ECONOMIC ANALYSIS OF VEGETATION MANAGEMENT ALTERNATIVES IN ONTARIO

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ABSTRACT

Homagain, K. 2011. Economic analysis of vegetation management alternatives in Ontario.

Key words: Aerial herbicides, BUCK-2 optimization software, brush saw, forest economics, forest vegetation management, FVS^{Ontario}, Glyphosate, Vision® , Release®, herbicides, internal rate of return, net present value, Silvana Selective®, Triclopyr.

Vegetation management practices have become an integral component of forest management. Economics of alternative vegetation management treatments were analyzed in this thesis on the basis of two journal papers. Six research sites established and managed by Vegetation Management Alternatives Program of Ontario were the sources of data. In the first paper, differences in stem quality, and volume and value of fibre produced by planted white spruce [*Picea glauca* (Moench) Voss] 16 years after vegetation management treatments in northwestern Ontario were examined. Forest Vegetation Simulator (FVS^{Ontario}) was used to project the total and merchantable volume to age 70 and BUCK-2 was used to optimize the resulting product mix. Projected value was based on 2009 prices for hog fuel and SPF (spruce-pine-fir) eastern green lumber prices. At 16 years post-treatment, gross total volumes in herbicide-treated and mechanically cut plots were significantly higher (120-165% and 94-98%, respectively) than that in control plots (14.73 m^3 ha^{-1}). Based on height, diameter, and taper criteria, observed tree quality did not differ among treatments. The projected value of the fibre produced was 36 to 53% higher in herbicide-treated plots and 24 to 37% higher in mechanically cut plots than in control plots ($18,486.76 ha^{-1}).

Second paper presents the stand-level benefit-cost analyses of 12 vegetation management treatments applied at six study sites in northern Ontario. Net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR) for crop and all species in each treatment and site were calculated and compared using 2009 constant dollars and variable real discount rates. Aerial herbicide treatments produced the highest NPV, BCR, and IRR. Internal rates of return of 4.32% for aerial herbicide, 2.90% for manual brush cutting, 2.82% for ground applied herbicide, and 2.50% for brush cutting plus herbicide treatments indicated that all of the vegetation management alternatives evaluated are economically viable.

LIST OF PAPERS

PAPER 1

Homagain, K., C. K. Shahi, M. Leitch, N. Luckai and F. W. Bell. 2011. Differences in extrinsic tree quality and value of fibre production following alternative vegetation management treatments in northwestern Ontario. Forestry Chronicle 87(2): ??-??. (*Accepted*)

PAPER 2

Homagain, K., C. K. Shahi, N. Luckai, M. Leitch and F. W. Bell. 2011. Benefit-cost analysis of vegetation management alternatives: An Ontario case study. Forestry Chronicle 87(2): ??-??. (*Accepted*)

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1. INTRODUCTION

1.1 THESIS RATIONALE AND OVERVIEW

The increasing global demand of forest and wood products has necessitated the need for intensive silvilculture and different forest vegetation management treatments[1]. Costs of forest vegetation management treatments occur early in the cycle of stand management, whereas the benefits in terms of increased stand yields are deferred until harvesting. Thus a significant effort is needed to find low-cost treatment combinations, and these costs must be evaluated with reference to the additional expected stand yield. Moreover, economic analysis is desired for rational decision making and for making long-term investments. Because quantified long-term benefits of silvicultural investments are often lacking, evaluations are made on the basis of degree of control achieved per dollar invested until better data are available. To properly evaluate the economic impact of forest vegetation management in young stands, the benefits of increased survival and growth have to be projected to the rotation

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[1] Forest vegetation management is defined as a part of silviculture directed at manipulating the rate and course of secondary forest succession to achieve a forest of a specific composition, structure, and rate of growth (Wagner 1993).

age. Stand growth and yield simulators, which initiate projections at an age when trees begin to reach merchantable size for the local market of interest, can be used for this purpose. In this way, benefit-cost analysis of different vegetation management alternative treatments using simulation and optimization models can be conducted. Such analysis will help forest practitioners and decision makers to choose options from the best alternatives. This thesis, with case studies from six sites of Ontario, provides an economic analysis of different vegetation management alternatives. In this chapter, a general background of the study, vegetation management alternative program, economic analysis and the thesis objectives are presented.

Chapter 2 and 3 are prepared as separate papers, which have been accepted for publication in *The Forestry Chronicle*, a peer reviewed journal of the Canadian Institute of Forestry. Chapter 2 deals with extrinsic tree qualities and fibre production values due to different vegetation management treatments from one of the six vegetation management alternatives program (VMAP) sites. Further it compares the present and projected future value of fibre production from different treatments. Chapter 3 provides the benefit-cost analysis of all alternative forest vegetation management treatments from the six research sites. It presents all cost information, projected yield up to the rotation age using Forest Vegetation Simulator, optimized product combination and future benefits of each treatment and site combination. On the basis of benefits and cost over time,

the net present values, benefit-cost ratios and the internal rates of return of different alternatives at 2009 prices are calculated. Chapter 4 synthesizes the findings of the two papers and presents conclusions, critiques and implications of this study based on economic analysis of forest vegetation management alternatives in Ontario.

