = S_k - S_k^B \qquad (3.7)$$

$$R_k = D_{k+1} - D_k \qquad (3.8)$$

Where:

S_k =Total ecosystem carbon stocks (tonnes) in period *k*

S^B_k =Baseline total ecosystem carbon stocks (tonnes) in period *k*

D_k =Difference between the baseline carbon stocks and the ecosystem carbon stocks

To account for some of the Moose Cree First Nation's traditional values, an additional area constraint is added to the model to ensure that the area available to be harvested is only a fraction of the total area available for harvest (Equation 3.9).

Area Constraint for Traditional Values:

$$\sum_{i=1}^{I}\sum_{k=1}^{N} X_{ijk} \leq T \qquad (3.9)$$

Where:

T = An area (ha) of the forest that excludes the portion of the forest reserved for traditional use

The last set of constraints (Equation 3.10) ensures that the variables do not take on negative values.

Non-Negativity Constraints:

$$X_{ijk} \geq 0; X_{ikl} \geq 0; W_{ij} \geq 0; W_{ik} \geq 0 \qquad \forall\ i,k; \qquad (3.10)$$

3.2.2 Modelling Carbon Pathways in the Central Unit

As stated in the background section, the amount of carbon present in a forest depends on several factors including stand initiation and harvesting activities. The level of carbon in forested stands can be simulated using the Canadian Forest Service's Carbon Budget Model (CBM-CFS3). The purpose of the CBM-CFS3 is to provide a consistent carbon accounting tool for forest managers all across Canada (Kurz *et al.* 2002). The CBM-CFS3 will be used to simulate the carbon levels in the Central Unit forest as different management activities are taking place over time. The goal of the carbon dynamic modelling is to capture an accurate representation of the carbon contained in both the biomass and the dead organic matter (DOM). Because the DOM pools are the main drivers of carbon levels when forests are harvested, separate DOM and biomass carbon yield curves were developed. Furthermore, mean annual temperature, a driver of decomposition rates and therefore the size of DOM pools (Kurz *et al.* 2002), is taken into account in CBM-CFS3 through the choice of terrestrial ecozones (Kull *et al.* 2006). The Central Unit falls into the Hudson Plains ecozone which is characterized by a mean daily temperature of 14°C in July and -24°C in January (Canadian Council on Ecological Areas, 2007). The ecozone is also characterized by a short growing season with only 500 to 1000 growing degree days above 5°C (Canadian Council on Ecological Areas, 2007).

Simulations were run in CBM-CFS3 to capture all combinations of species types, site classifications regeneration methods and timings of harvest activities. Each stand type was assigned a one hectare unit in CBM-CFS3. The biomass carbon and DOM carbon were simulated depending on the initial conditions of the stand. Each simulation in CBM-CFS3 created a carbon yield curve that was imported into Woodstock so that each forest stand in the Central unit will have a timber yield curve and several carbon yield curves associated with it. The initial conditions of the stand (i.e.: existing forest or harvested forest) are a driving factor in determining the levels of DOM in the stand. This adds a large amount of complexity to the modelling procedure. Each action that occurs to a stand will result in different carbon levels. For example, an existing stand that is harvested at year 60 will have a different level of carbon than a regenerated stand that is harvested at year 60. This is not only because of the different initial conditions, but also because the regeneration method will alter the level of carbon biomass. In general, stands that are naturally regenerated have a lower level of biomass than those that are regenerated through planted stock, both of which are different than the levels of carbon in an existing stand. This is due to the yield curves that are generated in M.O.S.S.Y. This complexity in carbon dynamics will create difficulty when trying to simulate the various actions and transitions that will occur to stands in the Central Unit.

Given that the Woodstock modelling system chooses the optimal harvest ages, the optimal number of rotations within the planning horizon and the optimal regeneration methods; there is a very large number of combinations of carbon yield curves that would need to be created. As such, some of the complexity must be reduced in order to feasibly model this type of system in Woodstock. In figure 3-1, a simple example is presented in which a single jack pine stand with only 2 possible harvest ages, 2 regeneration methods and 2 harvest rotations can generate 18 carbon yield curves. As different harvest ages are added, and the number of rotations increases, the number of carbon yield curves that need to be created increases exponentially.

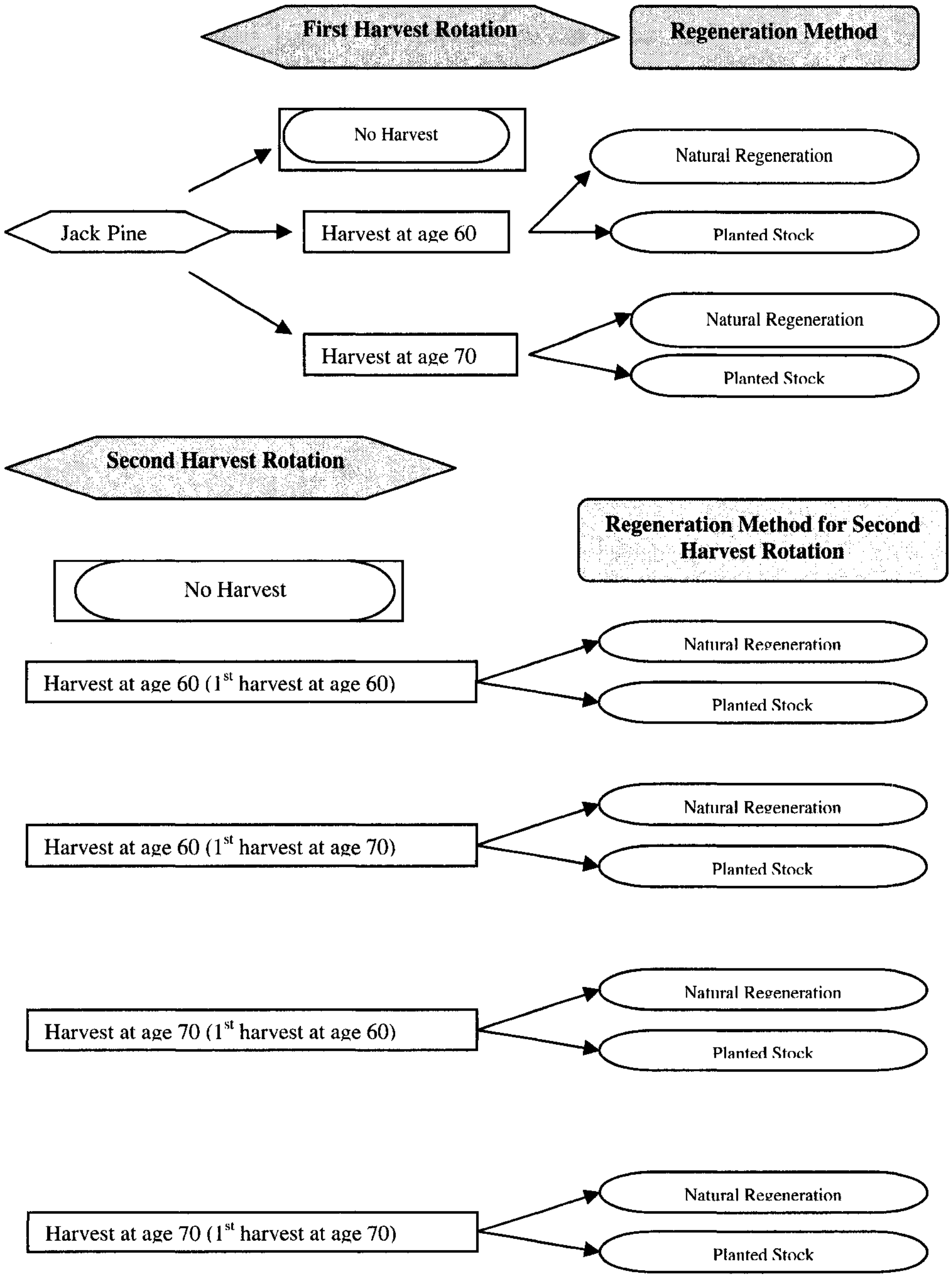

Figure 3-1: The flowchart illustrates an example of the various carbon yield curves that must be generated in CBM-CFS3. In this case a jack pine stand with 2 possible harvest ages, 2 possible regeneration methods and only 2 rotations would generate 18 carbon yield curves (the items in rectangles indicate actions whereas the items in ovals indicate yield curves that are developed)

In order to reduce the number of carbon yield curves, a rounding system is implemented similar to that of McCarney (2007). After each harvest event, two silvicultural activities are possible: regeneration through planted stock and natural regeneration. Each will result in different carbon curves. The age at which the harvest event occurred and the subsequent silvicultural activity will determine the appropriate carbon yield curve or pathway. The age at which the stand is harvested will be 'rounded' to the nearest age that a carbon yield curve is available in the model. For example, if a stand was harvested at age 60 and subsequently naturally regenerated and the closest carbon yield curve that is available is 70 years, then the model will reflect that level of carbon. This rounding system reduces the number of possible carbon modelling pathways. The weakness of this method is that the carbon modelling becomes less accurate through the rounding system, meaning there is the potential for both overestimation and underestimation of the carbon present in the forest stand. The rounding system is discussed in further detail in subsection 3.2.1.1.

In order to further reduce the number of carbon pathways, the silvicultural options of the model were limited. After the first harvest event and the initial regeneration method chosen, the subsequent harvests and regenerations would have to be the same. If a forested stand was naturally regenerated after the first harvest, then it would also be naturally regenerated after the harvests that followed. Furthermore, the number of rotations that a single stand could have was also limited. In this case, although the planning horizon was set to 200 years, the number of harvest rotations that a stand could have was limited to 3. When the Woodstock model for the Central Unit was run without the carbon yield curves present (timber supply model only), stands were rarely harvested more than three times and for this reason it was appropriate to limit the number of rotations to three, reducing the number of carbon yield curves needed.

3.2.2.1 Rounding System

As stated above, the rounding system for carbon yield curves decreases the number of yield curves needed. Several assumptions need to be made in order to create the rounding system. The first assumption involves deciding which harvest age to round the carbon pathway to. In this case, the various rotation ages were combined into three categories of rotations for the carbon pathways: short, medium and long. In order to determine which ages would fall into these categories, the timber supply model was run in Woodstock and the optimal harvest schedule was analyzed. The rotation categories reflect the most common harvest ages when the net present value of the forest is maximized without consideration of carbon. For jack pine and larch/cedar mixed stands, the short rotations were those that occurred between age classes 1 and 7[2], the medium rotation length from age class 8 to 9 and the long rotation length from age class 10 to 25[3]. Because the black spruce and black spruce/jack pine mixed stands tended to have longer rotation ages, their rotation categories were different. The short rotation reflected those stands harvested in age classes 1 to 7, the medium rotation 8 to 11 and the long rotation 12 to 25. The rotation categories were then rounded to an appropriate carbon yield curve. The rounding decision was based on the age that best reflected the level of carbon present in the stand. Various simulations in CBM-CFS3 were conducted in order to determine

[2] 10 year age classes

[3] The age of the stand is determined at the end of the age class, so in fact these rotation ages do reflect all the ages possible

the most appropriate rounding age. As stated above, this system attempts to accurately reflect carbon levels, but the nature of this system means that the carbon levels could be inaccurate. Table 3-1 reflects the various ages that the different species mixes and rotation lengths are rounded to. Because of the longer rotations in black spruce and jack pine/black spruce species mixes, the long rotation category is rounded to a later carbon yield curve (age class 12) than that of the other species mixes (age class10).

Table 3-1 Rounded carbon yield curve ages classes (10 year classes)

	Species Mix			
	Black Spruce	*Jack Pine*	*Larch and Cedar*	*Jack Pine and Black Spruce*
Short Rotation	7	7	7	7
Medium Rotation	9	9	9	9
Long Rotation	12	10	10	12

Even with the various assumptions to reduce the number of possible carbon pathways, there were still hundreds of carbon yield curves that needed to be developed. It is also important to remember that a possible outcome at any point in time is a no harvest scenario. Carbon pathways were also created in CBM-CFS3 for this possibility. Approximately 1,100 carbon yield curves were created to reflect the combinations of: harvest ages, rotation length, silvilcultural activities, species mixes and site productivities.

3.2.3 Derivation of Carbon Baseline and Area Constraint

Carbon baselines can be derived in several ways. The IPCC report on LULUCF identifies several. The business as usual scenario seemed most appropriate for forest operations, however, in the case of the Moose Cree First Nation, the definition of business as usual is complex. There are currently no forest activities in the Central Unit, but the Moose Cree First Nation is in the process of developing a land use plan that may include forest operations in that area. Should the business as usual baseline be a no activity, or a baseline with the forestry activities that will likely occur? The lack of a regulatory framework in Canada makes this decision arbitrary. Since a no activity baseline would likely mean that any harvesting activities would result in carbon decreases and not increases, it would make sense to use a business as usual carbon baseline for the perceived future activities. The business as usual baseline was derived by running the timber supply model of the central unit with carbon prices set to zero and maximizing the net present value. This represents a potential management regime for the Central Unit in the future. The total carbon in the ecosystem in each period that resulted from this model run was added to the model as the baseline. Any increases or decreases from this baseline will result in debits or credits as explained in section 3.2.

Although the linear programming framework outlined above contains an even flow harvesting restriction, this restriction can be turned off to assess the effects of such restrictions. When the even flow restrictions are eliminated, a new baseline had to be created in order to reflect the new conditions.

The area constraint simply reduces the size the Central Unit that is available for timber harvesting and thereby conserving areas for traditional land use. Moose habitat, access issues and to a lesser extent caribou habitats were identified as important issues for the Moose Cree First Nation. Each issue was assessed individually. Studies on moose indicate that the largest impact that timber harvesting has is the reduction in forest cover during the winter months and shade and protection from predators in the summer months (Ontario Ministry of Natural Resources, 1988; Dussault *et al.* 2006; Courtois *et al.* 2002). Conversely, these studies also show that clear cut harvesting can increase browse available. As such, it is difficult to determine the effects of forest harvesting on moose in terms of which habitat types to conserve when moose trade off cover and browse (Dussault *et al.* 2006).

The increase in access that forest activities such as clear cutting have can also affect moose populations through an influx of hunters into previously inaccessible areas. By building the roads necessary for timber harvesting, there is an increased level of access for hunters. Furthermore, clear cut sites are often used by moose to browse, providing little cover from hunters (Courtois and Beaumont, 2002). Although this has been a long held belief, a study in Northwestern Quebec found that harvesting activities did not in fact decrease moose populations or productivity (Courtois and Beaumont, 2002). Courtois and Beaumont (2002) found that hunters did not use forestry roads to access hunting grounds, but instead used boats or all-terrain vehicles (ATVs). Furthermore, in the study area there was already a large population of hunters and the increase in access did not create an increase in hunters. Similarly, Caribou are affected by timber harvesting activities through the direct loss of habitat when lichen is destroyed (Chowns, 2003). Road building to access harvest areas creates the greatest lichen destruction, while actual harvesting activities can affect lichen productivity by altering snow conditions (Chowns 2003). Again, it is not clear what role clear cutting would have on access in the Central Unit and its corresponding effect on moose hunting or caribou and moose populations.

Given all of the information on access and moose and caribou habitats; creating specific constraints to address these three issues would create too much complexity to the model. This is because such a simple total area constraint was applied. The area available for harvest is reduced systematically from 100% availability, down to only 40% availability. This reduction in area is intended to partially address the traditional value concerns of the Moose Cree First Nation.

3.2.4 Carbon Pricing

Although carbon is not traded in any market in Canada, it is traded in Europe through the European Emissions-Trading Scheme and more recently on the Chicago Climate Exchange (Point Carbon, 2007a; Chicago Climate Exchange, 2007). In the European carbon market, the price of carbon refers to one EU allowance which is equivalent to one metric tonne of CO_2 emissions (Point Carbon, 2007a). One tonne of carbon (C) is equal to 3.667 tonnes of CO_2. Therefore, a European market price of $1 per tonne of CO_2 would equate to $3.67 tonnes of C. In Europe, the price of carbon has been very volatile recently. Under the first allowance system (2005-2008 allowances), too many allowances had been handed out by the European Commission which caused the price of carbon to plummet (The Economist June 2nd 2007, pg 8-9). Between May 30, 2007 and June 7th, 2007, the price of carbon in Europe varied between €0.27 and €0.55

which was equivalent to \$0.39 CDN and \$0.80 CDN respectively (Point Carbon, 2007b). However, since the release of the second phase of allowances, the price of carbon has rebounded. On July 13, 2007, the price of CO_2 for December 2008 allowances was €19.93 (Point Carbon, 2007b). To reflect the volatility of these prices, a range of carbon prices were included in the model. Table 3-2 illustrates the price of carbon credits in both CO_2 emissions credits and carbon credits which were used in the model.