1.2 BACKGROUND

The forest sector is a key component of Ontario's economy. With more than 26 million ha of productive and commercially managed forest, this sector generated about $14 billion revenue in 2008 by employing 200,000 people directly and indirectly from more than 260 communities (MNDMF 2010). Most of Ontario's managed forest falls in the boreal and Great Lakes-St. Lawrence region with approximately two-thirds of the total volume occupied by commercially important conifer species (OMNR 2007). Forest industries are heavily dependent on conifer fibre to satisfy domestic and international markets. To remain competitive in the present era of globalization, forest industries need to achieve maximum economic efficiency from forest resource management. The current economic downturn coupled with a high Canadian dollar value, high energy prices and decreased housing starts in the United States, means that forest industries are facing serious challenges and losing their competitive edge in global markets. In the mean time, Scandinavian and Southern hemisphere coun-

tries have shown significant improvements into entering forest product markets. These improvements are resulting from higher growth rates and intensive silviculture including increased investment in artificial regeneration, tree improvement, release treatments and other stand tending operations. Ontario, as one of the major exporters of forest products, recognizes the necessity to manage its forest resources to improve productivity through more intensive silvicultural practices. Forest management in Ontario is guided and regulated by the Crown Forest Sustainability Act - 1994 (CFSA) which states that "large, healthy, diverse and productive Crown forests and their associated ecological processes and biological diversity should be conserved." One of the legal requirements under CFSA is maintenance of forest composition at a threshold level so that sustainable forest management objectives can be attained within the forest management plan period. From a timber industry perspective, forest management is a planned ecological disturbance that makes growing space available for the myriad of desired plant species that are established on a disturbed site after fire or harvest. Plants that establish first in these disturbed areas initiate the process of secondary forest succession that will eventually lead to development of a new forest stand. Because some less desirable plants can prevent the successful regeneration of more desirable tree species, vegetation management is a vital part of the reforestation plans for harvested sites.

1.3 FOREST VEGETATION MANAGEMENT

Forest vegetation management (FVM) is that part of silviculture used to direct the rate and course of secondary forest succession to achieve a forest of the desired composition, growth and form (Wagner and McLaughlan 1996). Vegetation management recognizes the importance of suppressing the influence of undesirable species only when they significantly interfere with desirable species. It also emphasizes the inherent value in having the flexibility to choose from a variety of techniques to efficiently manipulate competing vegetation (Walstad and Kuch 1987). One of the common reasons for practising forest vegetation management is to improve crop tree survival and growth rates by channelling limited site resources into the crop rather than associated non-commercial species. So for the purpose of this thesis, the term 'vegetation management' is defined as selective manipulation of forest plant communities to ensure that desired crop tree species achieve a dominant position in a mature forest within a desired period of time. Competing vegetation in the Canadian forestry context is often controlled by FVM treatments known as 'vegetation release'. Vegetation release is defined here as cutting or chemical treatment of nearby competing vegetation to reduce its negative influence on the growth and survival of established conifer trees (Dampier 2006). 'Vegetation management treatments' are also referred to as 'release treatments' and these phrases are sometimes used interchangeably throughout this thesis.

1.4 VEGETATION MANAGEMENT ALTERNATIVE PROGRAM

Vegetation management research efforts in Ontario have been led by the Vegetation Management Alternatives Program (VMAP) since 1991. The program established a network of research sites in northern Ontario (Figure 1.1) covering most of the common forest and species types in the area of undertaking. These sites provide the specific sources of data for this thesis. The objectives of the program were (i) to develop approaches to managing forest vegetation that could reduce dependence on herbicides in Ontario's forests, (ii) to determine economically- and ecologically sound vegetation management practices that are socially acceptable and (iii) to advance forest regeneration knowledge and further all aspects of forest vegetation management (Wagner and McLaughlan 1996). Over the past several years, the program has made substantial progress in developing and refining a number of alternatives to aerial herbicide application, including: manual/mechanical cutting, cover cropping, mulching, animal grazing, prescribed burning, biological control and ground-applied herbicides (Wagner et al. 1995). Evaluating whether these alternatives are effective, economical, environmentally sound and socially acceptable has been an important part of this effort. All of the six sites have been re-measured periodically. Since the inception of VMAP, a series of technical recommendations have been made available to forest managers about how to apply many of these alternatives in the most effective manner.
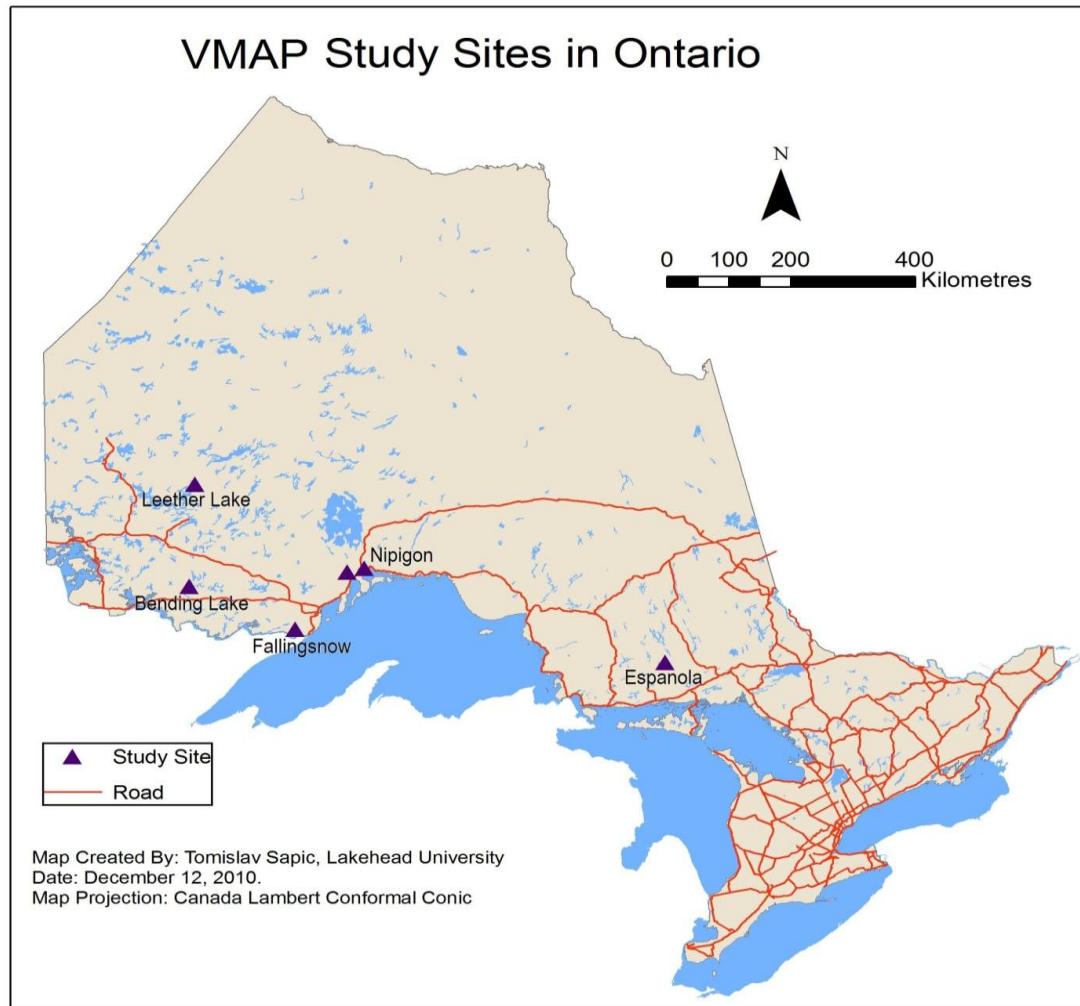
Figure 1.1 Vegetation management alternative program study sites in Ontario.

The latest effort on this endeavour is, according to Bell et al. (2011), a multi agency partnership project on 'Silvicultural effectiveness and consequences of using vegetation management alternatives in boreal and temperate coniferous forests' which was initiated in 2007 with funding from the Agricultural Research Institute of Ontario (ARIO). With the series of 10 peer reviewed journal papers, this partnership updated the Canadian Forest Pest Management database; synthesized relevant forest vegetation management literature related

to ecological, efficacy, environmental, and social issues; conducted stand-level analyses of wildlife habitat, crop species tree quality, yield, and benefit-cost; and determined the landscape-level effects of a systematic reduction in herbicide use on forest management objectives. As well, efforts were made to transfer the resulting information to forest managers. The papers presented in this thesis are also part of this publication series.

1.5 ECONOMIC ANALYSIS OF VEGETATION MANAGEMENT

Biological and silvicultural evaluations of vegetation management programs are based on quantitative and qualitative assessments of competition and growth of desired species in stands. However, economic evaluations of vegetation management programs focus on comparing expected benefits and costs of controlling competition versus letting the stand develop on its own (Brodie et al. 1987). There are very few studies that evaluate the benefits from forest vegetation management in the long-term, because of the complexities involved in forest vegetation management coupled with long rotation periods (Walstad and Kuch 1987, Wagner 1993). Brodie et al. (1987) described three approaches for economic analysis of forest vegetative management at the stand level. These include (i) Yield-table assumption method: It is the simplest approach and can be conducted for any species for which the yield tables exist. However, problems arise when the yield tables are based on data from unmanaged stands; (ii) Simu-

lated managed stand comparison method: It is a computer-based model where growth from managed and unmanaged stands are projected independently and compared. However, it can only be applied to situations where accurate data from managed stands exist; (iii) Optimization method: It is based on an optimization algorithm developed on the basis of projected or actual growth from different treatments. The model finds the optimal solution through iterative simulations on the targeted objective function of highest volume or value production. Objective functions can be user, market or industry specific. A good historical database or reliable projections are needed for the optimization.

There are a few studies on economic analysis of forest vegetation management using each of these three methods. Stavins et al. (1981) used the yield-table assumption method to conduct sensitivity analysis for changes in cost, interest rate, and yield assumptions in vegetation management of Douglas fir stands in the Pacific Northwest. They found that minor delays or productivity losses due to competition from unwanted vegetation during the regeneration phase resulted in substantial value losses and justified considerable expenditures for competition release treatments. Roberts (1982) and Walstad et al. (1986) used simulated managed stand comparison methods for economic analysis of treatments including herbicides and commercial thinning, and found that stand conditions in both treated and untreated stands varied from pure to mixed species stands. In comparisons of all stand conditions, treated stands attained a

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higher net present value (NPV) than untreated stands. Dagget (2003) also used a simulation approach to analyse the NPV, benefit-cost ratio (BCR) and internal rate of return (IRR) of herbicide treated and commercially thinned plantations and found that herbicide had no effect on total stand volume at rotation age and no effect on maximum NPV but that the mean IRR for the herbicide treatments with no thinning was 8.2% in a 100 year rotation. For thinning only the IRR was 6.3%. The mean IRR for plots receiving both herbicide and thinning treatments was 5.8%. Brodie et al. (1987) utilized an optimization model to forecast future stand development for loblolly pine plantations at different stand densities which resulted in a different hardwood basal area in the main canopy. They found that the optimal rotation in terms of NPV was increased and yields of target crop declined due to hardwood competition. However, no economic analysis studies have been conducted for vegetation management program in spruce-pine-fir forests of Northern Ontario. As an alternative to benefit-cost analysis, Dampier et al. (2007) used cost effectiveness analysis (CEA) to compare vegetation management treatment alternatives from a planted conifer component of these young stands. They found that the aerial application of herbicide is most cost-effective (dollars invested to spruce volume produced in 10 years) among treatments with no regard for potential product value.