Table 3-2: Prices of Carbon and Carbon Dioxide Credits used in the Model

Carbon Credit Price	CO_2 Credit Price
\$2.00	\$0.55
\$4.00	\$1.09
\$6.00	\$1.64
\$8.00	\$2.18
\$10.00	\$2.73
\$20.00	\$5.45
\$30.00	\$8.18
\$40.00	\$10.91

3.3 Sawmill Size Problem Formulation

This section discusses the mixed integer programming framework that was created to analyze the economic potential of building a saw mill in Moose Factory. Subsection 3.3.1 outlines the timber supply model that was created using GAMS. This section also integrates the timber supply model with information regarding mill sizes in Ontario and outlines the 4 different mill sizes that may be optimal.

The timber supply model described in section 3.1 was used as the base for the mill optimization model. Constraints were added to the model to include capital costs of building a mill. These costs were incorporated into the objective function. Additional variables were added to the model whereby the model selected the optimal choice of mill size from four different sawmill capacities. The capacities were determined based on the different sizes of mill that are currently located in Northern Ontario. Currently, in Ontario, there are 60 sawmills whose capacities vary from a small capacity mill (10,000 cubic meters per year) to a large mill which processes in excess of 300,000 cubic meters of wood per year. Table 3-3, contains a breakdown of the distribution of sawmill sizes in Ontario (Natural Resources Canada, 2006).

Table 3-3: Description of Characteristics of Ontario's Sawmills

Cubic meters Per Year	10,000-29,999	30,000-99,999	100,000-299,999	300,000 +
Million Board Feet Per Year[4]	4.24-12.69	12.7-42.37	42.37-126.9	127+
Number of Sawmills	13	20	11	16

We can see from this table that the most common sawmill size in Ontario is a medium sized mill that processes 30,000 m^3 to 100,000 m^3 per year. There are 16 fairly large sized mills which process in excess of 300,000 m^3 per year. This is notable because the Pricewaterhouse Coopers report (2005) on Watson Lake states that a benchmark mill in Canada is considered a mill which processes 500,000 m^3 per year. In fact, they state that "today's investment climate tends to require forestry companies to secure greater than 500,000 m^3 of renewable tenure" (pg 5). Given that many of Ontario's sawmills are smaller than this benchmark level, this statement may be making reference to an increased competitiveness in the forest industry and that future sawmills may address this through economies of scale.

[4] 1 cubic meter = 424 board feet (Natural Resources Canada, 2006)

To the best of our knowledge, the literature does not contain studies that have specifically examined optimal sawmill size determination using mathematical programming. There is one study from Chile (Troncoso and Garrido, 2005) that tried to determine optimal mill locations using mixed integer programming. Mill locations were determined based on haul distances and proximity to markets for the final products. The model then used mixed integer programming to determine an optimal location. Although mill size was determined exogenously, the model allowed for mill expansion at the mill sites. The objective function in this case was to minimize the present value of the total costs associated with forest management. The costs in this study included: harvesting, transportation of raw logs, operational costs, transportation costs for the final products, expansion costs (if applicable) and the costs associated with construction of the facility at the various sites. This paper was more of a logistical programming problem. However, because of the possibility of expansion it is somewhat similar to this study.

The agricultural literature contains studies on optimal implement and equipment sizes. One of the first studies to determine optimal equipment size using computer aided linear programming was done by Brown and Schoney in 1985. Their study tried to determine optimal machinery sizes for grain farms in Saskatchewan. They used a least cost approach where they minimized the sum of the fixed operating and timeliness costs for the entire farm machinery complement. This study was used liberally as a base for the mill optimization model, although the Brown and Schoney model uses different types of programming and different equations for costs.

3.3.1 Mixed Integer Programming Formulation

The basic mill optimization model can be formulated as follows:

Objective Function

$$\max_{X_{ijk}} \sum_{i=1}^{I} \sum_{j=-M}^{k-M} \sum_{k=1}^{N} \left[Y_{ijk} X_{ijk} - (C^{H}_{ijk} + C^{R}_{ijk}) X^{p}_{ijk} + C^{C}_{k} \right] e^{-10\delta k} \qquad (3.11)$$

Subject to

<u>*Area Constraints*</u>

$$\sum_{k=1}^{N} X_{ijk} + W_{ij} = A_{ij} \qquad \forall\ i,j \qquad (3.12)$$

$$\sum_{i=k+1}^{N} X_{ikl} + W_{ik} - \sum_{j=-M}^{k-1} X_{ijk} = 0 \qquad \forall\ i,k \qquad (3.13)$$

Where

Y_{ijk}	=Revenue (\$/ha) for timber from forest type *i* which was born in period *j* and harvested in period *k*
$X_{ijk}(X_{ikl})$	=Area (ha) of forest type *i* which was born in period *j(period k)* and harvested in period *k(period l)*
C^{H}_{ijk}	=Harvesting cost (\$/ha) associated with forest type *i* which is born in period *j* and harvested in period *k*.
C^{R}_{i}	=Regeneration costs (\$/ha) associated forest type *i*.
C^{C}_{k}	= Capital costs (\$) associated with building a mill in time period *k*
$W_{ij}(W_{ik})$	= Area (ha) of forest type *i* which is born in period *j(period k)* and never harvested within the planning horizon
A_{ij}	=area of forest in forest type *i* born in period *j*
δ	= Discount rate (%)
N	= The number of periods in the planning horizon
M	=Age (in periods) of the oldest age class of forest type I that is present at the beginning of the planning horizon (period 0)
p	= used to classify the regeneration strategy used, either natural regeneration or planted stock

The objective function maximizes the sum of the net present value of the forest over the planning horizon. The area constraints (Equations 3.12 and 3.13) ensure that each forest unit is assigned to an action or is left as standing inventory at the end of the planning horizon. Equation 3.12 ensures that the harvest areas do not exceed the existing forest and Equation 3.13 ensures that the harvest area does not exceed the total area of new or managed forest (those forests that were born during the planning horizon).

As most forests in Canada are regulated to some extent, harvest volume constraints (equations 3.14 and 3.15) were added to the model to ensure than an even flow of timber is being harvested each period. In this case, the volume harvested from the preceding period must be the same volume harvested in the current period.

Harvest Constraints

$$H_k = \sum_{i=1}^{I} \sum_{j=-M+1}^{K} V_{ijk} * X_{ijk} \qquad \forall k \qquad (3.14)$$

$$H_k - H_{k+1} = 0 \qquad \forall k \qquad (3.15)$$

Equations 3.16 constrain the area planted to be equal to the area harvested. In other words, every hectare that is harvested is reforested through tree planting. This is consistent with most government regulations concerning reforestation (Ontario Ministry of Natural Resources, 2006):

Regeneration Constraint

$$\sum_{j=-M}^{k-M} \left[\sum_{p=1}^{P} X^{P}{}_{ijk} - X_{ijk} \right] = 0 \qquad \forall k \qquad (3.16)$$

An additional volume constraint is added to assign the appropriate harvest volume, depending on which mill size is optimal. Equation 3.18, ensures that no oversupply of timber would occur in any one period. Furthermore, depending on which mill size was built, there would be different capital costs (Equation 3.17). Therefore, a capital cost function needed to be incorporated to ensure that the proper capital costs are assigned to the optimal mill size. This means of incorporating the costs of capital uses a return on equity (ROE) approach[5]. That is to say, that the cash flows are measured taking into consideration the principal and interest payments on the debt (Barry *et al.*, 1988; Robison and Barry, 1996). The opportunity of cost of equity capital is the discount rate in this case (Robison and Barry, 1996).

Capital Cost Function

$$C_k^C = \sum_{k=1}^{N}\sum_{z=1}^{Z}[B_z * CS_z] \qquad \forall k \qquad (3.17)$$

Where:

B_z =Binary number (0,1) indicating which mill size, z, is being built.

CS_z =Capital costs associated with building mill sizes, z.

Volume Constraint for Mill Size

$$H_k - \sum\sum[B_z * S_z] \leq 0 \qquad \forall k \qquad (3.18)$$

Where:

S_z = Sawmill capacities (m^3/period) for each mill size *z*.

[5] There is debate about how to calculate the costs of capital. In the literature there are two approaches: return on equity (ROE) and return on assets (ROA). This paper uses the ROE approach. In the ROA approach, the annual cash flows do not include interest and principal payments on the loan. The weakness with the ROE approach is that if you are evaluating two projects with similar returns to assets but very different debt and equity capital you make get similar NPV calculations that do not reflect the risk associated with investing in a project that is highly leveraged (Barry *et al.*, 1988).

To account for some of the Moose Cree First Nation's traditional values an additional area constraint, as described in section 3.2.3, is added to the model to ensure that the area available to be harvested is only a fraction of the total area available for harvest.

Area Constraint for Traditional Values

$$\sum_{i=1}^{I}\sum_{k=1}^{N} X_{ijk} \leq T \qquad (3.19)$$

Where:

T = An area (ha) of the forest that is proportional to the total size of the forest available for timber harvest. The area excludes the portion of the forest reserved for traditional use

To ensure that only one mill size will be optimal a constraint needs to be added in order to ensure that only whole integers are chosen. Furthermore by setting the constraint less than or equal to 1 it allows for the possibility that the optimal solution may be not to build a mill at all (Equation 3.20).

Integer Constraint

$$\sum_{z=1}^{Z} B_z \leq 1 \qquad \forall\, k \qquad (3.20)$$

The last constraint (Equation 3.21) ensures that the variables do not take on negative values.

Non-Negativity Constraints

$$X_{ijk} \geq 0; X_{ikl} \geq 0; W_{ij} \geq 0; W_{ik} \geq 0; B_z \geq 0 \qquad \forall\, i,k; \qquad (3.21)$$

3.3.2 Sawmill Costing

The four mill sizes were chosen, as stated above, based on current mill sizes in Ontario. The four output capacities are 20,000 m^3 /year, 60,000 m^3/year, 200,000 m^3/year and 300,000 m^3/year of lumber per year respectively. These four output capacities require 37,011 m^3/year, 111,033 m^3/year, 370,110 m^3/year and 555,165 m^3/year of timber, respectively, to support them[6]. The approximate costs of building each mill were obtained through personal communications with Todd Nash at Bearingpoint[7]. The costs for building each mill are: $4 million, $12 million, $42 million and $65 million respectively. The model assumes that the life of a mill is 30 years (or 3 periods) and that there will be a mill retro-fit every 30 years for which costs would be equal to the original building costs. The model also assumes that the capital costs of building the mill will be financed and a down payment will be made. In this case, the down payment used was 10% (the down payment amount is varied in the sensitivity analysis) and payments were made every period based on the following formula (Davis *et al.* 2001):

$$p = Vo \frac{i(1+i)^n}{(1+i)^n - 1} \tag{3.22}$$

Where p is the payment amount each period, Vo is the amount of capital that is being financed, i is the interest rate on the capital and n is the number of payments. The interest rate on capital was determined by examining the Bank of Canada's prime business lending rate. According to Statistic's Canada's CANSIM database, the corporate lending rate was 4.6% at the time the analysis was conducted (December 2006). A more

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[6] The U.S. Forest Service's Report on Canadian and American Sawmills (Spelter and Alderman, 2005) reports that sawmills in Canada's boreal forest on average have a lumber recovery factor of 229 board feet of lumber per cubic meter of log. Therefore, a mill requires 1.85055 times more timber than its mill output capacity.

[7] Bearingpoint is a management and technology consulting company with expertise in forest sector management.

conservative estimate was chosen for this model and in this case the interest rate on capital was set at 10%. It is difficult determine an interest rate because payments are only made once every 10 years and most lending rates are based on monthly or yearly payments. There are financial formulas to convert annual interest rates into periodic ones but instead of trying to determine a precise interest rate, a sensitivity analysis on various interest rates will be conducted. In this case, the interest rate is lower than the discount rate. To account for this effect, both the interest rates and discount rates were varied in the sensitivity analysis.

3.4 Model Parameters

To determine the feasibility of both carbon management and sawmill sizing, the costs and revenues must be calculated over the planning horizon. The following table is a list of the parameters used in both models.

Table 3-4: Parameters used in the timber supply model

Parameter	Value
The Discount Rate	5%
Mill Gate Timber Value (Carbon Management Problem)	$45/m^3$
Mill Gate Timber Value (Sawmill Sizing Problem)	$50/m^3$
Reforestation Costs	$1200/ha
Harvesting and Transportation Costs	$30/m^3$

The discount rate in this case was set to 5%, which is commonly used in forest sector analyses (Murray 2000).

The mill gate timber value is the sawmill's willingness to pay for the timber as delivered to the mill gate. The value of the wood was determined through communications with individuals in the forest industry and by comparing these communications to a Pricewaterhouse Coopers report (2005) commissioned by the Watson Lake Chamber of Commerce and the Yukon Government. The personal communications with forestry professionals indicated that mills in Ontario generally have a willingness to pay for timber at their mill gate of $50/m^3$. The Watson Lake analysis indicated that a benchmark sawmill which processes 500,000 m^3 a year will have a fiber price of up to $57/m^3$. The residual value method can also be used to derive these economic rents. Haener (1998) derived these measures using Alberta lumber prices and the average variable costs of production. Her estimate for mill gate price, or the value of the timber in Alberta, was $60.89/m3 in 1996. Since the quality of the log profile in this case is unknown, a more conservative value of $45/m^3$ was chosen for the base model in the carbon management problem, whereas the $50/m^3$ was used in the sawmill optimization model. The mill gate price will be varied in the sensitivity analysis for the sawmill optimization model, therefore a less conservative number was applied for that model.

The reforestation costs were also estimated from personal communications with industry professionals and by again comparing these figures to the Pricewaterhouse Coopers 2005 report. The Pricewaterhouse Coopers report shows a reforestation cost of $3/m^3$ which can be converted to dollars per hectare by assuming how many cubic meters of wood there is in a hectare. Insley and Rollins (2005) estimated that the most valuable jack pine stands, in the Romeo Mallete forest unit (in proximity to the Moose Cree region), at 100 years-old, have a peak yield of 300 cubic meters per hectare. This would translate to a reforestation cost of $900 per hectare using the Pricewaterhouse Coopers figures. Since the area is very remote and access for reforestation companies would be an issue, the reforestation costs were estimated to be higher than the Pricewaterhouse Coopers report and closer to the figures cited by consultations with forestry professionals.

3.5 Solving the Models

3.5.1 Carbon Management Model

The optimization model was developed in Remsoft's Spatial Woodstock modelling system (Remsoft Inc. 1998). The planning horizon for the model is 200 (20 ten-year periods) years, but the model was run for an additional 50 years (5 periods) to effectively induce an ending inventory constraint. This ensures that the model does not harvest a large area in the last period of the model. The objective of this model is to maximize the net present value from the Central Unit for the Moose Cree First Nation, where both timber and permanent carbon credits are considered.

The model was run several times changing both the carbon prices and the area constrained for tradition values, while keeping the other parameters constant. The model was solved using Woodstock with the MOSEK solver. This approach will show the value that carbon management might have for the Moose Cree First Nation as well as the feasibility of a forest industry in this area, while attempting to maintain some of their traditional territory by limiting the area available for harvest.

3.5.2 Mill Optimization

The planning horizon for the model is 200 (20 ten-year periods) years, but the model was run for an additional 50 years (5 periods) to effectively induce an ending inventory constraint. Again, this ensures that the model does not harvest a large area in the last period of the model.

The model was solved using GAMS mixed integer programming and the OSL solver. The mixed integer programming approach allows for the optimal mill size to be a binary choice. In essence, the model chooses to build one of the mill sizes, or chooses not to build that mill.

Chapter 4 : Results I –Timber and Carbon Management

The experimental design in Chapter Three was used to answer several key questions for the Moose Cree First Nation. Firstly, given the forest inventory available, is timber harvesting feasible and if so, to what extent? Secondly, given the various prices of carbon, what role might carbon incentives play in a more broad land use plan? Lastly, what effect does reducing the area available for timber harvest have on the forest in terms of both timber management and carbon management? This chapter will answer these questions as well as summarize the results from the optimization modelling.

4.1 Carbon Baselines

The carbon baselines were derived by setting the price of carbon to zero in the linear programming model as discussed in Chapter Three. The even flow baseline was derived by applying a volume constraint on harvesting. The no restrictions baseline was created by not applying any harvest volume constraints. Figure 4-1 illustrates the two different baselines. Any increases or decreases from the baselines will result in permanent carbon credits or debits if they are present in the subsequent period (as shown in equations 3.7 and 3.8). Both baselines are declining over time, which is largely due to the initial age class structure of the forest. In this case, the even flow baseline and the no restrictions baselines are similar until the end of the planning horizon. The even flow baseline generates more carbon at the end of the horizon because it is constrained to harvest the same amount of timber volume each period. In order to satisfy this constraint, a larger area of forest is regenerated with planted stock, which yields greater timber volume as well as carbon volume than those naturally regenerated. Figure 4-2 illustrates the difference in harvest levels between the two baselines.