One of the common reasons for practising forest vegetation management is to improve crop tree survival and growth rates by channelling limited site re-

sources into the crop species rather than associated non-commercial species (Walstad and Kuch, 1987). Most vegetation management research has focused on development of treatments to exclude unwanted vegetation from stands, often using herbicides and brush cuttings. These intensive practices are most commonly employed in plantation forests where the predominant goal is achieving a satisfactory level of profit within specific environmental and social constraints (Richardson et al. 2006). In other words, vegetation management decisions are being driven by the need to maximize growth at minimum treatment costs. From a commercial perspective, it is always necessary to balance the benefits and costs of alternative treatment regimes (sequences of treatments). Forest vegetation management decisions are amongst the most important decisions that a manager will make during a stand rotation, as these can have a marked effect on future crop survival and productivity (Mason and Dzierzon 2006, Wagner et al. 2006). Yet, with so many different variables (crop and weed species, site types and stand histories) and treatment options (different herbicides methods, mechanical options, biological control, and timing of application of these techniques), decision-making becomes a complex process. For this reason there has been considerable effort over the last 20 years to improve decision support systems in forest vegetation management (Richardson et al. 2006). Traditional benefit-cost analysis (Nautiyal et al. 2001), sometimes referred to as discounted cash flow analysis (McKenney 2000), is a very simple and commonly utilized method. The benefit-cost analysis uses three common measures: net

present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR). NPV is the difference between the discounted present value of future benefits and the discounted present value of future costs. BCR is the ratio of discounted present value of benefits to the discounted present value of costs. A positive NPV or a BCR greater than one indicates that the project is economically profitable. And, IRR is the interest rate when NPV is equal to zero or the BCR is one. In this thesis, I analyzed the NPV, BCR and IRR of vegetation management alternative treatments using simulation and optimization methods.

1.6 THESIS OBJECTIVES

The general purpose of this research is to evaluate the economic efficiency of different alternatives (release treatments), which have been practised under the vegetation management alternative program in Ontario. The analysis would provide a management tool to evaluate the quality and value of trees subjected to different release treatments, thereby building a competitive, knowledge-based forest industry that is sustainable under growing global competition. The specific objectives are: (i) to study and evaluate the growth and yield of crop species, (ii) to estimate the differences in tree quality and value of fibre production, and (iii) to conduct a benefit-cost analysis of alternative release treatments at different research sites under the vegetation management alternative program in Ontario.

2. PAPER I

DIFFERENCES IN EXTRINSIC TREE QUALITY AND VALUE OF FIBRE PRODUCTION FOLLOWING ALTERNATIVE VEGETATION MANAGEMENT TREATMENTS IN NORTHWESTERN ONTARIO

2.1 ABSTRACT

We examined differences in stem quality, and volume and value of fibre produced by planted white spruce 16 years after vegetation management treatments in northwestern Ontario. Forest Vegetation Simulator (FVS[Ontario]) was used to project the total and merchantable volume to age 70 and BUCK-2 was used to optimize the resulting product mix. Projected value was based on 2009 prices for hog fuel and SPF (spruce-pine-fir) eastern green lumber prices. At 16 years post-treatment, gross total volumes in herbicide-treated and mechanically cut plots were significantly higher (120-165% and 94-98%, respectively) than that in control plots (14.73 m^3 ha^{-1}). Based on height, diameter, and taper criteria, observed tree quality did not differ among treatments. The projected value of the fibre produced was 36 to 53% higher in herbicide-treated plots and 24 to 37% higher in mechanically cut plots than in control plots ($18,486.76 ha^{-1}).

Key words: Brush saw, Fallingsnow Ecosystem Project, forest economics, forest vegetation management, glyphosate, Herbicides, Silvana Selective, Triclopyr

2.2 INTRODUCTION

Achieving economic efficiency from forest resources is key for forest companies to remain competitive in the present era of globalization. Canada has been losing its competitive edge in global markets, whereas other countries, especially in Scandinavia and the southern hemisphere have shown significant growth in the forest products markets (NRCan 2002). This growth is in part attributable to major gains in forest productivity resulting from more intensive silviculture, including major investments in regeneration, release treatments, and other stand tending operations (NRCan 2003). Thus, to maintain Canada's international economic competitiveness and to meet global demand for Canadian wood products, the forest industry has sought to improve forest productivity through more intensive silvicultural practices (NRCan 2009a).

Ontario is one of the most forest-rich provinces in Canada, having 32.7 million ha of productive forest area (OMNR 2006a). Most of these forests are in the boreal region, where the goal is to optimize growth rates within the primary objective of sustainable forest management (Hearnden et al. 1992). Maintaining overall forest composition is a legal requirement under Ontario's Crown Forest Sustainability Act 1994, which stipulates that "large, healthy, diverse and productive Crown forests and their associated ecological processes and biological diversity should be conserved" (Statutes of Ontario 1995). Ontario Ministry of Natural Resource's directive "Aerial Spraying for Forest Management" states

that much of Ontario's forest industry requires coniferous species and that aerial application of herbicides is the most cost effective way to regenerate conifers (OMNR 2006b). Accordingly, Ontario's forest industry relies heavily on the use of herbicides for forest regeneration, with approximately half of the harvested areas treated (NRCan 2009b) once in a 60- to 70-year cycle.