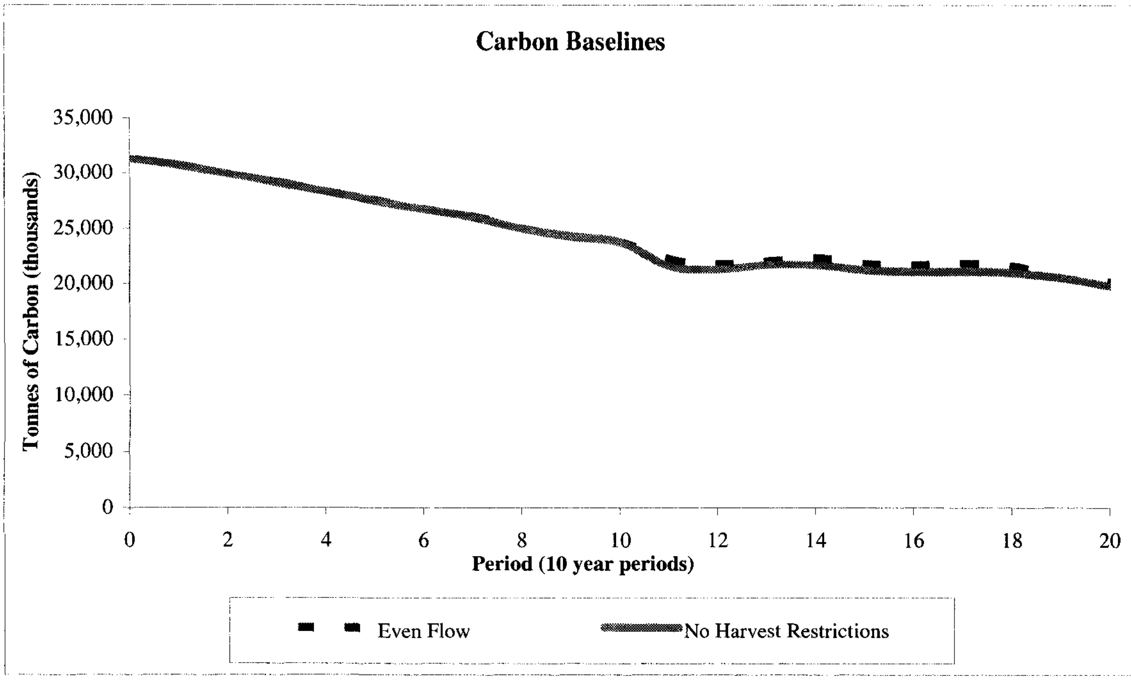


Figure 4-1: Carbon baseline results for the central unit forest

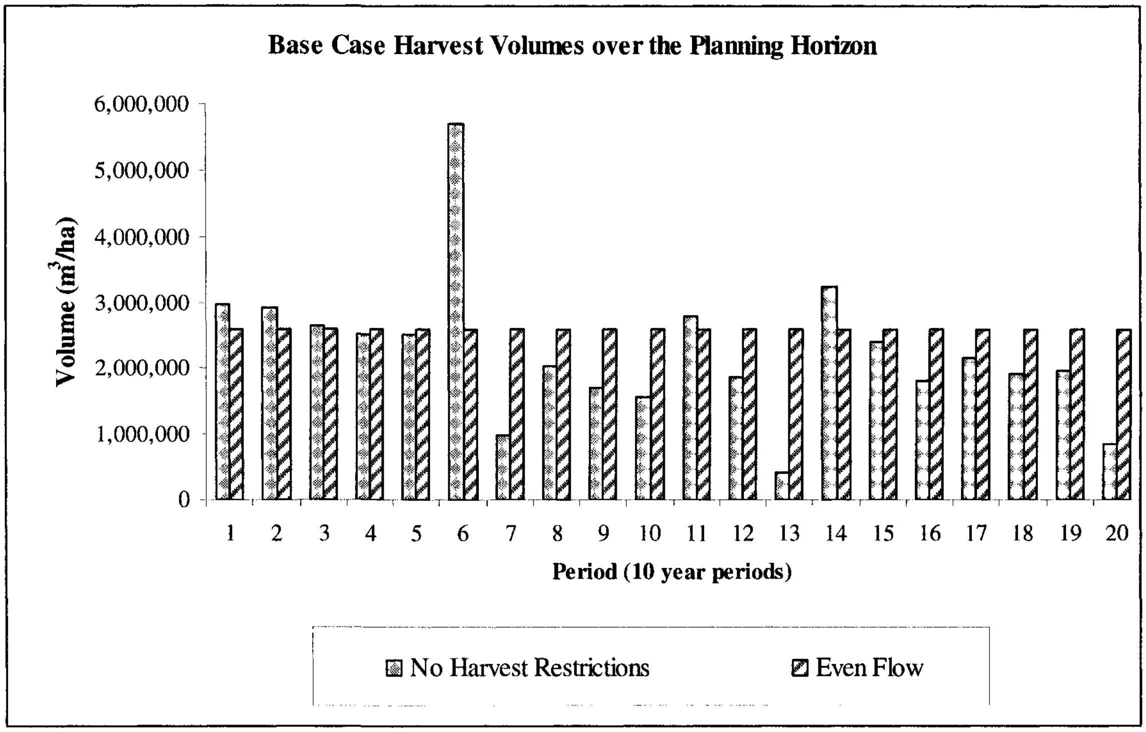


Figure 4-2: Harvest volumes from the baseline runs for both even flow and no restriction cases.

The timber harvest pattern for the unrestricted case is quite interesting. There is a large spike in harvesting in period six. This spike can be explained by the fire that burned a large area of jack pine stands. After 60 years, the jack pine stands are likely mature and ready for harvest. In fact, the results from the baseline case show that approximately 800,000 m^3 of jack pine are harvested in this period, which accounts for the increased volume during this period. Towards the end of the planning horizon, the volume of timber harvested in the unrestricted case begins to decrease. This is likely an effect of time and discounting; the future value of the wood is decreased.

4.2 Net Present Value Results

The objective of the linear programming model was to maximize the net present value that could be derived from the Central Unit over the planning horizon when both timber and carbon revenues were included. The first set of results considers the model results without harvest volume constraints. Table 4-1 illustrates the net present values derived from the Central Unit with increasing carbon credit prices and increasing area restrictions.

Table 4-1: Net present value ($) from the Central Unit with no harvest volume constraints

	Area Constraint (% of area unavailable for timber harvesting)			
Permanent Carbon Credit Price ($/t C)	***0***	***20***	***40***	***60***
0	67,828,027	67,817,862	67,685,397	66,286,183
2	67,814,413	67,803,998	67,677,642	66,312,304
4	67,820,601	67,809,291	67,693,189	66,326,286
6	68,105,713	68,094,253	67,997,305	66,742,326
8	68,674,850	68,663,702	68,583,359	67,857,345
10	69,266,849	69,256,030	69,187,615	68,317,947
20	72,538,510	72,534,676	72,524,654	72,436,102
30	77,340,258	77,340,258	77,336,388	77,312,799
40	91,257,212	91,257,212	91,256,668	91,253,386

The net present value (NPV) results reveal that over the 200 year planning horizon, the Moose Cree First Nation stand to gain approximately $67 million when the price of carbon is zero and there are no constraints on the area available for harvest. As the price of carbon is increased, the net present value generally increases. However, there is an exception to this trend in these results. As the price of carbon increases from $0 to $2, the net present value actually decreases. This is an unexpected result. The result can be explained by the effect of the permanence constraint on the carbon credits. When the price of carbon is zero, any increase or decrease in carbon does not result in a debit or credit. When the price of carbon is anything greater than zero, the permanence restriction discussed in Chapter Three comes into effect. The presence of the permanence constraint also contributes to a decline in NPV through a reduction in the volume harvested (Table 4-6) to reduce the number of debits and an increase in the proportion of area planted (Table 4-7) in order to increase the yield of carbon. All of these factors act to reduce the NPV when carbon prices are introduced. Table 4-2 shows the debits and credits accrued in model as the price of carbon is $2, $4 and $6 respectively. This result shows that at low carbon prices, implementing a carbon program would actually result in a decrease in net present value when carbon management contracts are subject to this type of permanence constraint. In addition, this result also reveals that it would not be in the Moose Cree's best interest to enter into a carbon contract if the price of carbon is less than $6 per tonne in this unrestricted case.

Table 4-2: The pattern of debits and credits at low carbon prices and no area constraints

Period	Price of Carbon $2/t C			Price of Carbon $4/t C			Price of Carbon $6/t C		
	Change in Carbon from the baseline ($S_k - S_k^b$)	*Permanent credit* (R_k)	*Credit (positive) or Debit (negative)*	*Change in Carbon from the baseline* ($S_k - S_k^b$)	*Permanent credit* (R_k)	*Credit (positive) or Debit (negative)*	*Change in Carbon from the baseline* ($S_k - S_k^b$)	*Permanent credit* (R_k)	*Credit (positive) or Debit (negative)*
1	0	0	0	0		0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	1157573	1157573	6945438
7	0	0	0	0	0	0	3851421	2693848	16163088
8	0	0	0	1806	1806	7224	6856967	3005546	18033276
9	306011	306011	612022	487428	485622	1942488	10036446	3179479	19076874
10	410408	104397	208794	647738	160310	641240	12568081	2531635	15189810
11	363549	-46859	-93718	668787	21049	84196	13864206	1296125	7776750
12	409242	45693	91386	759830	91043	364172	14491620	627414	3764484
13	0	-409242	-818484	252239	-507591	-2030364	15431884	940264	5641584
14	0	0	0	0	-252239	-1008956	16354302	922418	5534508
15	0	0	0	0	0	0	11960598	-4393704	-26362224
16	0	0	0	0	0	0	8524896	-3435702	-20614212
17	351527	351527	703054	240847	240847	963388	4620933	-3903963	-23423778
18	0	-351527	-703054	-1	-240848	-963392	0	-4620933	-27725598
19	0	0	0	-1	0	0	0	0	0
20	0	0	0	-1	0	0	0	0	0

Table 4-1 also reveals that with high carbon prices the Moose Cree First Nation can increase their net revenues significantly. With a carbon credit price of $40/t C they stand to increase their revenues by $23 million, which is a $200,000 per year increase from the no carbon scenario.

The NPV results also show what happens as the area available for harvest decreases. Intuitively, as the area available decreases, the net present value decreases. However, the decrease is not as large as expected. With only 40% of the original area left to harvest, there is only a $1.5 million decrease in NPV. This is unexpected and largely due to the reforestation constraint. Each hectare of harvested forest must be regenerated either naturally or through planting. The model assumes perfect regeneration. Therefore, sites that are harvested are available for second or third rotations. This leaves enough area available for harvest without decreasing the NPV significantly.

The most interesting result is the interaction between the area constraint and the carbon prices. As carbon prices increase, the effect of the area constraint is minimized. As the carbon prices increase, the volume of timber that is harvested decreases, which is acting somewhat like an area constraint. At the $40/t C price, the area constraint is not binding at 20% and only decreases the NPV by $4,000 at 40% unavailability.

Table 4-3 breaks down the NPV into the components from timber and carbon net revenues. As the price of carbon increases, the proportion of NPV from timber decreases, although only at the highest carbon price is there a complete switch from timber harvesting to only carbon management. Similarly, as the area available for harvest decreases, the proportion of revenues from timber decreases, but only slightly.

Table 4-3: The proportion of revenues from carbon management and timber management with no harvest restrictions.

Carbon Credit Prices ($/t C)		Area Constraint (% of area unavailable for timber harvest) 0	20	40	60
0	*Timber*	100.00%	100.00%	100.00%	100.00%
	Carbon	0.00%	0.00%	0.00%	0.00%
2	*Timber*	99.99%	99.99%	99.97%	99.96%
	Carbon	0.01%	0.01%	0.03%	0.04%
4	*Timber*	99.96%	99.96%	99.91%	99.85%
	Carbon	0.04%	0.04%	0.09%	0.15%
6	*Timber*	97.57%	97.57%	97.47%	96.60%
	Carbon	2.43%	2.43%	2.53%	3.40%
8	*Timber*	96.59%	96.59%	96.52%	95.34%
	Carbon	4.30%	3.38%	3.45%	4.66%
10	*Timber*	95.70%	95.70%	95.64%	94.19%
	Carbon	4.30%	4.30%	4.36%	5.81%
20	*Timber*	88.65%	88.59%	88.51%	88.41%
	Carbon	11.35%	11.41%	11.49%	11.59%
30	*Timber*	69.49%	69.49%	69.48%	69.43%
	Carbon	30.51%	30.51%	30.52%	30.57%
40	*Timber*	0.27%	0.27%	0.27%	0.26%
	Carbon	99.73%	99.73%	99.73%	99.74%

The addition of the even flow constraint results in significantly lower net present values. Tables 4-4 and 4-5 describe the results of the model runs when harvesting is restricted to even flow. The net present value in the even flow case (when the price of carbon is zero and there is no area constraint) is $6 million less than in the no restrictions case. The difference in NPV is due to the harvest levels at the end of the planning horizon, as well as the differences in the levels of planting which have increased costs. The no restrictions case does not harvest as much volume in the second half of the planning horizon as the even flow case. As the carbon price is increased, the difference between the two models becomes less pronounced. This is likely due to the fact that at higher carbon prices, there is very little timber harvesting at the beginning or the end of the planning horizon. In this case, there is no decrease in NPV at low carbon prices as was the case in the unrestricted model. This is likely due to the effect that the even flow constraint has on harvesting and planting. The constraint restricts the level of harvesting to such a level that debits are minimal and in addition the proportion of area that is planted is increased. This results in higher carbon yields, which increases the number of credits. These effects result in a net increase in the NPV from the base case.

Table 4-4: Net present value ($) from the Central Unit with even flow harvest constraint

	Area Constraint (% of area unavailable for timber harvest)			
Carbon Credit ($/t of C)	***0***	***20***	***40***	***60***
0	61,718,025	59,390,872	54,392,976	45,175,854
2	61,885,616	59,767,060	55,159,421	46,806,838
4	62,253,478	60,324,047	56,064,666	48,427,169
6	62,785,463	60,996,388	57,028,901	50,052,042
8	63,345,808	61,685,015	58,025,907	51,695,374
10	63,935,404	62,435,581	59,038,312	53,334,733
20	68,888,505	68,109,447	66,298,690	63,141,080
30	76,075,624	76,018,988	75,725,102	74,947,258
40	90,722,863	90,722,863	90,722,863	90,722,863

In the even flow case, the area constraint has a larger impact on the net present value at low carbon prices. When the carbon price is $2/t C and the area constraint is at 60%, the NPV is reduced by $16.5 million compared to the 0% area constraint over the planning horizon. That is compared to a $1.5 million difference in the no restriction case. At the $40/t C price the area constraint is no longer binding at any level, likely because the high carbon price results in very little harvesting (see table 4-5).

Table 4-5: The proportion of revenues from carbon management and timber management with even flow harvesting

		Area Constraint (% of area unavailable for harvest)			
Carbon Credit ($/t C)		***0***	***20***	***40***	***60***
0	***Timber***	100.00%	100.00%	100.00%	100.00%
	Carbon	0.00%	0.00%	0.00%	0.00%
2	***Timber***	99.53%	99.20%	98.45%	96.54%
	Carbon	0.47%	0.80%	1.55%	3.46%
4	***Timber***	98.33%	97.83%	96.63%	93.30%
	Carbon	1.67%	2.17%	3.37%	6.70%
6	***Timber***	97.38%	96.67%	94.87%	90.24%
	Carbon	2.62%	3.33%	5.13%	9.76%
8	***Timber***	96.45%	95.50%	93.11%	87.36%
	Carbon	4.66%	4.45%	6.77%	12.64%
10	***Timber***	95.34%	94.00%	91.43%	84.66%
	Carbon	4.66%	6.00%	8.57%	15.34%
20	***Timber***	81.89%	80.07%	74.15%	65.53%
	Carbon	18.11%	19.93%	25.85%	34.47%
30	***Timber***	66.70%	65.69%	60.39%	50.17%
	Carbon	33.30%	34.31%	39.61%	49.83%
40	***Timber***	0.07%	0.07%	0.07%	0.10%
	Carbon	99.93%	99.93%	99.93%	99.90%

The results from the even flow model are very similar to those of the unrestricted case. In both models, the point at which carbon management is preferred to timber harvesting occurs at $40/t C. However, the proportion of NPV from carbon is generally larger in the even flow case than the no restriction case. Since the even flow constraint is forcing harvesting throughout the planning horizon; lower volumes of timber are harvested throughout the entire planning horizon resulting in slightly higher NPV from carbon than in the no harvest volume restrictions case (harvest volumes are discussed in more detail in section 4.3).