Over the past few decades, a substantial amount of research has been focused on quantifying the gains in wood yield following the management of competing vegetation (Wagner et al. 2006). The results of about 60 long-term studies in North America, South Africa, South America (Brazil), New Zealand, and Australia have reported 30 to 500% increases in wood volume following effective vegetation treatments (Wagner et al. 2006). To ensure that forest management practices on Crown lands are socially acceptable and consistent with the principles of sustainable management, the Vegetation Management Alternatives Program (VMAP) was initiated in Ontario in 1991 to develop and/or refine the use of several alternatives to aerial herbicide application, including motor-manual/mechanical cutting, prescribed burning, biological control, and ground-applied herbicides (Wagner et al. 1995). One of the studies initiated under that program was the Fallingsnow Ecosystem Project established near Thunder Bay in northwestern Ontario, where vegetation management treatments were tested for white spruce (*Picea glauca* [Moench] Voss). Tenth-year post-treatment stocking, cost-effectiveness, and stand-level volumes have been

reported by Pitt and Bell (2005), Dampier et al. (2006), and Bell et al. (2011a), respectively. Bell et al. (2011a) assessed stand-level volume responses for 31 combinations of site, species, and treatments from six VMAP studies, including the Fallingsnow Ecosystem Project and reported that 10th-year preferred conifer and gross total volumes ranged from -49 to +556% and -71 to +116%, respectively. However, long-term effects of different vegetation release treatments on crop tree quality and value have not been quantified. These growth and yield characteristics, in combination with tree geometry and wood characteristics or defects (Steele et al. 1994, Guddanti and Chang 1998), affect the quality and value of fibre production and potential future wood products.

Tree diameter at breast height (dbh) and total height are the two most important variables used to determine the yield and quality of lumber, since they affect volume and grade (Houllier et al. 1995, Zhang and Chauret 2001). Several studies have shown that value recovery is directly related to tree diameter (Zhang et al. 2002, Lei et al. 2005, Liu and Zhang 2005). In addition, tree taper influences the value of lumber, as noted for black spruce (*Picea mariana* [Mill.] B.S.P.) by Chuangmin et al. (2007). Aubry et al. (1998) reported that stem volume was the best single predictor of total value of an individual tree. Cotterill and Jackson (1985) also found significant effects of stem height and diameter on the product value of trees.

The assessment of tree quality has become a crucial issue in the operational value chain as resource managers and the wood processing industry are under increasing pressure to maximize extracted value. Stem quality is an important consideration in quantifying potential lumber recovery and valuing harvested stems and can be classified using measures and observations of standing trees (Stayton et al. 1971). Agestam et al. (1998) identified ten quality classes for standing trees based on height, stem form, presence of knots, and branch thickness and applied the classification system to assess timber quality in Scots pine. Similarly, Schmidt and Kandler (2009) used six quality classes to grade mature Norway spruce (*Picea abies* [L.] Karst.) trees on the basis of bark characteristics, branch characteristics, stem form, and stem damage. To apply these classification systems to younger trees, some method of projecting future growth and yield is required.

Several simulation models have been developed to project tree growth and quality. Hansen et al. (1995) used the ZELIG model to simulate the ecological and economic effects of alternative silviculture regimes for Douglas-fir (*Pseudotsuga menziessii* [Mirb.] Franco var. *menziessii*). Soalleiro et al. (2000) used the PINASTER model to evaluate silvicultural alternatives. The Tree and Stand Simulator (TASS) model has been used for over two decades to generate yield tables for managed stands in British Columbia (Harper and Polsson 2007, Harper et al. 2008). Another model, SYLVER is also used in British Columbia to

evaluate the effects of silvicultural treatments on yield, lumber value, and economic return (DiLucca 1999). Kabzems et al. (2007) used a mixed growth model (MGM) to compare the yield of white spruce in pure vs. mixed stands. In Ontario, Forest Vegetation Simulator (FVS[Ontario]) has been used to project the growth of forest stands. The model simulates growth and mortality of individual trees within a stand over a specified time period. It can be used to model stands composed of one or several species of any age. Future value of the fibre produced, however, depends on the desired forest product mix. Software such as BUCK-2, a product mix optimization tool (Zakrzewski et al. 2010), can be used to optimize the products based on growth and yield projections.

This is one of a series of papers related to forest vegetation management published in the March/April 2011 issue of the Forestry Chronicle (see Bell et al. 2011b). In this paper, we present results of a study to assess crop tree stem quality and estimate the value of fibre produced following vegetation management treatments in the Fallingsnow Ecosystem Project in northwestern Ontario. The specific objectives were to: (i) compare post-treatment growth and yield characteristics (height, diameter, and gross total volume) of white spruce crop trees, and (ii) estimate stem quality and value of fibre produced 16 years post-treatment, and to use that information to (iii) project expected volume up to age 70 (standard rotation age for white spruce in Ontario) for all treatments, and (iv) generate possible product mixes to compare the projected value of total fibre produced among treatments.

2.3 METHODS

2.3.1 Study location and design

The Fallingsnow Ecosystem Project (89º 49-53' W and 48º 8-13' N at 380 to 550 m above sea level) was established approximately 60 km southwest of Thunder Bay, Ontario (Bell et al. 1997) in the transition between the boreal and the Great Lakes-St. Lawrence forests (Rowe 1972). Before harvesting, the site supported three different stand types of 75- to 101-year-old natural forest. The study area was clearcut between 1986 and 1988. Each stand formed one block[2] of 20 or more hectares in a randomized complete block design.

2.3.2 Vegetation management treatments

The original stands were harvested and planted between 1986 and 1989 with 82-cm tall bareroot white spruce stock (2+2), at 2- to 2.5-m spacing. White spruce was the preferred crop tree and all analyses reported here are for this species. Within each block, each vegetation management release treatment was applied to a minimum 4 ha plot. Treatments, applied in 1993, were: (i) brush saw (BRU) – motor-manual cutting with brush saws (18 cm above ground line in mid- to late-October), (ii) Silvana (SIL) – mechanical cutting using a Ford trac-tor mounted with a parallelogram boom attached to a Silvana Selective cutting

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[2] Four blocks were included in the original study design (as per Bell et al. 1997) but operational issues resulted in Block 1 being discarded.

head (33 cm above ground line in late October to early November), (iii) Vision (VIS) – glyphosate herbicide (trade name Vision®) applied at 1.5-kg acid equivalent (a.e.) ha⁻¹ delivered aerially via a Bell 206 helicopter in August, (iv) Release (REL) – triclopyr herbicide (trade name Release®) applied at 1.9 kg a.e. ha⁻¹ delivered aerially via a Bell 206 helicopter in August, and (v) control (CON) – untreated control (for additional details about study establishment see Bell et al. 1997).