The NPV value results are consistent with McCarney's (2007) results in which similar scenarios were examined. With a business as usual baseline, he found that the inclusion of carbon management within a timber management framework increased the net present value of the forest throughout the planning horizon.

4.3 Effects of the Area Constraint and Carbon Prices on the Central Unit

Carbon incentives and an area constraint will affect the composition of the central unit forest. The harvest volumes and species harvested may vary depending on the carbon prices, the level of area available for harvest as well as the harvesting restrictions. Table 4-6 describes the harvest volume results from both models (even flow and no restriction). These results are intuitive, as the carbon price increases, the volume of timber harvested decreases and similarly, as the area available for harvest decreases, the volume also decreases. As stated above, the even flow model has higher levels of harvesting compared to the no restriction case regardless of carbon price and area constraint, except when the price of carbon is $40/t C. At the $40/t C price level (no area constraint) the area harvested in the no restriction case is much higher than the even flow model. In fact in the even flow case there is only 2,525 m^3 per period scheduled for harvest. This equates to only 252 m^3 per year, which in a productive stand could translate to 1 ha of forest. In this case, it is reasonable to assume this optimal decision is basically a no harvest decision. With an even flow constraint and high carbon prices, there is little incentive for timber harvesting.

Table 4-6: Volumes harvested over the planning horizon in the Central Unit (m^3)

Harvesting Framework	Carbon Credit ($/t of C)	Area Constraint (% of area unavailable for harvest)			
		0	*20*	*40*	*60*
Even Flow	*0*	51,994,160	50,030,474	45,944,200	38,164,461
	2	51,969,920	50,007,060	45,945,800	38,138,133
	4	51,989,280	50,030,320	45,843,100	38,136,480
	6	51,931,920	49,997,020	45,780,969	38,120,740
	8	51,897,120	49,969,440	45,717,340	38,087,300
	10	51,804,780	49,835,780	45,670,840	38,077,100
	20	48,870,860	47,194,080	42,537,140	35,670,868
	30	44,055,140	43,363,880	39,763,900	32,660,700
	40	50,500	50,500	50,500	50,500
No Harvest Restrictions	*0*	44,954,284	42,914,921	38,099,398	32,350,477
	2	43,108,124	41,508,077	37,153,477	31,462,774
	4	42,603,324	40,751,989	37,341,416	30,316,498
	6	47,548,055	45,791,096	42,787,624	37,219,954
	8	37,837,235	35,914,410	30,891,535	25,458,145
	10	38,119,356	36,196,531	31,173,654	25,631,733
	20	38,274,802	34,641,787	30,378,440	25,808,158
	30	28,799,198	28,799,198	25,131,796	21,538,298
	40	16,157,598	16,157,598	14,680,928	9,504,932

Much like the NPV results the impact of the area constraint is not as large as expected. In general, as the area constraint is increased, the proportion of area planted increases (Table 4-7). This compensates for the loss of area and results in a much smaller loss in volume than expected because planting stock has a higher productivity than natural regeneration. Therefore, a stand with planted stock will yield higher volumes than one that is naturally regenerated.

The relationship between areas planted and the carbon price is a little less obvious. As the price of carbon increases, the area planted increases, but when the price of carbon is $40/t C, the area planted decreases. Because planting stock results in higher levels of carbon, as the price of carbon increases there should be an increase in planting to maximize the level of carbon available in later time periods. However, when the price of carbon is high enough, it is no longer optimal to harvest timber. Therefore, if very little area is harvested, then the area planted will decrease accordingly. Table 4-6 shows this result: the harvest volume decreases substantially in both the even flow and unrestricted models with the price of carbon is $40/t C regardless of the area constraint. This large decrease explains the reduction in planting when the price of carbon is very high.

Once again, there is a large difference between the size of the areas planted in the even flow and no restrictions models. The even flow model favours planting more so than the no restriction case. The increase in planting likely ensures that there is enough volume in subsequent periods to satisfy the even flow constraint, since planted stock has higher productivity than the regenerated stock (Table 4-7).

Table 4-7: Total area harvested and proportion of area planted in the Central Unit

		Total Area Harvested (ha)				Proportion of Area Regenerated with Planting Stock			
Management Framework	Price ($/t C)	Area Constraint (proportion of area unavailable for harvest)							
		0	*20*	*40*	*60*	*0*	*20*	*40*	*60*
No Harvest Restrictions	*0*	482,476	445,656	369,011	287,768	2%	2%	2%	1%
	10	427,990	390,313	307,097	223,330	15%	16%	21%	29%
	40	185,664	185,664	169,359	121,255	10%	10%	11%	15%
Even Flow	*0*	480,390	429,991	334,689	223,608	49%	48%	57%	46%
	10	467,859	416,435	330,795	223,421	55%	56%	60%	43%
	40	655	655	655	655	8%	8%	8%	8%

Table 4-8 reveals that neither the area constraint, nor the carbon prices, affect the species composition of the central unit to any substantial degree. Although there are differences in the amount of carbon between species, the main driver of differences between carbon yield curves are the site productivity and the type of silviculture used.

McCarney's (2007) results indicated that as carbon incentives or prices increased, aspen stands were favored for conservation. This does not appear to be the case here. Unlike McCarney's hypothetical forest, the Central Unit does not contain any measurable aspen or deciduous species in its inventory. Deciduous trees generally have larger carbon values because of the large amounts of carbon stored in the leaves and the soil carbon that is accumulated as the leaves fall off and decompose (Kurz and Apps, 1999). However, McCarney did find that mixed coniferous forest remained unchanged as a result of the increasing carbon prices. This is consistent with the results presented in Table 4-8.

As in the case of carbon incentives, the area constraint did not alter the species composition of the forest greatly. There is one small pattern however, as the area available for harvest increases, the volume harvested from mixed black spruce and jack pine stands tends to increase. The mixed stands account for 55% of the total forest area. As the total area available for harvest decreases, it makes sense that a greater number of the more abundant species mixes would be accessed.

Table 4-8: Proportion of total volume harvested by species mix in the Central Unit

Management Framework	Carbon Credit ($/tonne of C)	Species Mix	Area Constraint (% of area unavailable for harvest)			
			0	20	40	60
Even Flow	0	Jack Pine	6%	5%	6%	7%
		Black Spruce	22%	21%	13%	5%
		Black Spruce/Jack Pine	72%	73%	79%	88%
		Larch/Cedar	1%	1%	1%	0%
	6	Jack Pine	6%	6%	5%	7%
		Black Spruce	20%	19%	13%	5%
		Black Spruce/Jack Pine	73%	74%	80%	88%
		Larch/Cedar	1%	1%	1%	0%
	8	Jack Pine	6%	6%	5%	7%
		Black Spruce	19%	19%	13%	5%
		Black Spruce/Jack Pine	74%	74%	80%	88%
		Larch/Cedar	1%	1%	1%	0%
	10	Jack Pine	6%	6%	5%	7%
		Black Spruce	19%	18%	13%	5%
		Black Spruce/Jack Pine	74%	75%	81%	88%
		Larch/Cedar	1%	1%	1%	0%
	30	Jack Pine	6%	6%	6%	5%
		Black Spruce	22%	18%	11%	5%
		Black Spruce/Jack Pine	8%	76%	82%	90%
		Larch/Cedar	1%	1%	1%	0%
	40	Jack Pine	0%	0%	0%	0%
		Black Spruce	74%	74%	74%	74%
		Black Spruce/Jack Pine	26%	26%	26%	26%
		Larch/Cedar	0%	0%	0%	0%
No Harvest Restrictions	0	Jack Pine	5%	5%	6%	7%
		Black Spruce	24%	24%	17%	5%
		Black Spruce/Jack Pine	70%	69%	76%	87%
		Larch/Cedar	1%	1%	2%	0%
	6	Jack Pine	5%	5%	5%	6%
		Black Spruce	22%	22%	15%	4%
		Black Spruce/Jack Pine	72%	71%	78%	90%
		Larch/Cedar	1%	1%	1%	0%
	8	Jack Pine	6%	6%	7%	9%
		Black Spruce	29%	30%	20%	6%
		Black Spruce/Jack Pine	63%	62%	71%	85%
		Larch/Cedar	2%	2%	2%	0%
	10	Jack Pine	6%	6%	7%	9%
		Black Spruce	29%	30%	20%	7%
		Black Spruce/Jack Pine	64%	62%	71%	85%
		Larch/Cedar	2%	2%	2%	0%
	30	Jack Pine	10%	10%	11%	13%
		Black Spruce	15%	15%	12%	6%
		Black Spruce/Jack Pine	74%	74%	76%	81%
		Larch/Cedar	1%	1%	1%	0%
	40	Jack Pine	0%	0%	0%	0%
		Black Spruce	27%	27%	29%	35%
		Black Spruce/Jack Pine	73%	73%	71%	65%
		Larch/Cedar	0%	0%	0%	0%

4.4 Optimal Rotation Lengths

Many studies in the literature indicate that as carbon incentives or prices increase, so do the rotation lengths (van Kooten *et al.* 1995, Creedy and Wurzbacher 2001, Murray 2000, Hoen and Solberg 1997; Plantinga and Birdsey 1994). Table 4-9 shows that this is the case in the Central Unit for both types of harvesting (even flow and no restrictions). As the carbon price is increased to $40/t C, the harvest moves from younger aged stands to older stands. In the base case (carbon price $0/t C; no area constraint) for both management frameworks, the majority of stands are harvested between the ages 50 to 120 years. In contrast, as the carbon incentive is increased, the majority of stands are harvested between the ages of 130 to 250 years of age. This means that as carbon incentives increase, harvests are being delayed, resulting in forests with older age class distributions.

The area constraint does not have the same effect on rotation lengths. In fact, it has the opposite effect in that it decreases the rotation length. When the area constraint is applied to 60% of the Central Unit, there is a shift to harvest more stands in middle age (50 to 70 years) and far fewer stands in the old growth category (130 to 250 years). The reason for this trend is not clear. Perhaps, it is simply due to the availability of harvestable forest area. As the area constraint increases, there is less forest available for harvest. Therefore, it may be beneficial to harvest stands earlier in order to regenerate them and have them available for future rotations. This is consistent with Table 4-7 that shows that as the area constraint is increased, the proportion of areas planted increases.

Planting decisions result in higher yield curves which would likely reduce harvest rotations.

The combination of the area constraint and the carbon price increases rotation lengths. As is evident in the previous analyses, the area constraint does not have a large impact and therefore, when the two are combined, the carbon price's effect is stronger. Table 4-9 shows that the combination of high carbon prices and a large area constraint results in virtually identical results to the no area constraint and $40/t C case.

Table 4-9: The proportion of total area harvested by harvest age.

Management Framework	Area Constraint Level (percent of area unavailable for harvest)	Carbon Credit Price ($/t C)	Harvest Age (years)			
			10-40	*50-70*	*80-120*	*130-250*
No Harvest Restrictions	*0*	*0*	2%	40%	35%	22%
	0	*40*	0%	10%	4%	87%
	60	*0*	4%	65%	26%	5%
	40	*40*	0%	11%	4%	85%
Even Flow	*0*	*0*	0%	30%	45%	25%
	0	*40*	0%	8%	6%	86%
	60	*0*	0%	6%	75%	19%
	40	*40*	0%	8%	6%	86%

4.5 Shadow Price Analysis on Area Constraint

The shadow prices on the area constraint reveal the implicit price of the timber as carbon prices and area constraints are altered. Remsoft's Woodstock provides shadow prices for each period in the planning horizon. Therefore, the shadow prices presented in table 4-10 represent the highest shadow price represented throughout the planning horizon and throughout each scenario. In this case, the shadow price is interpreted as the additional net present value from timber management that could be achieved if the area constrained was increased (decreased) by one hectare[8].

Table 4-10: Highest shadow price ($/ha) of the area constraint through out the planning horizon and within each scenario.

Management Framework	Carbon Credit Price ($/t C)	Area Constraint Level (% of area unavailable for harvest)		
		20	*40*	*60*
No Harvest Restrictions	*0*	9.35	51.62	960.01
	6	10.18	50.99	901.07
	10	9.82	35.35	462.39
	40	0.01	0.30	1.27
Even Flow	*0*	2037.60	2759.39	8098.16
	6	1563.52	2180.63	5385.25
	10	1193.10	2008.72	3818.35
	40	0	0	0

The even flow scenarios generate much higher shadow prices than the no restriction scenarios. This is as expected because both the even flow constraint and the area constraint are restricting the amount of timber that can be harvested and therefore the two are reinforcing each other. As expected, as the area constraint is increased, the shadow price also increases; each additional hectare is worth more as the area available decreases. Interestingly, as the carbon incentives are increased, the shadow prices are decreased, regardless of the level of area constraint. This is likely because as the price of carbon increases, the area harvested decreases. Therefore, constraints to reduce the area harvested have less of an impact. In the even flow case, when the price of carbon is $40/t C, the shadow prices are zero, which means that the area constraint at all levels is non-binding. In the no harvest restriction scenarios, the shadow prices are very low indicating

[8] Although the area constraint is presented in percentage form, due to the programming framework the proportion of area available for harvest was calculated in hectares and used for the constraint.

that even though the area constraint is binding, it does not have much of an impact on the objective function.

4.6 Summary

The results indicate that timber harvesting is economically feasible given the parameters used and that the inclusion of carbon incentives alters the timber management strategy, but only marginally. By incorporating carbon incentives, that figure can increase to approximately $90 million over the planning horizon, while harvesting less volume which is likely favorable to the Moose Cree First Nation. At low carbon prices, the impact on the net present value is relatively small and in the case of an unrestricted forest it can actually result in a decrease in NPV. Because of these small impacts, carbon management would likely not be adopted at low carbon prices. At high carbon prices, there is significant substitution to carbon management as opposed to timber harvesting. Interestingly, the area constraint, which limits the area available for harvest, has very little impact on both timber harvesting and carbon management. As often shown in the literature, the addition of carbon incentives into a linear programming framework results in increased rotation lengths and increased revenues. The implications of these results will be discussed in Chapter Six.

Chapter 5 : Results II- Sawmill Optimization

This chapter present the results of the sawmill optimization model as outlined in Chapter Three. The first results presented will be from the timber supply analysis that was used as a base for the sawmill optimization. Next, the results of the sawmill optimization and a sensitivity analysis on the parameters used in the model will be presented. Lastly, this chapter will examine the effect of incorporating an area constraint to address the traditional values of the Moose Cree First Nation.

5.1 Timber Supply Model

The optimal solution given by the timber supply model, before the mill optimization formulation is added, yields a net present value of $98 million over the 20-year planning horizon. We can see from Table 6-1 that this results from an even flow harvest of 3 million cubic meters of wood harvested per period, or a harvest of 300,000 cubic meters per year. The total volume of timber harvested over the planning horizon is 93 million cubic meters. For the first six periods, the optimal solution is to harvest timber solely from the existing forest. The managed forest will have young forests with small yields at the beginning of the planning horizon. Therefore, the optimal solution contains harvests predominantly from the existing forest. After period six, timber from both the managed forest and the existing forest are harvested. In period seven, 0.2% of the timber is harvested from the managed or planted forest and 99.8% is from the existing forest. In periods 8 through 11, the proportion of existing forest that is harvested decreases and the proportion of managed forest harvested increases. The managed forest has higher yields because the yield curves for planted stock are greater than the yield curves for the existing forest stock. It is logical that as the managed forest grows, the model will favour the planted forest over the existing one. After period 11, the timber is harvested solely from the managed forest.

The results of the unrestricted model, where the even flow constraint was removed, are very different. The unrestricted model yielded an NPV of $143 million while harvesting less timber volume. The results show that a large volume of forest is harvested in the first period. Approximately 7 million more cubic meters were harvested in the first period in the unrestricted case. Overall, the unrestricted model harvests less volume per period, with the exception of a few periods. It appears that without the even flow constraint, more volume is harvested at the beginning of the planning horizon to reduce the impact that discounting has on the NPV at the end of the planning horizon. As a result, less timber is harvested while generating a higher NPV. Unlike the even flow case, in the unrestricted model timber is harvested from existing and managed stands throughout the planning horizon.

Table 5-1: Volume of Timber Harvested over the planning horizon for both even flow and unrestricted models[9]

	Even Flow			Unrestricted		
	Volume of wood harvested from existing forest (m^3)	Volume of wood harvested from managed forest (m^3)	TOTAL	Volume of wood harvested from existing forest (m^3)	Volume of wood harvested from managed forest (m^3)	TOTAL
Period 1	3,017,300	0	3,017,300	10,051,000	0	10,051,000
Period 2	3,017,300	0	3,017,300	1,581,500	0	1,581,500
Period 3	3,017,300	0	3,017,300	1,415,300	0	1,415,300
Period 4	3,017,300	0	3,017,300	1,020,700	0	1,020,700
Period 5	3,017,300	0	3,017,300	832,240	0	832,240
Period 6	3,017,300	0	3,017,300	30,342	146,820	177,162
Period 7	3,009,600	7,741	3,017,341	91,521	68,970	160,490
Period 8	602,870	2,414,400	3,017,270	509,810	7,565,330	8,075,140
Period 9	1,330,800	1,686,500	3,017,300	113,120	1,372,400	1,485,520
Period 10	99,934	2,917,400	3,017,334	204,150	2,486,500	2,690,650
Period 11	1,067	3,016,300	3,017,367	152,980	1,232,300	1,385,280
Period 12	0	3,017,300	3,017,300	159,400	330,300	489,700
Period 13	0	3,017,300	3,017,300	337,920	283,000	620,920
Period 14	0	3,017,300	3,017,300	141,050	191,590	332,640
Period 15	0	3,017,300	3,017,300	2,327,000	8,571,800	10,898,800
Period 16	0	3,017,300	3,017,300	70,271	1,580,800	1,651,071
Period 17	0	3,017,300	3,017,300	107,080	1,627,600	1,734,680
Period 18	0	3,017,300	3,017,300	44,174	967,700	1,011,874
Period 19	0	3,017,300	3,017,300	32,797	741,670	774,467
Period 20	0	3,017,300	3,017,300	29,309	958,580	987,889
TOTAL	23,148,071	37,198,041	60,346,112	19,251,664	28,125,360	47,377,024

The area of the forest that is harvested each period varies between periods in both the even flow and the unrestricted model (Table 5-2). The average harvest area per period in the even flow model is approximately 32,000 hectares. Therefore, the yearly timber harvest is approximately 3,200 hectares, which is 1.4% of the total existing forested area in the Central Unit. Conversely, the unrestricted model harvested 20,600 hectares per period, which is only 0.9% of the total forest area.

[9] The differences between the GAMS model and the Woodstock model will be discussed in section 6.5

Table 5-2: Results from the timber supply model for both the even flow and unrestricted models

		Area Harvested (ha)	Revenue from Timber ($)	Harvesting Costs ($)	Planting Costs ($)	Net Revenues ($)	Discounted Net Revenues ($)
Even Flow	Period 1	15,429	150,870,000	90,520,000	18,514,886	41,835,114	41,835,114
	Period 2	15,929	150,870,000	90,520,000	19,114,876	41,235,124	25,314,789
	Period 3	16,332	150,870,000	90,520,000	19,597,990	40,752,010	15,359,004
	Period 4	18,069	150,870,000	90,520,000	21,682,878	38,667,122	8,946,700
	Period 5	18,136	150,870,000	90,520,000	21,763,663	38,586,337	5,481,023
	Period 6	40,345	150,870,000	90,520,000	48,414,102	11,935,898	1,040,855
	Period 7	66,473	150,870,000	90,520,000	79,767,695	-19,417,695	-1,039,536
	Period 8	28,866	150,870,000	90,520,000	34,638,803	25,711,197	845,029
	Period 9	43,745	150,870,000	90,520,000	52,493,969	7,856,031	158,511
	Period 10	26,357	150,870,000	90,520,000	31,628,190	28,721,810	355,775
	Period 11	27,949	150,870,000	90,520,000	33,538,750	26,811,250	203,886
	Period 12	37,955	150,870,000	90,520,000	45,545,779	14,804,221	69,113
	Period 13	41,856	150,870,000	90,520,000	50,226,906	10,123,094	29,013
	Period 14	34,208	150,870,000	90,520,000	41,049,912	19,300,088	33,959
	Period 15	45,386	150,870,000	90,520,000	54,463,630	5,886,370	6,358
	Period 16	44,089	150,870,000	90,520,000	52,907,092	7,442,908	4,936
	Period 17	34,328	150,870,000	90,520,000	41,193,062	19,156,938	7,799
	Period 18	34,824	150,870,000	90,520,000	41,788,961	18,561,039	4,639
	Period 19	38,359	150,870,000	90,520,000	46,031,142	14,318,858	2,197
	Period 20	39,014	150,870,000	90,520,000	46,816,526	13,533,474	1,275
	TOTAL	667,649	3,017,400,000	1,810,400,000	801,178,811	405,821,189	98,660,437
Unrestricted	Period 1	65,508	502,570,000	301,540,000	78,609,000	122,421,000	122,421,000
	Period 2	14,543	79,076,000	47,446,000	17,452,000	14,178,000	8,704,062
	Period 3	11,919	70,767,000	42,460,000	14,302,000	14,005,000	5,278,337
	Period 4	9,783	51,035,000	30,621,000	11,740,000	8,674,000	2,006,968
	Period 5	10,137	41,612,000	24,967,000	12,165,000	4,480,000	636,365
	Period 6	2,056	8,858,300	5,315,000	2,466,700	1,076,600	93,884
	Period 7	2,037	8,024,500	4,814,700	2,444,300	765,500	40,981
	Period 8	62,860	403,750,000	242,250,000	75,432,000	86,068,000	2,828,725
	Period 9	12,755	74,278,000	44,567,000	15,307,000	14,404,000	290,629
	Period 10	27,131	134,530,000	80,718,000	32,557,000	21,255,000	263,284
	Period 11	13,641	69,265,000	41,559,000	16,369,000	11,337,000	86,212
	Period 12	6,022	24,485,000	14,691,000	7,225,900	2,568,100	11,989
	Period 13	8,560	31,046,000	18,628,000	10,272,000	2,146,000	6,151
	Period 14	4,369	16,632,000	9,979,200	5,242,700	1,410,100	2,481
	Period 15	103,080	544,940,000	326,960,000	123,700,000	94,280,000	101,840
	Period 16	14,485	82,555,300	49,532,000	17,382,000	15,641,300	10,372
	Period 17	15,294	86,736,000	52,041,000	18,353,000	16,342,000	6,653
	Period 18	8,928	50,594,000	30,356,000	10,713,000	9,525,000	2,381
	Period 19	9,440	38,723,000	23,234,000	11,328,000	4,161,000	638
	Period 20	11,420	49,394,000	29,637,000	13,704,000	6,053,000	570
	TOTAL	413,966	2,368,871,100	1,421,315,900	496,764,600	450,790,600	142,793,523

Table 5-2 also reveals the potential cash flow from the Central Unit when timber harvesting is applied to the area. The revenue from the timber is constant each period because of the even flow constraint on volume. It generates $150 million per period, or $1.5 million per year. The harvesting costs are also constant and are $90 million per period. The planting costs vary from period-to-period because they are based on the area harvested. Therefore, periods with large area harvests will have much larger planting or reforestation costs. The discounted net revenues are all positive except for period seven. Negative discounted net revenues are common because of the effect discounting has. The unrestricted model has variable costs and revenues depending on the level of harvest but does not have any negative net revenues.

In the timber supply portion of the model, there were only two constraints: an even flow of timber volume and areas harvested must be planted. We can examine the impact of these two constraints by evaluating the shadow prices. In the case of the planting constraint, the shadow prices were too small to be recorded by the software in the output. Therefore, we can conclude that the constraint on planting did not have a large impact on the optimal solution.[10] However, the even flow constraint did yield shadow prices. These shadow prices are represented in Table 5-3 and can be interpreted as the change in the objective function if the volume of timber harvested in period two did not have to equal the volume of harvest in period one. The shadow prices are all negative, which indicates that imposing the constraint has a negative impact on the objective function and are steadily increasing in value. This is likely due to the effect of discounting. The values were "undiscounted" to reveal their impact on the objective function. The undiscounted values reveal that the largest impact on the objective function occurs in the beginning of the planning horizon and that there is very little effect on the objective function at the end of the planning horizon. In other words, the value of timber in period one could be increased by \$6.18/m^3 if there was no even flow constraint.

[10] The GAMS software reported the shadow price on planting as EPS which means that the value is very close to zero but different from zero (Rosenthal, 2007)

Table 5-3: Shadow prices from the Even Flow Constraint

Period (10 year periods)	Shadow Price ($/m^3)	Future Value (undiscounted) Shadow Price ($/m^3)
1	-10.06	-6.1760
2	-14.35	-5.4084
3	-15.62	-3.6141
4	-15.03	-2.1349
5	-13.57	-1.1834
6	-11.64	-0.6232
7	-9.58	-0.3149
8	-7.77	-0.1568
9	-6.29	-0.0779
10	-4.99	-0.0379
11	-3.88	-0.0181
12	-2.99	-0.0086
13	-2.31	-0.0041
14	-1.79	-0.0019
15	-1.36	-0.0009
16	-1.03	-0.0004
17	-0.76	-0.0002
18	-0.55	-0.0001
19	-0.38	0.0000
20	-0.26	0.0000

5.2 Mill Optimization Model

When mill sizes and costs were added to the timber supply model, the optimal solution changed. The optimal solution from the mill optimization model is to build the second largest mill size with a capacity of 3,017,300 m^3/period. The second largest mill has a capacity of 3,701,100 per period. Therefore, this mill would be operating at 683,800 m^3 per period below its maximum input capacity. This level of harvest and mill size yields an optimal NPV of approximately $53 million. Table 5-4 illustrates the volume harvested each period. The level of harvest is constrained by the capacity of the sawmill and the even flow constraint. The model including mill sizes harvests the same amount of volume as the timber supply model with an even flow constraint (Table 5-1). Like the timber supply model, the mill optimization model splits the volume harvested between the existing forest and the managed forest. The first six periods harvest exclusively from the existing forest and then the following periods harvest more and more volume from the managed forest. In period 12, like in the timber supply model, harvests occur solely from the managed forest because it likely has higher yields. There are no shadow prices to interpret because the model was solved using mixed integer programming, which does not include shadow prices in the output. Only the even flow constraint was included in this model because in order to support a sawmill, a regular supply of timber is required. However, the effect of the constraint is analyzed in the sensitivity analysis in section 5.3.6.

Table 5-4: Volume of Timber Harvested

Period (10 year periods)	Volume of wood harvested from existing forest (m^3)	Volume of wood harvested from managed forest (m^3)	Total Volume Harvested (m^3)
1	3,017,300	0	3,017,300
2	3,017,300	0	3,017,300
3	3,017,300	0	3,017,300
4	3,017,300	0	3,017,300
5	3,017,300	0	3,017,300
6	3,017,300	0	3,017,300
7	3,009,600	7741	3,017,341
8	602,870	2,414,400	3,017,270
9	1,330,800	1,686,500	3,017,300
10	99,935	2,917,400	3,017,335
11	1,068	3,016,300	3,017,368
12	0	3,017,300	3,017,300
13	0	3,017,300	3,017,300
14	0	3,017,300	3,017,300
15	0	3,017,300	3,017,300
16	0	3,017,300	3,017,300
17	0	3,017,300	3,017,300
18	0	3,017,300	3,017,300
19	0	3,017,300	3,017,300
20	0	3,017,300	3,017,300
TOTAL	23,148,073	37,198,041	60,346,114

The area harvested (Table 5-5) is similar to the timber supply model with an average area harvested of 32,000 hectares per period. The revenue from timber harvesting is $151 million per period and is constant because of the even flow constraint. The harvesting costs are $91 million per period and the planting costs vary from period-to-period, but the average cost is $38 million. The capital costs vary depending on whether or not the mill is built in that period or not. The down payment increases the costs of the mill in the year it is built. The next two periods are lower because they are simply the payments on the capital. The net revenues are interesting. They are only positive for the first 50 years, after which they are all negative or very small positive values. It would be very difficult to remain in business with either minimal or negative net revenues for 150 years. The re-tooling of the mill every three periods and the requirement to reforest harvested stands seems to decrease revenues substantially. The effect of discounting on the net revenues allows for a total positive net present value, even with such large negative net revenues.

Table 5-5: Results from the mill optimization model

Period (10 year periods)	Area Harvested (ha)	Revenue from Timber ($)	Harvesting Costs ($)	Planting Costs ($)	Capital Costs associated with optimal mill size ($)	Net Revenues ($)	Discounted Net Revenues ($)
1	15,429.00	150,870,000	90,519,000	18,514,800	19,400,000	22,436,200	22,436,200.00
2	15,929.00	150,870,000	90,519,000	19,114,800	15,200,000	26,036,200	15,983,968.25
3	16,331.00	150,870,000	90,519,000	19,597,200	15,200,000	25,553,800	9,630,958.47
4	18,069.00	150,870,000	90,519,000	21,682,800	19,400,000	19,268,200	4,458,226.96
5	18,136.00	150,870,000	90,519,000	21,763,200	15,200,000	23,387,800	3,322,136.01
6	40,345.00	150,870,000	90,519,000	48,414,000	15,200,000	-3,263,000	-284,545.76
7	66,473.00	150,870,000	90,520,230	79,767,600	19,400,000	-38,817,830	-2,078,132.86
8	28,865.00	150,870,000	90,518,100	34,638,000	15,200,000	10,513,900	345,551.60
9	43,744.00	150,870,000	90,519,000	52,492,800	15,200,000	-7,341,800	-148,135.32
10	26,356.00	150,870,000	90,520,050	31,627,200	19,400,000	9,322,750	115,480.09
11	27,947.00	150,870,000	90,521,040	33,536,400	15,200,000	11,612,560	88,307.60
12	37,954.00	150,870,000	90,519,000	45,544,800	15,200,000	-393,800	-1,838.45
13	41,855.00	150,870,000	90,519,000	50,226,000	19,400,000	-9,275,000	-26,582.64
14	34,208.00	150,870,000	90,519,000	41,049,600	15,200,000	4,101,400	7,216.44
15	45,386.00	150,870,000	90,519,000	54,463,200	15,200,000	-9,312,200	-10,058.90
16	44,089.00	150,870,000	90,519,000	52,906,800	19,400,000	-11,955,800	-7,928.37
17	34,327.00	150,870,000	90,519,000	41,192,400	15,200,000	3,958,600	1,611.59
18	34,824.00	150,870,000	90,519,000	41,788,800	15,200,000	3,362,200	840.32
19	3,859.00	150,870,000	90,519,000	4,630,800	19,400,000	36,320,200	5,572.81
20	39,013.00	150,870,000	90,519,000	46,815,600	15,200,000	-1,664,600	-156.80
TOTAL	633,139	3,017,400,000	1,810,383,420	759,766,800	333,400,000	113,849,780	53,838,691

5.3 Sensitivity Analysis

Although the optimal solution to the mill sizing problem is to build a large mill; optimal mill size will be sensitive to the model parameters. Therefore, the sensitivity analysis examines changes in: interest rate, mill gate price, down payment, harvesting costs, discount rate and the effect of the even flow constraint. Table 5-6 represents 15 runs of the mill optimization model. A base model, as represented in the above results, was used to compare each of the different scenarios. The base model is an even flow model with a capital loan rate of 10%, a discount rate of 5%, a mill gate price of $\$50/m^3$, a 10% down payment and $\$30/ m^3$ harvesting costs. All runs include constraints restricting harvesting to even flow (except 16 and 17) force areas that were harvested to be planted and allow for the option to not build a mill.

Table 5-6: Sensitivity analysis for the mill sizing problem[11]

[11] Where the X's represent the various mill output capacities: X4= 300,000 m^3/year; X3= 200,000 m^3/year; X2= 60,000 m^3/year; X1= 20,000 m^3/year.

Testing	Run	Interest Rate (loan rate)	Millgate Price ($/m3)	Down Payment	Harvesting Cost ($/m3)	Discount Rate	NPV ($)	Optimal Mill Size
Baseline		10%	50	10%	30	5%	53,838,691	X3
Loan Rate	1	5%	50	10%	30	5%	57,233,604	X3
	2	15%	50	10%	30	5%	50,305,026	X3
	3	20%	50	10%	30	5%	46,707,184	X3
	4	25%	50	10%	30	5%	43,028,913	X3
Millgate Price	5	10%	45	10%	30	5%	14,909,688	X3
	6	10%	43	10%	30	5%	7,308,659	X2
	7	10%	40	10%	30	5%	0	none
Down Payment	8	10%	50	20%	30	5%	52,726,136	X3
	9	10%	50	30%	30	5%	51,636,164	X3
Harvesting Costs	10	10%	50	10%	35	5%	14,909,688	X3
	11	10%	50	10%	39	5%	1,556,976	X2
	12	10%	50	10%	40	5%	0	none
Discount Rate	13	10%	50	10%	30	7%	45,876,298	X3
	14	10%	50	10%	30	10%	38,608,986	X3
	15	10%	50	10%	30	15%	32,541,665	X3
Evenflow	16	10%	50	10%	30	5%	68,702,454	X3
	17	10%	60	10%	30	5%	171,791,832	X4

5.3.1 Capital Loan Rate

According to Statistics Canada's CANSIM database, the current corporate lending rate is 4.3% and therefore Run #1 lowers the loan rate to 5%. This change does not alter the optimal mill size but it increases the net present value to $57.2 million. The optimal size decision does not change with increasing loan rates, however the NPV is impacted by increases in loan rates. The sensitivity analysis shows that in this case, the model is not very sensitive to changes in loan rates. Considering the corporate lending rate is 4.3%, the interest rate would have to increase by a very large factor for the model to consider it not efficient to build a mill, which is not very realistic.