2.3.3 Data collection and analyses

2.3.3.1 Tree measurements

Two crop tree plots (approximately 30 m X 40 m) were established in each block/treatment combination before the vegetation management treatments were applied (Bell et al. 1997). In each plot, 20 crop trees were permanently marked for periodic remeasurement. The plots were remeasured in 2000 (7 years post-treatment), 2003 (10 years post-treatment), and 2009 (16 years post-treatment). In the summer of 2009, diameter at breast height (dbh), total tree height, average crown width, and height of the lowest living branch were measured. Crop tree mortality estimates were based on the number of living trees in each treatment plot. Previous crop tree measurement data were obtained from MNR's Ontario Forest Research Institute (2000 data -- Bell, unpubl.

data; 2003 data -- Bell et al. 2011a). Gross total volume (GTV) was computed us-

ing Honer's equation (Honer et al. 1983):

$$V_T = \frac{0.0043891 \times D^2 (1 - 0.04365 \times B_2)^2}{(C_1 + 0.3048 \times C_2 / h)}$$

[1]

where: V_T = gross total volume (m³)

D = diameter at breast height (cm)

h = total tree height (m)

B_2, C_1 and C_2 are constants

Volume was not computed from 2000 (i.e., 7th year post-harvest) data

because the trees were too small for the models used in FVS[Ontario]. Stem taper

was calculated using the ratio of dbh to total height (cm:m) for 2009 data.

2.3.3.2 Growth projection model

We used FVS[Ontario] – a non-spatial, individual-tree growth model – to

project expected crop tree volumes. The model simulates (projects) changes in

diameter increment of individual trees using current size and calibrated values

of previous growth. An increment model accumulates periodic increments over

successive time intervals (e.g., 5 or 10 years) (for details about FVS[Ontario], see

ESSA 2008). For all treatments, we used the same forest region, site quality (Site

quality II, Ontario West), crop species, and plantation year. We simulated total

volume assuming equal spacing between existing trees and no intermediate sil-

vicultural operations. The existing inventory condition was defined using the 2003 and 2009 tree measurements (height, diameter, and number of trees per ha) for all three blocks combined. To compare the value of fibre produced among treatments, merchantable volume was projected to 70 years. Value was linked to product recovery and stem quality attributes.

2.3.3.3 Product-mix optimization model

Future value of projected fibre production, which was based on volume estimates obtained using FVS[Ontario], depends on the desired forest product mix. We used BUCK-2 software (Zakrzewski et al. 2010) to optimize the future forest product mix. Roundwood timber products and desired size limits (length, minimum diameter) and rankings of log categories (sawlogs, veneer logs, etc.) were defined as follows: 2.44 m (8 feet) minimum length and 30 cm minimum diameter for the first category of saw log (Rank I); 2.44 m (8 feet) minimum length and 20 cm minimum diameter for the second category of saw log (Rank II); 1.22 m (4 feet) minimum length and 10 cm minimum diameter for pulp logs (Rank III) and a kerf factor of 1.5 cm (assuming wastage allowance for circular saw). We did not specify or rank products for utility pole or veneer logs.

2.3.3.4 Stem quality and value

Based on the 2009 assessment, all measured stems were assigned to four quality classes: Q1 to Q4, from highest to lowest (Table 2.1). Since height, diameter, and taper are the major attributes of tree quality, these simple parameters are often used to assess grades (Agestam et al. 1998). In addition to these attributes, we included crown width and height to the lowest living branch to define tree quality grades. An equal weight was assigned to each criterion (measured attribute) to calculate the stem quality classes. We assumed that internal defect levels were consistent among treatments.

Table 2.1 Criteria for tree quality classes applied in this study, modified from Agestam et al. (1998).

Quality class	Measured attribute				
	DBH (cm)	Height (m)	Crown width (m)	Crown height (m)	Taper (cm/m)
1	>9.0	>6.0	>3.0	>1.5	>1.5
2	6.0 to 9.0	4.0 to 6.0	2.0 to 3.0	1.0 to 1.5	1.0 to 1.5
3	3.0 to 6.0	2.0 to 4.0	1.0 to 2.0	0.5 to 1.0	0.5 to 1.0
4	<3.0	<2.0	<1.0	<0.5	<0.5

As of 2009, the fibre produced in the white spruce plantations was considered juvenile and not appropriate for structural use. Thus, its merchantable value was limited to hog fuel. In Thunder Bay, Ontario, hog fuel value estimates are based on hog fuel prices for mixed conifer species. We estimated a price of CDN \$20 m^{-3} of hog fuel wood, based on local market value (Buchanan Pulp

Sales Thunder Bay, 2009, pers. comm.). After 50 years the trees would be large enough to produce additional products. Wood price statistics for 2009 (December average) (Random Lengths 2009) were used to estimate the value of lumber that could be recovered from the 70-year projected volumes from stems in different treatments. Lumber price was calculated by averaging prices given for SPF eastern green lumber for 2x4s, precision end trim (PET), stud grade, #1 and 2, and random. Stem taper and diameter affect the value of lumber recovered from conifer logs. Generally 50 to 80% of the wood volume can be recovered (turned into a product) depending on species and age of the crop (Zhang 2003). Accordingly, we used lumber recovery ranges of 50 to 80% in 10% increments linked to the four quality grades. We assumed that the current stem quality grades will remain valid to rotation age and that the effects of other damaging agents, such as fire and insects, would be similar among treatments and quality grades. The value of pulp wood was estimated using the current market price ($31.25 green ton^{-1}) for white spruce in the Thunder Bay area (Buchanan Pulp Sales Thunder Bay, 2009, pers. comm.). Volume that could not be assigned to lumber or pulp was considered hog fuel and valued at $20.00 m^{-3}.