5.3.2 Mill Gate Price

The next parameter analyzed was the mill gate price. The mill gate price is essentially the willingness to pay for the timber as it arrives at the mill gate. This is a price that is very difficult to estimate. The base model uses a price of $50 per cubic meter of wood. Since this price would be considered a high estimate, the price was decreased to see the effects. When the price was decreased to $45/ m^3, the optimal mill size did not change, but the NPV decreased dramatically from $54 million to just $14 million. In run six, the mill gate price was decreased to $43/m^3, and the optimal mill size decreased to the medium mill, followed by a $7 million decrease in NPV. When the mill gate price was decreased to $40/ m^3, the optimal choice is to not build a mill and to not harvest anything.

This is a very interesting result. Considering the fact that mill gate price is very difficult to estimate and that small changes in price result in dramatically different optimal solutions, it could be very risky for the Moose Cree to build a mill. Although it is difficult to get accurate mill gate prices, lumber prices are readily available from Statistics Canada. Figure 5-1 shows the volatility in Ontario's softwood lumber prices since the 1980's. Although prices seem to be on a downward trend since 1997, they are also quite volatile in that they increase and decrease from one year to the next.

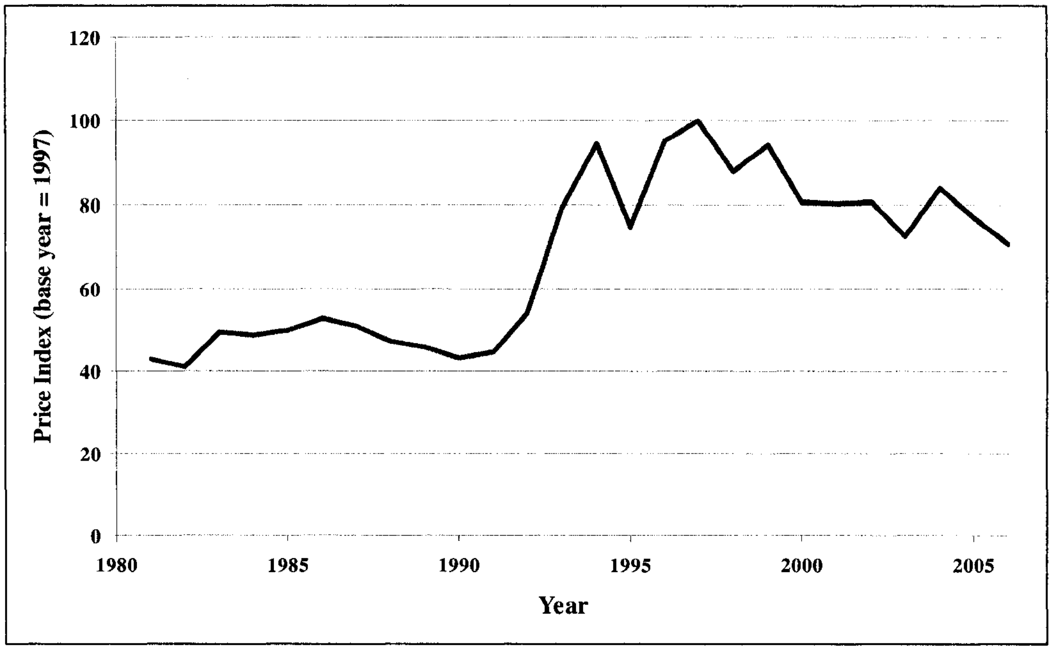


Figure 5-1: Ontario's softwood lumber industrial price index (Source: Statistic's Canada CANSIM database)

5.3.3 Down Payment

As can be seen in runs eight and nine, the results are not as sensitive to changes in the down payment amount as they are to changes in mill gate price. Even with a 30% down payment of capital, the model will still choose the large mill size as the most optimal. This could show that the Moose Cree First Nation would not require a large outlay of capital in order to build their mill. They would simply need to be able to find investors to finance the operation. The investors would have to be willing to partake in a risky investment because the model is so responsive to changes in costs and prices.

5.3.4 Harvesting Costs

Harvesting costs are also difficult to estimate. The first sensitivity run (run #10), increases the costs by $\$5/m^3$. This does not alter the optimal mill size, but it does decrease the NPV by almost $10 million from the baseline run. Run #11 increases the harvesting costs to \$39/ m^3, which results in a decrease in mill output capacity from 200,000 m^3 per year to 60,000 m^3 per year. When the costs are again increased by just \$1, it is no longer optimal to build a mill or harvest any timber. Like the mill gate price, the costs associated with harvesting and hauling are difficult to estimate and can fluctuate depending on variables such as: road building costs, fuel prices, road conditions, species harvested and haul costs. According to PricewaterhouseCoopers (2005), harvesting costs vary across the country. For example, in British Columbia, the harvesting costs are estimated at \$28/m^3 and in Ontario they are estimated at \$31/m^3. This analysis shows that even this relatively small regional variability is enough to alter the optimal decision. This represents another large risk to the Moose Cree First Nation in their decision to build a mill.

5.3.5 Discount Rate

In the base run, the interest on capital is lower than the discount rate. To determine what effect a higher discount rate has on the model, the discount rate was increased. Runs 13 through15 show that the optimal sawmill size is insensitive to changes in the discount rate. This is even true when the discount rate is greater than the capital loan rate. The NPV is affected by changes in the discount rate. With a discount rate of 15%, the NPV is diminished by \$21 million from the baseline run.

5.3.6 Even Flow

Run #16 shows that the even flow constraint reduces the NPV significantly, but does not alter the optimal sawmill size decision. The constraint decreases the NPV by

$15 million over the planning horizon. Run #17 shows that if the mill gate price was high enough, the extra large mill size could be chosen in the unrestricted case. The same run with the even flow constraint imposed does not result in a change in mill size. This is likely due to the fact that there is not enough timber to support both volume restrictions and an extra large output capacity.

5.4 Allowing for Traditional Use

The last component of the mill optimization model was to determine the effect of incorporating traditional uses. In this case, the traditional values are incorporated by imposing an area constraint that limits the area of existing forest that is available for harvest. Much like the above sensitivity analysis, we will gradually decrease the area available for harvest and see how that affects both the decision to build a mill and the mill size that is optimal. The total existing forest area that is available for harvest is approximately 230,000 hectares. Table 5-7 displays the various areas associated with the corresponding constraint levels as well as the results from the 9 runs.

Table 5-7: Optimal mill sizes given varying levels of area constraint

Constraint Level (%)	Area Available for Harvest (ha)	Optimal Mill Size	Net Present Value ($)
0	240,515	X3	53,816,110
20	192,412	X3	49,798,006
30	168,361	X3	46,666,492
40	144,309	X3	42,054,724
50	120,258	X3	35,966,651
60	96,206	X3	27,710,089
70	72,155	X3	27,439,551
80	48,103	X2	26,482,379
90	24,052	X1	9,174,218

Much like the loan rate, the down payment level and the discount rate, the model is relatively insensitive to the additional area constraint to maintain Moose Cree traditional values. The analysis reveals that optimal size decisions do not change until the area is constrained by 80%. The NPV decreases as the area is restricted, but there is no change in mill size until the constraint allows only 20% of the area to be harvested. At that level, the optimal size is a 60,000 m^3 per year output capacity mill. When harvesting is permitting on just 10% of the existing forest, the optimal output capacity drops to 20,000 m^3 per year.

Because the model has a reforestation requirement, there must be enough managed forest to accommodate the constraint on the existing forest area. This is why the constraint does not affect the optimal mill choice or the net present value in a significant way. This is a positive result for the Moose Cree, who would like to minimize the area affected by forestry to maintain their traditional values and way of life.

5.5 Model Verification

The validity of these types of models is often difficult to determine. In this case, the timber supply model was compared to the same model solved with Remsoft's Woodstock software. The harvest volume results were quite similar. Table 5-7 compares the two models. There is a large difference in NPV between the two values. Many of the differences can be accounted for by the difference in volume yields. The net return from timber is $20 per cubic meter[12] and the difference in harvesting between the two models is approximately 120,000 cubic meters per period, which results in an increase in

[12] The mill gate price is $50/$m^3$ and the harvesting costs are $30/$m^3$

revenues of approximately $2.5 million per period or $50 million over the entire planning horizon. This is close to the difference between the net present values.

Table 5-7: Comparison of the Woodstock and GAMS timber supply models

	Woodstock	GAMS
Volume harvested per period (m^3)	2,894,254	3,017,300
Net Present Value ($)	58,066,508	93,184,343

The differing optimal solutions within these models are likely due to the differences in the software packages. Remsoft's Woodstock is a software package specifically designed for modelling timber supplies. It has many components that cannot be "seen" by the user. It also has some built-in features that are difficult for GAMS, a more generic mathematical programming software, to replicate. The main source of difference is the transitions section within Woodstock. Woodstock follows a specific stand type from birth to death and all activities in between. The user has to state what happens to a specific forest stand[13] after it has been harvested, after it has been planted and after it dies. More specifically, the Woodstock model tells the forest to regenerate to the forest stand type that it was before it was harvested. The GAMS model does not have these constraints. In the GAMS model after a forest stand has been cut, the model decides what to regenerate itself back to. This means that it could regenerate to a higher yielding species or site class and therefore achieve a higher objective function value. Further investigation into the "unseen" portions of the Woodstock model and addition of transitions to the GAMS model, may help bring the objective functions closer together.

[13] Forest stand in this case means a group of trees that are the same species, have the same site classification and the same "birth" (either from the existing forest or from a planted tree)

5.7 Summary

Chapter Five reveals that although there is economic potential for the creation of a sawmill in Moose Factory, it is a very risky decision. The optimal solution suggests that a 200,000 m^3/year capacity sawmill could be supported in the area. However, the sensitivity analysis reveals that small changes in harvesting costs and mill gate prices result in a no sawmill optimal solution. Furthermore, even with stable costs and prices, the results indicate that the sawmill would be losing money after 50 years. Given this information, the Moose Cree First Nation will have to weigh the potential benefits in terms of employment and revenues, with the risks associated with changing market conditions.

Chapter 6: Discussion and Conclusion

The results presented in both Chapters Five and Chapter Six reveal that forest management is financially feasible in the Moose Cree's traditional territory, specifically in the Central Unit management area. The results indicate that for some levels of carbon prices[14] and area constraints, the Moose Cree would receive positive returns from both timber management and carbon management; although large increases in NPV are only achieved with high carbon prices (>$30/t C). Furthermore, when the market produces high timber prices and low operational costs, the construction of a mill would also result in positive returns. This chapter will discuss the implications of timber and carbon management as well as the potential for the construction of a sawmill.

6.1 Policy Implications of Carbon Management

Discussions with the Moose Cree First Nation reveal that although they are interested in increasing the economic activity in their community they are not willing to do so at the expense of wildlife habitat quality and quantity. Carbon management could provide a partial solution to the problem of increasing economic activity and maintaining environmental quality. With high carbon prices such as $40/t C the Moose Cree could generate more revenue from carbon management than from timber management and harvest very little if any forest. Furthermore, the addition of the area constraint reveals that limiting the area available for harvest does not affect positive returns in a significant way.

[14] In the unrestricted case when carbon prices are below $6/t C there is actually a decrease in net present value as compared to the base case or when the price of carbon is $0/t C.

Although carbon management may be an innovative means for the community to increase their economic activity, it will not likely result in an increase in employment. Timber harvesting activities are more likely to result in employment for the community with individuals needed to survey areas, build roads, harvest trees and to regenerate stands if timber management is included in their new land use plan. The decision for the Moose Cree First Nation in terms of which management scheme to adopt will have to consider this trade-off.

Although carbon management appears to be profitable and feasible in this case, there is still the issue of Canada not having a regulatory framework for buying or selling carbon credits from forests. The future of Kyoto in Canada is unclear. Although the current government seems to be implementing its own "Made in Canada" plan, the Parliament passed Bill C-288 which requires Canada to meet its Kyoto requirements and also requires the government to come up with a plan within 60 days of royal assent to reduce greenhouse gas emissions (Government of Canada 2006; Canadian Broadcasting Corporation, 2007; The Liberal Party of Canada 2007). Without regulations, or a market in which to sell credits, it would prove difficult for the Moose Cree First Nation to benefit from carbon management. Ontario's government has been showing signs of creating its own climate change plan which includes carbon credit trading. This could result in a market for Moose Factory's carbon (Ontario Office of the Premier, 2007). In addition, there are third parties that may be willing to partner with the Moose Cree First Nation and join voluntary carbon credit markets such as the Chicago Climate Exchange (Chicago Climate Exchange, 2007).

The issue of baselines would most certainly arise in any discussions the Moose Cree First Nation might have regarding their selling of carbon credits. Given that the Central Unit and most of their traditional territory has never been accessed for industrial purposes, it may be a difficult argument to make that the baseline in this case would include harvesting. Other baselines, such as a constant baseline or a no-activity baseline, would likely result in decreases in carbon if timber harvesting were introduced. McCarney's (2007) results indicate that different baselines, specifically constant ones, result in negative net present value figures. In other words, if your carbon management scenario resulted in negative NPV's, then it is unlikely that you would engage in that type of management. Furthermore, given that under some circumstances (low carbon prices) a carbon management scheme can result in lower returns than a no carbon situation, both the decision to enter into a carbon market and the type of contracts that are signed are important for the Moose Cree to consider, given that such a system could end up reducing their revenues.

6.2 Policy Implications of the Mill Optimization

The mill optimization model shows that a forest industry in Moose Factory could be financially feasible. The right economic environment could also support a mill with a yearly output of 200,000 cubic meters. That being said, there are some challenges that the Moose Cree First Nation would face in beginning to consider this type of development. The main issue that currently faces this community is the lack of secure forest tenure. They have begun a land use planning study, but have not had tenure approved by the Government of Ontario in terms of a forest management plan or their access rights to these forested lands (Personal communications with John Turner). This makes outside investment difficult to attract. A large amount of capital would be needed; at least $65 million for the large mill which does not include labour costs or the costs of equipment in terms of loaders for the mill.

The sensitivity analysis shows that although the optimal solution is to build a very large mill, this is only true under a very specific set of parameters. When the cost of harvesting or the value of the timber is changed, the optimal solutions for the model are very different. The costs of harvesting and hauling are very difficult to estimate in this area because it has yet to be accessed. Transportation costs will likely be high. Most of these factors mean that the cost of harvesting could be very high or could fluctuate dramatically in response to changes in the economy such as increases in fuel prices and construction costs. For this reason, the risk involved in building a mill in this region is quite high. If the Moose Cree community is risk averse, this is not likely an investment that they would be willing to undertake. More research needs to be done to narrow down the costs associated with this kind of operation, as well as the value they could receive from their timber. These are two large unknowns in this model that have the most significant impact on the profitability of the mill.

The Watson Lake economic assessment (Pricewaterhouse Coopers, 2005) provides a list of challenges that communities face when trying to develop forest industries and many of these challenges are present in Moose Factory. These challenges include: limited skilled work force, high energy costs, remote location, the potential for environmental damage and the willingness of the community to support forestry activities. These challenges are especially evident in Moose Factory because there is a small population (2700 full time residents) and it is remote with no road access. These factors would increase transportation and road-building costs. Consultations with members of the Land and Forests Secretariat have also revealed that the Moose Cree First Nation is divided on their acceptance of forestry within their traditional territory. Many would not accept large harvest areas. However, the mill optimization model shows that it is relatively insensitive to the area constraint. Therefore, the area required to support a mill may be small enough to satisfy member's reservations. However, it is important to remember that this constraint is not spatial and if it was applied operationally to the area, the spatial component may not be as insensitive when factors such as traditional land use areas, proximity to roads and so-on are considered. In order to satisfy the area constraint, large areas of forest are planted. This may not be desirable to the Moose Cree because of the high costs. Conversely, tree planting may be an employment opportunity in Moose Factory. The other option for this community may be to simply employ their own logging companies to harvest the timber and then sell the logs to one of the forest companies in the area. This could increase economic activity in the community and could potentially satisfy those who are leery of large-scale forestry operations within the traditional territory. Much like the carbon management decision, there will be many tradeoffs that this community will have to consider in their decision to build a sawmill.

6.3 Limitations

Both sets of modelling systems have limitations associated with them. In terms of the carbon management model, the main limitation is the use of the rounding system. This type of system does not accurately measure the level of carbon present in the forest at any one time; it is almost always going to be either an overestimate or an underestimate of the true carbon levels. Unfortunately, due to the nature of the dynamics of the dead organic matter, creating a better system most certainly involves a much larger and much more complicated modelling scheme; one that Woodstock likely would not be able to process. This makes this kind of optimization modelling less accessible to forest managers.

Secondly, the area constraint is not spatial in either modelling system. Although less area is being harvested, there is no specific habitat type that is being conserved. Attempts were made to remove areas from harvest that surrounded water bodies, but the Central Unit contained far too many water bodies to make this feasible. Further effort should be made to not only include spatial information for the area constraint, but for the carbon modelling as well. There are most certainly areas of forest that will be more productive in terms of carbon productivity and forest productivity. Furthermore, through the land use planning process, the Moose Cree have spatial information regarding traditional uses in their territory. Unfortunately, this information was not available for this study, but future work should include this information. Spatial data will be essential for the Moose Cree to be able to identify the areas suitable for harvest, carbon management and conservation

Lastly, the parameters used in both models were difficult to obtain, since many forest companies do not wish to reveal their costs and revenues. The mill optimization model is very sensitive to such parameters. Therefore, it is very important for the Moose Cree First Nation to gather accurate information that represents their costs and potential revenues in order to make a decision regarding any type of forest or carbon management.

6.4 Extensions

Carbon management, timber management and the mill optimization model, provide the Moose Cree many options for the management of their traditional territory. The next step would be to incorporate carbon yields into a mill optimization framework to determine what size of mill, if any, should be built when carbon is part of the model. Furthermore, given the limitation of the area constraint, incorporating a spatial aspect into this model would also improve the quality of the models and give the Moose Cree a better idea of where harvesting would occur. This information could be incorporated with information on their traditional land use to improve overall management.

Lastly, it would be interesting to incorporate other parameters into the mill optimization model and the carbon management model to see how they affect the feasibility of constructing the sawmill and the net returns. Since much of the decline in the forest industry is blamed on lower commodity prices and the high Canadian dollar, including these parameters would provide more information for the Moose Cree. Furthermore, the transportation of the timber from the forest to the mill, as well as the shipment of lumber, are going to be a very large expense for the Moose Cree. For this reason, some logistical analysis in terms of where to locate a mill and where to build roads would be very beneficial. Combining these models with another where mill size is determined endogenously, such as Troncoso and Garrido's (2005) logistical planning model, could provide a more accurate picture of the feasibility of such a facility in that location.

6.5 Conclusion

This study shows that given the data from the Central Unit and a specific set of parameters; timber harvesting, carbon management and even the construction of a sawmill can result in positive returns for the Moose Cree First Nation. Carbon management alone could be more profitable for the Moose Cree over the 200-year planning horizon with high carbon prices. Even with lower prices, it is an additional revenue source that adds to overall returns. However, the models did not provide clear answers to the other questions that face the Moose Cree in terms of employment and environmental tradeoffs. Buongiorno and Gilless (2003) provide an interesting insight into what models actually represent:

> "Models are abstract representations of the real world that are useful for the purposes of thinking, forecasting and decision making" (pg. 2)

The important portion of this quote is the term "abstract". This model is not the real world, it is just a theoretical representation of the real world and should only be used as a tool within the decision-making process and not as the decision making process. This study represents a tool for the Moose Cree in their decision making process, but further research and refinement of the model is needed to make this model a little more representative of the conditions that are faced in Moose Factory.

Literature Cited

Anderson, R.B. 1997. Corporate/Indigenous Partnerships in Economic Development: The First Nations in Canada. *World Development.* 25(9): 1483-1503.

Apps, M.J., W.A. Kurz, S.J. Beukema and J.S. Bhatti. 1999. Carbon Budget of the Canadian Forest Product Sector. *Environmental Science and Policy.* 2: 25-41.

Barry, P.J, J.A. Hopkin and C.B. Baker. 1988. *Financial Management in Agriculture.* Danville, Illinois, USA: The Interstate Printers and Publishers: Danville

Benitez, P.C. and G.C. van Kooten. 2005. *Carbon Sinks and Reservoirs: The Value of Permanence and Role of Discounting.* Resource and Environmental Economics and Policy Analysis (REPA) Research Group. Working Paper 2005-11.

Berkes, F., R.J. Preston and P. George. 1993. *Aboriginal Land Use and Harvesting in the Moose River Basin: A Historical and Contemporary Analysis.* Quantitative Studies in Economics and Population (QSEP) Research Report 298. McMaster University, Hamilton Ont.

Bhatti, J.S., M.J. Apps and H. Jiang. 2002. Influence of Nutrients, Disturbances and Site Condition on Carbon Stocks Along the Boreal Forest Transect in Central Canada. *Plant and Soil.* 242: 1-14.

Brown, W.J. and R.A. Schoney. 1985. Calculating Least-Cost Machinery Size for Grain Farms Using Electronic Spreadsheets and Microcomputers. *Canadian Journal of Agricultural Economics.* 33(March 1985): 47-65.

Buongiorno, J. and J.K. Gilless. 2003. *Decision Methods for Forest Resource Management.* San Diego, USA: Academic Press - an Imprint of Elsevier Science

Canadian Council on Ecological Areas. 2007. Hudson Plains Terrestrial Ecozone - Climate and Landforms. Available Online: http://www.ccea.org/ecozones/terr-hp-landclim.html

Canadian Broadcasting Corporation. 2007. *Opposition MPs pass Kyoto bill despite Tory resistance.* February 14, 2007. Available Online: http://www.cbc.ca/canada/story/2007/02/14/kyoto-vote.html

Chicago Climate Exchange. 2007. *Climate Change and Emissions Trading. Available Online*: http://www.chicagoclimatex.com/content.jsf?id=221

Chladna, Z. 2006. Determination of optimal rotation period under stochastic wood and carbon prices. *Forest Policy and Economics.* 9(8):1031-1045

Chowns, T.J. 2003. *State of Knowledge of Woodland Caribou in Ontario.* Prepared for the Forestry Research Partnership. Available online: http://www.cif-ifc.org/pdfs/14caribou_report_FRP.pdf

Courtois, R. and A. Beaumont. 2002. A Preliminary Assessment of the Influence of Habitat Composition and Structure on Moose Density and Clear-Cuts of North-Western Quebec. *Alces.* 38:167-176

Courtois, R. and C. Dussault, F. Potvin and G. Daigle. 2002. Habitat Selection by Moose (*Alces Alces*) in Clear-Cut Landscapes. *Alces.* 38: 177-192.

Creedy, J. and A.D. Wurzbacher. 2001. The Economic Value of a Forested Catchment with Timber, Water and Carbon Sequestration Benefits. *Ecological Economics.* 38(2001): 71-83.

Davis, L.S., K.N. Johnson, P.S. Bettinger and T.E. Howard. 2001. *Forest Management to Sustain Ecological, Economic, and Social Values. Fourth Edition.* Boston, USA: McGraw Hill, Inc.

Dussault C., R. Courtois and J.-P. Ouelett. 2006. A Habitat Suitability Index Model to Assess Moose Habitat Selection at Multiple Spatial Scales. *Canadian Journal of Forest Research.* 36: 1097-1107.

Marsh, J. 2007. *Moose Factory, Ontario.* The Encyclopedia of Canada Online. Available Online: http://www.thecanadianencyclopedia.com/index.cfm?PgNm=TCE&Params=A1ARTA0005424

Environment Canada. 2007. *Species at Risk – Woodland Caribou, Boreal Population.* Available Online: http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=636

Forestry Research Partnership. 2006. *Modeling Ontario's Stand Succession and Yield. Version 1.0.* Canadian Ecology Centre. Available online: http://www.forestresearch.ca/partnership_projects/120-303.htm

Government of Canada. 2006. *Canada's Fourth National Report on Climate Change: Actions to Meet Commitments Under the United Nations Framework Convention on Climate Change.* Issued by Environment Canada, Ottawa Ont.

Haener, M. K. 1998. *Regional Forest Resource Accounting in Alberta.* Unpublished M.Sc. Thesis, Department of Rural Economy. University of Alberta, Edmonton, Alberta.

Hartman, R. 1976. The Harvesting Decision When a Standing Forest Has Value. *Economic Inquiry.* 14(1): 52-58.

Hoen, H.F. and B. Solberg. 1997. CO2-Taxing, Timber Rotations and Market Implications. *Critical Reviews in Environmental Science and Technology.* 27(special): S151-S162

Insley, M. and K. Rollins. 2005. On Solving the Multirotational Timber Harvesting Problem with Stochastic Prices: A Linear Complementarity Formulation. *American Journal of Agricultural Economics.* 87(3): 735-755.

IPCC. 2007. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Johnson, K. and H. Scheurman. 1977. Techniques for Prescribing Optimal Timber Harvests and Investment Under Different Objectives—Discussion and Synthesis". *Forest Science.* Monograph 18.

Krcmar, E. and G.C. van Kooten. 2005. Boreal Forest Carbon Sequestration Strategies: A Case Study of the Little Red River Cree First Nation Land Tenures. *Canadian Journal of Agricultural Economics.* 53(4): 325-341.

Kuhnke, D.H., W.A. White and R.A. Bohning. 2002. *The Alberta Logging Cost Survey: Data for 1996-1998.* Canadian Forest Service, Northern Forestry Centre Information Report Nor-X-375. Natural Resources Canada. Edmonton, Alberta.

Kull, S.J., W.A. Kurz, G.J. Rampley, G.E. Banfield, R.K. Schivatcheva and M.J. Apps. 2006. *Operational-Scale Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) Version 1.0: User's Guide***.** Natural Resources Canada – Canadian Forest Services.

Kurz, W.A. and M.J. Apps. 1999. A 70-Year Retrospective Analysis of Carbon Fluxes in the Canadian Forest Sector. *Ecological Applications.* 9(2): 526-547

Kurz, W.A., M. Apps, E. Banfield and G. Stinson. 2002. Forest Carbon Accounting at the Operational Scale. *Forestry Chronicle.* 78(5): 672-679

Liberal Party of Canada. 2007. *Conservatives Must Move Quickly to Implement Kyoto Bill.* News Release Issued on June 22 2007. Available Online: http://www.liberal.ca/story_12929_e.aspx

Marland, G., K. Fruit and R. Sedjo. 2001. Accounting for Sequestered Carbon: The Question of Permanence. *Environmental Science and Policy* 4(2001):259-268.

Marland, G., B. Schlamadinger and P. Libey. 1997. Forest/Biomass Based Mitigation Strategies: Does Timing of Carbon Reductions Matter. *Critical Reviews in Environmental Science and Technology.* 27(Special): S213-S226

McCarney, G.R. 2007. *Management Decisions in the Boreal Forest Considering Timber and Carbon Market Incentives.* Unpublished M.Sc. Thesis, Department of Rural Economy. University of Alberta, Edmonton, Alberta.

Moose Cree First Nation. 2006. *Community Profile.* Available Online: http://www.moosecree.com/community-profile/index.html

Murray, B.C. 2000. Carbon Values, Reforestation, and 'Perverse' Incentives under the Kyoto Protocol: an Empirical Analysis. *Mitigation and Adaptation Strategies for Global Change* 5: 271-295.

Natural Resources Canada. 2006. *Sawmills.* Available Online: http://atlas.nrcan.gc.ca/site/english/maps/environment/forest/useforest/sawmills/1#operator

Ontario Ministry of Natural Resources. 2006. *Managing Ontario's Forest-Silviculture in Ontario*. Available online: http://ontariosforests.mnr.gov.on.ca/spectrasites/internet/ontarioforests/silvicultureoverview.cfm

Ontario Ministry of Natural Resources. 1988. *Timber Guidelines for the Provision of Moose Habitat.* Wildlife Management Branch. Toronto, Ont: Queen Printer's for Ontario.

Ontario Office of the Premier. 2007. *McGuinty and Schwarzenegger Team Up to Curb Climate Change, Boost Stem Cell Research.* News Release issued May 30, 2007. Available Online: http://www.premier.gov.on.ca/news/Product.asp?ProductID=1281

Penner, M. 2004. *Development of Empirical Yield Curves For the PJ1, SP1, SB1, PO1, and SF1 Standard Forest Units.* Prepared for Forestry Research Partnership.

Plantinga A.J. and R.A. Birdsey. 1994. Optimal Forest Stand Management When Benefits are Derived from Carbon. *Natural Resource Modeling.* 8(4): 373-383.

Plantinga, A.J., T. Mauldin and D.J. Miller. 1999. An Econometric Analysis of the Costs of Sequestering Carbon in Forests. *American Journal of Agricultural Economics.* 81(4):812-824.

Point Carbon. 2007a. *Price information – methodology.* Available Online: http://www.pointcarbon.com/Home/Market%20prices/Methodology/category745.html

Point Carbon. 2007b. *Point Carbon EUA OTC closing price.* Available Online: http://www.pointcarbon.com/

PricewaterhouseCoopers LLP. August 2005. *Economic Assessment of Forest Industry in Southeast Yukon.* Prepared for the Watson Lake Chamber of Commerce and the Yukon Government.

Remsoft Inc. 1998. *Woodstock's User Guide. Version 1.0.* Remsoft Inc. Fredericton New Brunswick.

Robison, L.J. and P.J. Barry. 1996. *Present Value Models and Investment Analysis.* Northport Alabama, USA: The Academic Page

Sedjo, R.A. 2001. *Forest Carbon Sequestration: Some Issues for Forest Investments.* Resources for the Future. Discussion Paper 01-34. Washington, D.C.

Sohngen, B. and R. Mendelsohn. 2003. An Optimal Control Model of Forest Carbon Sequestration. *American Journal of Agricultural Economics.* 85(2):448-457.

Spelter, H. and M. Alderman. 2005. Profile 2005: Softwood Sawmills in the United States and Canada. United Sates Department of Agriculture: Forest Service Research Paper FPL-RP-630.

Statistics Canada. 2006. *Bank of Canada price corporate paper rate* (Table number 1760043). CANSIM database.

Statistics Canada. 2007. Industrial *Product Price Index for Ontario's Softwood Lumber* (Table Number 1575012). CANSIM database.

Stinson, A., M. Woods and M. Penner. **2004**. *An Approach to Mixedwood Yield Curve Development in Ontario.* Forest Research Partnership. Project Number 130-009, Catalogue Number RP-022.

Sun, B. and B. Sohngen. 2006. *Optimal Set-Asides for Carbon Sequestration and Co-Benefits of Forestry.* Paper presented in a Chinese Economic Association in North American Session at the 2006 ASSA Meetings, Boston MA, January.

The Economist. 2007. *Cleaning Up: A Special Report on Business and Climate Change.* June 2nd , 2007. Volume 383(8531):1-30.

Tronscoso, J.J. and R.A. Garrido. 2005. Forestry Production and logistics planning: An Analysis Using Mixed-Integer Programming. *Forest Policy and Economics.* 7(2005): 625-633.

van Kooten, G.C., C.S. Binkley and G. Delcourt. 1995. Effect of Carbon Taxes and Subsidies on Optimal Forest Rotation Age and Supply of Carbon Services. *American Journal of Agricultural Economics.* 77(1995): 365-374.

van Kooten, G.C., A.J. Eagle, J. Manley and T. Smolak. 2004. How Costly are Carbon Offsets? A Meta-Analysis of Carbon Forest Sinks. *Environmental Science.* 7(2001): 239-251.

Watson, R.T., I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo and D.J. Dokken (eds.). 2000. *The Intergovernmental Panel on Climate Change (IPCC) Special Report on Land Use, Land-Use Change and Forestry.* Cambridge, U.K.: Cambridge University Press.