3.3.3.5 Statistical analysis

To elucidate the differences in white spruce height, diameter, and gross total volume among treatments, we applied analysis of variance (ANOVA) with a post hoc Duncan's test at 5% significance level using SPSS (SPSS Inc. 2008).

ANOVA with planned orthogonal contrasts (SPSS Inc. 2008, Field 2009) was used to compare overall stem quality among treatments and the projected future value of fibre produced (based on 2009 prices). The orthogonal contrast comparisons were: within mechanical cutting treatments (BRU vs. SIL), within herbicide treatments (REL vs. VIS), between herbicides and cutting treatments (BRU + SIL vs. REL + VIS), and between control and all release treatments combined (CON vs. (BRU + SIL + REL + VIS)/4).

The linear model for the ANOVA was:

$$Y_{ij} = \mu + B_i + T_j + \varepsilon_{ij} \qquad\qquad\qquad [2]$$

where: Y_{ij} is the calculated response from i^{th} block and the jth treatment

μ is the overall mean

B_i is the random effect of the ith block (i = 1, 2, 3)

T_j is the fixed effect of the jth treatment (j = 1, 2, 3, 4, 5)

ε_{ij} is the (pooled) interaction effect of the ith block and the jth release treatment with error term to test the treatment effect

Statistical significance of differences among treatments was tested by pooling the interaction term (B*T$_{ij}$) with the error term in the model.

2.4 RESULTS

2.4.1 Crop tree growth and yield: Observed

2.4.1.1 Diameter

Figure 2.1a shows the average diameter of crop trees from all treatments. In all cases, REL and VIS plots contained stems with the highest average diameters. Sixteenth-year (2009) post-treatment diameter of trees in the control plots differed significantly (p <0.001) from that of trees in the mechanical cutting (BRU and SIL) and herbicide treatment (REL and VIS) plots. However, differences between trees within the mechanically cut (BRU and SIL) and those within the herbicide (REL and VIS) treated plots were not significant (p = 0.113). A similar trend was observed for the 10th-year post-treatment (2003) data, but was less apparent in the 7th-year post-treatment (2000) data.

2.4.1.2 Height

Average crop tree height 16 years post-treatment (2009) was 4.97 m for trees in the control plots compared to 5.83 m in VIS, 6.04 m in SIL, 6.31 m in BRU, and 6.55 m in REL (Figure 2.1b). Average height of trees in the control and VIS plots in 2009 differed significantly (p <0.001) from those in BRU, SIL, and REL plots. In 2000 and 2003, REL differed significantly from VIS and control. Effect of treatments on total height of the crop trees is more evident in 2009 than in 2000 and 2003.

a) Diameter at breast height
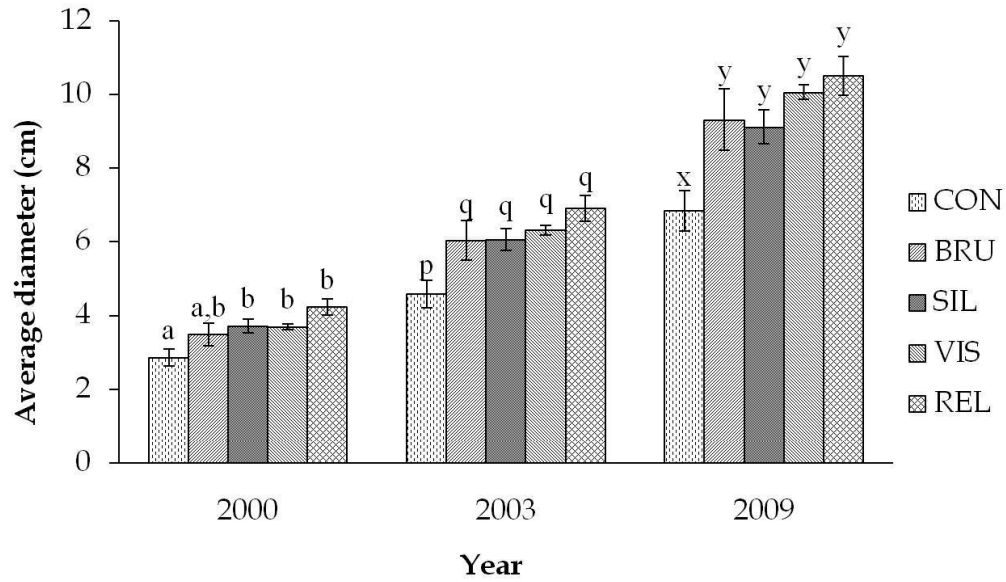
b) Total height
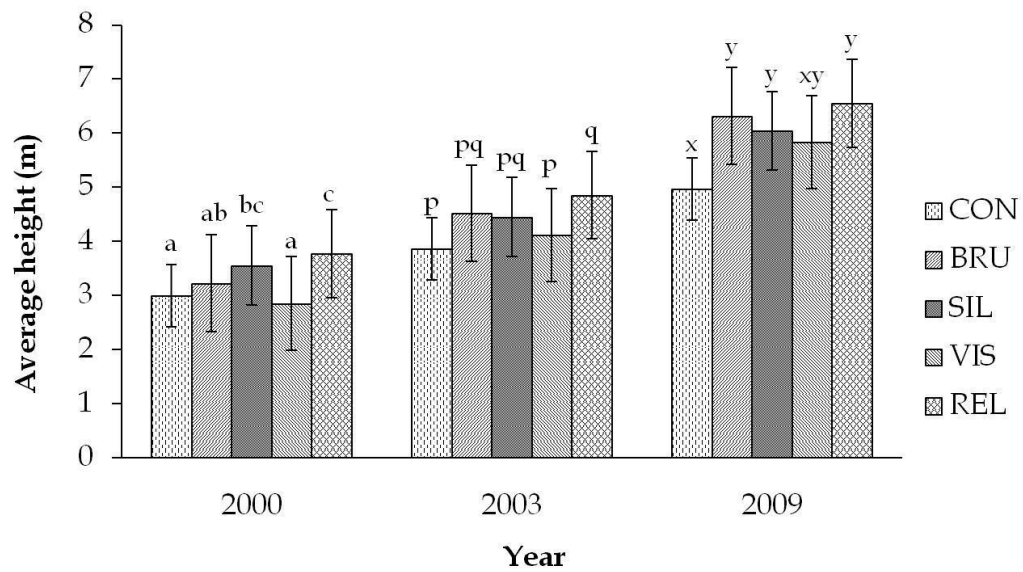
Figure 2.1 Average size of white spruce crop trees at 7 (2000), 10 (2003), and 16 (2009) years after vegetation management treatments (CON – control, BRU – brush saw, SIL – Silvana Selective, VIS – Vision herbicide, REL – Release herbicide) in northwestern Ontario: (a) diameter at breast height, and (b) total height. Letters above each bar show the statistical significance (p ≤ 0.05); a, b and c for 2000; p and q for 2003; x and y for 2009; and bars are the standard errors of the mean.