Appendix

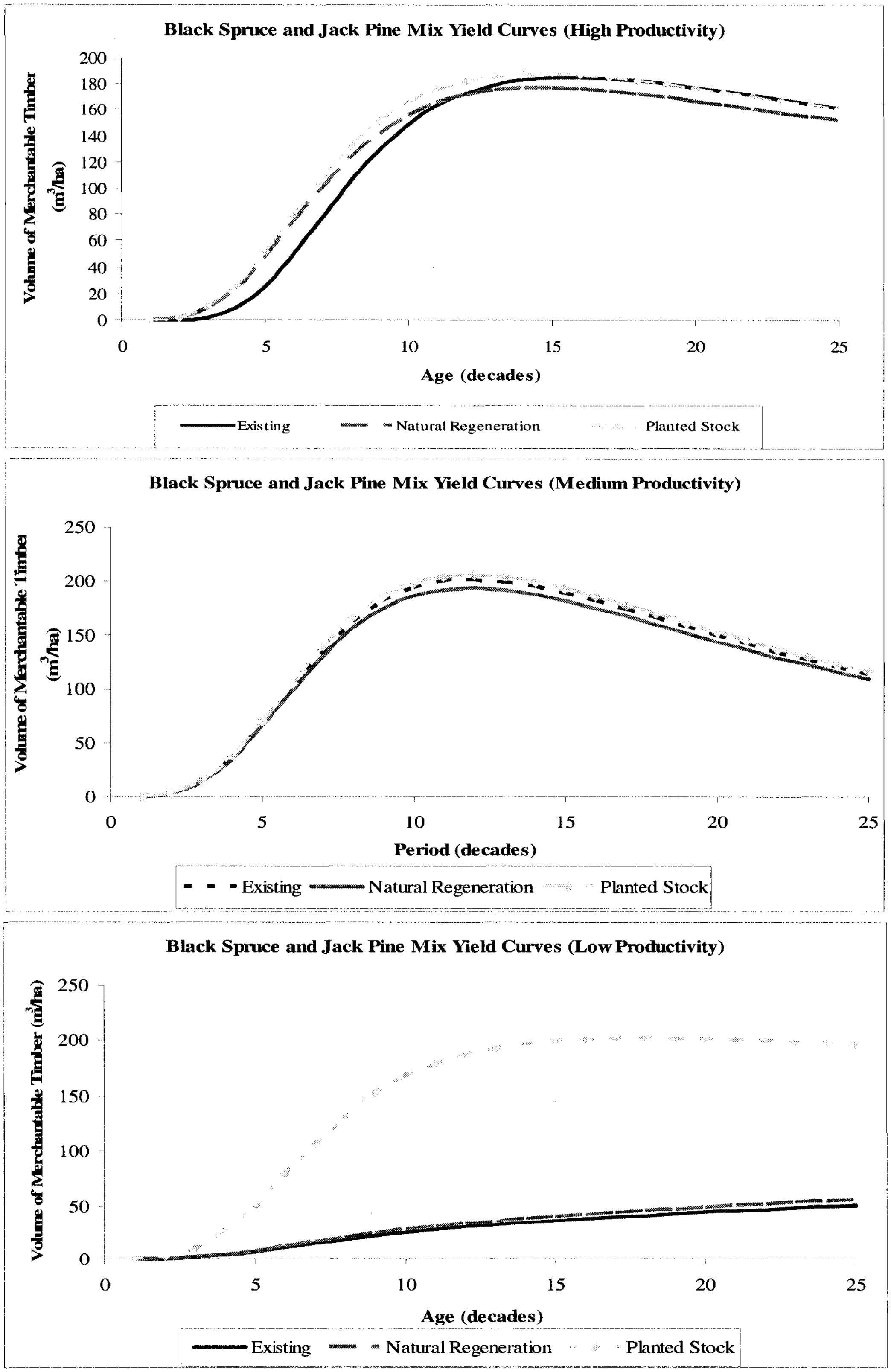


Figure A-1 Growth and Yield Trajectories assigned to Black Spruce and Jack Pine Mixes.

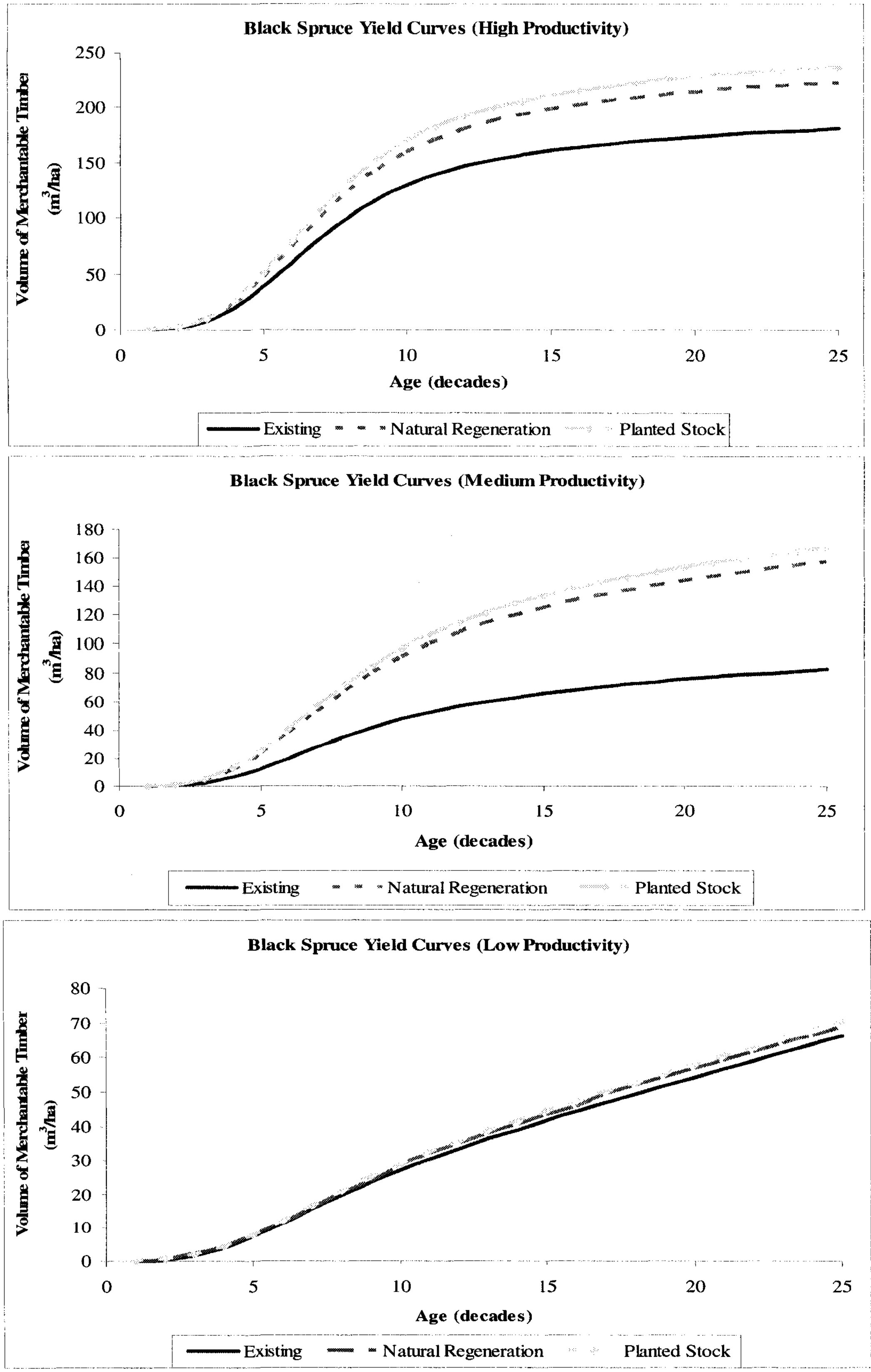
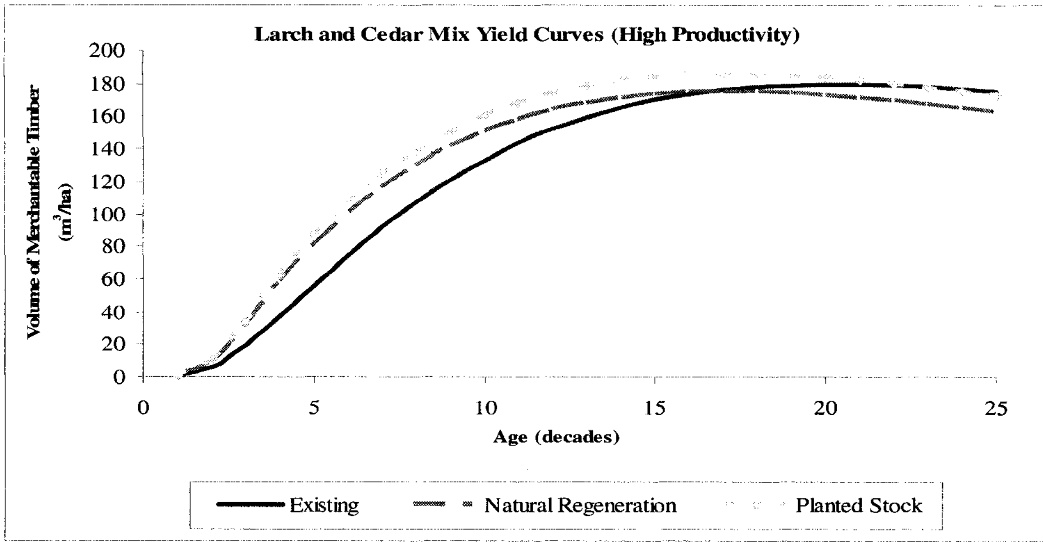
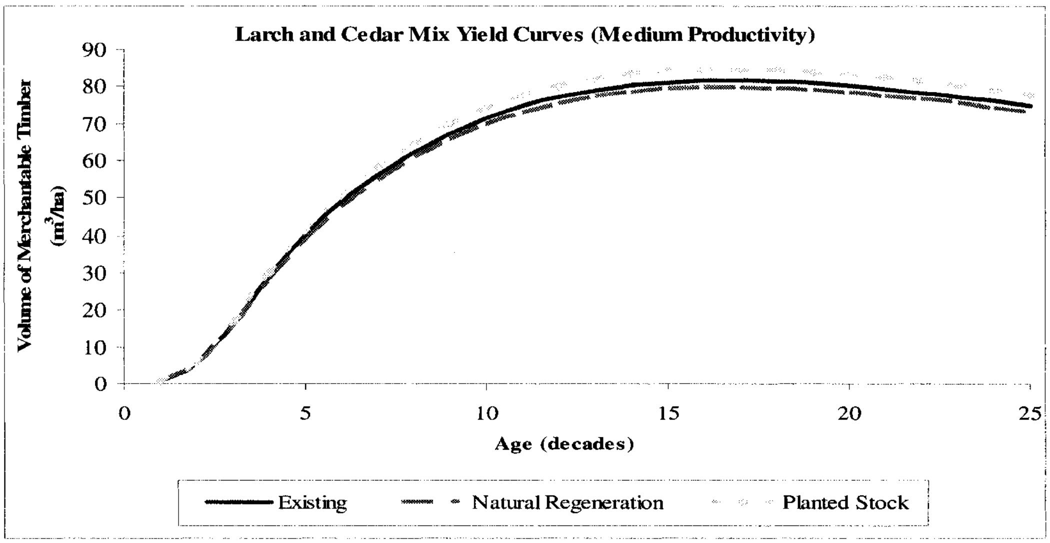


Figure A-2 Growth and Yield Trajectories assigned to Black Spruce.





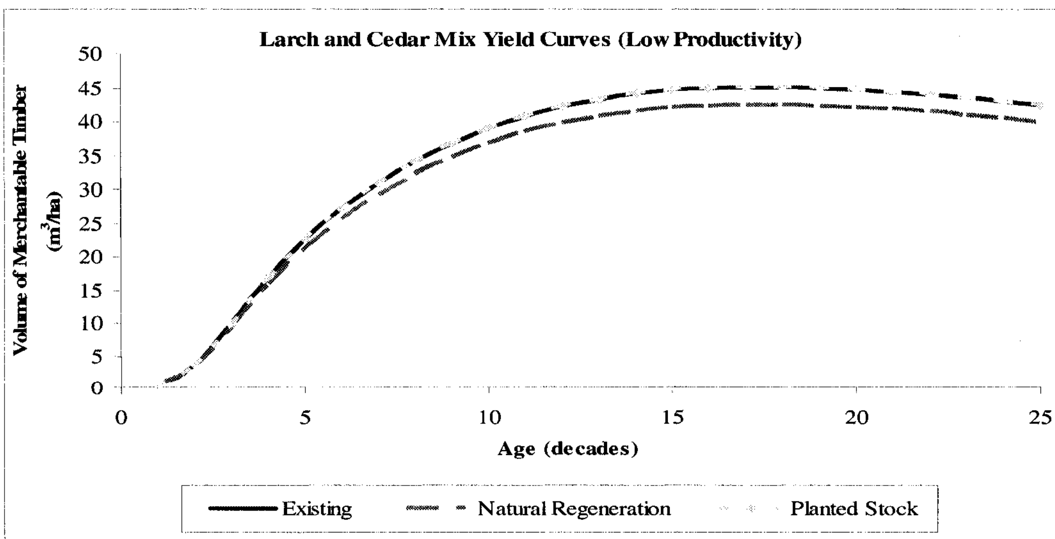


Figure A-3 Growth and Yield Trajectories assigned to Larch and Cedar Mixes.

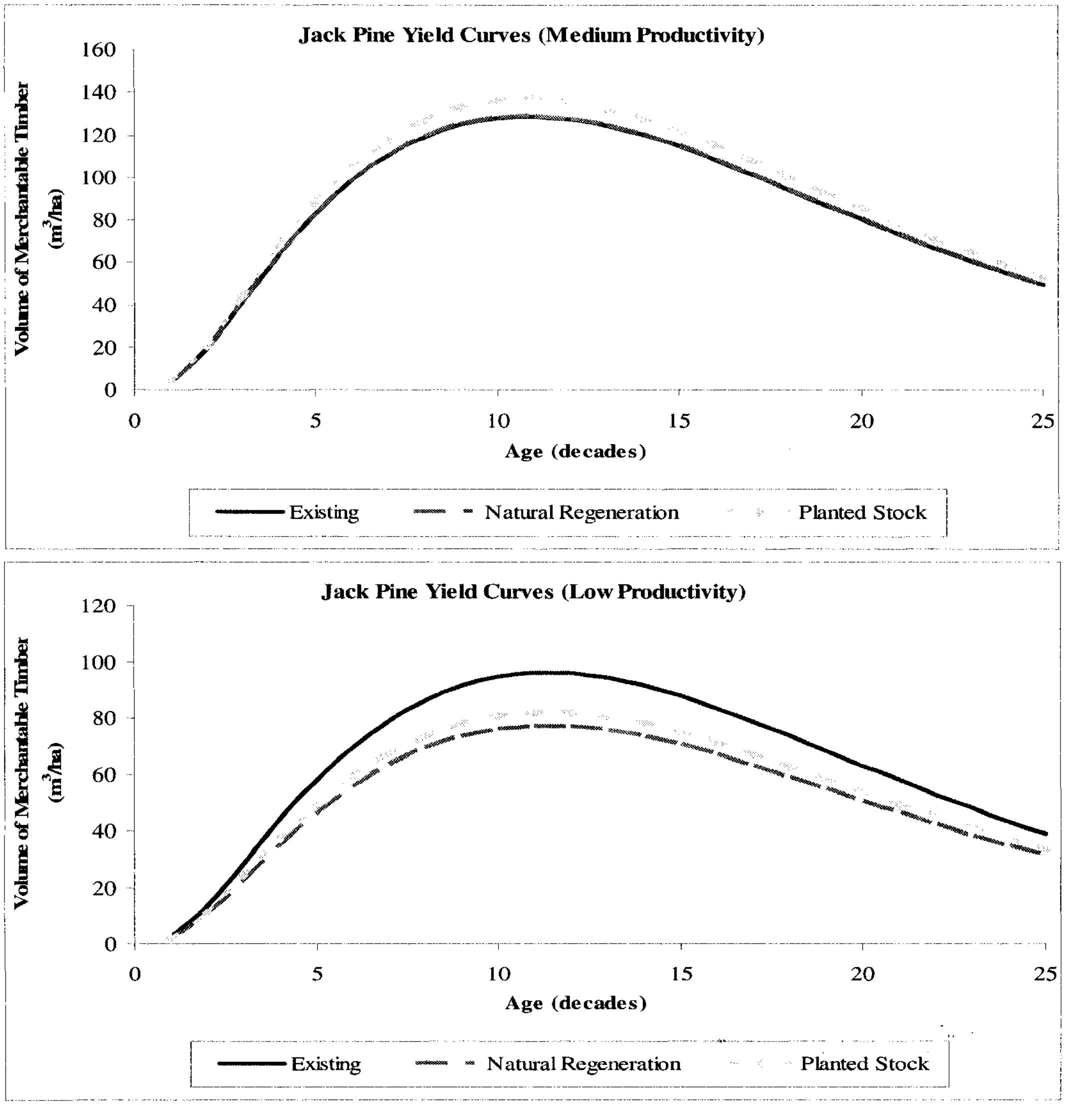


Figure A-4 Growth and Yield Trajectories assigned to Jack Pine.