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2.4.1.3 Gross total volume

Volume in 2009 was highest for trees in the REL treatment plots (39.01 m3 ha⁻¹) followed by those in the VIS (32.42 m3 ha⁻¹), SIL (29.16 m3 ha⁻¹), BRU (28.56 m3 ha-1), and control (14.73 m3 ha⁻¹) plots (Figure 2.2).
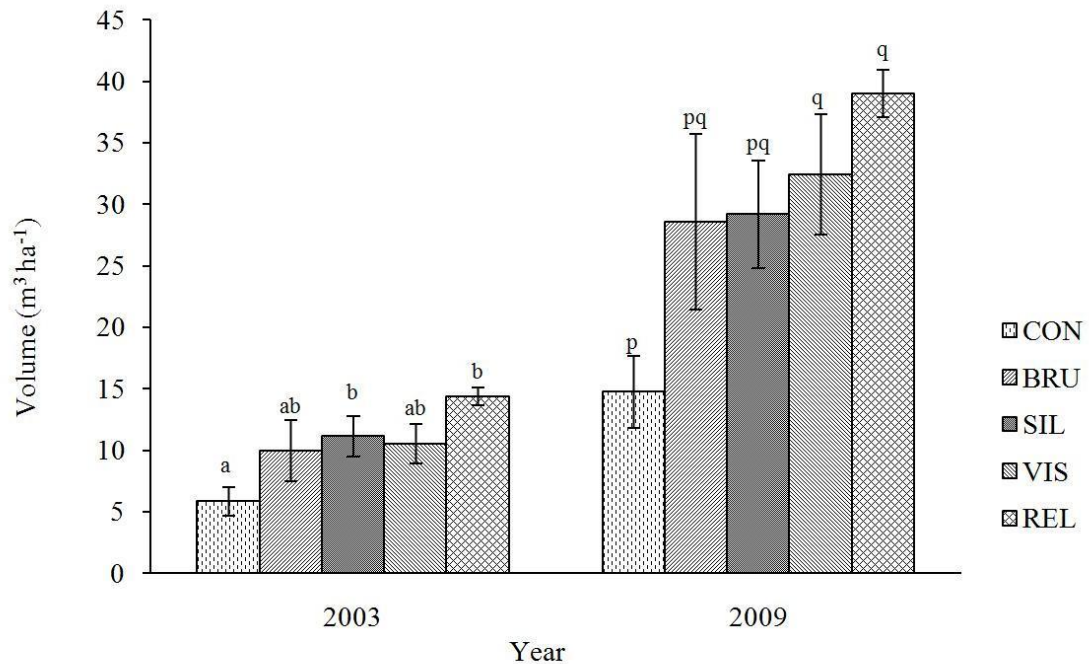
Figure 2.2 Average gross total volume of white spruce crop trees at 10 (2003) and 16 (2009) years after vegetation management treatments (CON – Control, BRU – brush saw, SIL – Silvana Selective, VIS – Vision herbicide, REL – Release herbicide) in northwestern Ontario. Letters above each bar show the significance (p ≤ 0.05); a and b for 2003; p and q for 2009; and bars are the standard errors of the mean.

Similarly in the 2003 measurement, the REL treatment produced the highest average volume (14.39 m3 ha⁻¹), followed by SIL (11.23 m3 ha⁻¹), VIS (10.53 m3 ha⁻¹), BRU (9.98 m3 ha⁻¹), and control (5.86 m3 ha⁻¹) plots. In 2003, the orthogonal contrast test established that the average volumes of trees in the REL and SIL treatments differed significantly (*p* <0.001) from those of trees in the

VIS, BRU, and control plots but did not differ between trees in the herbicide (REL + VIS) and mechanically cut (BRU + SIL) plots. By 2009, the gross total volume of trees in the herbicide-treated plots was significantly higher (p <0.001) than those in the mechanically cut and control plots. White spruce mortality was highest in control plots, and differed significantly (p <0.001) from mortality levels in all other treatment plots (Figure 2.3). Mortality of trees in REL and BRU plots was significantly lower than that in VIS and SIL (p = 0.012) plots but did not differ significantly between the two mechanical cutting and the two herbicide treatments. On average, trees in herbicide-treated plots produced 140% more volume and those in the mechanically cut plots produced about 95% more volume than those in the control plots (Table 2.2).
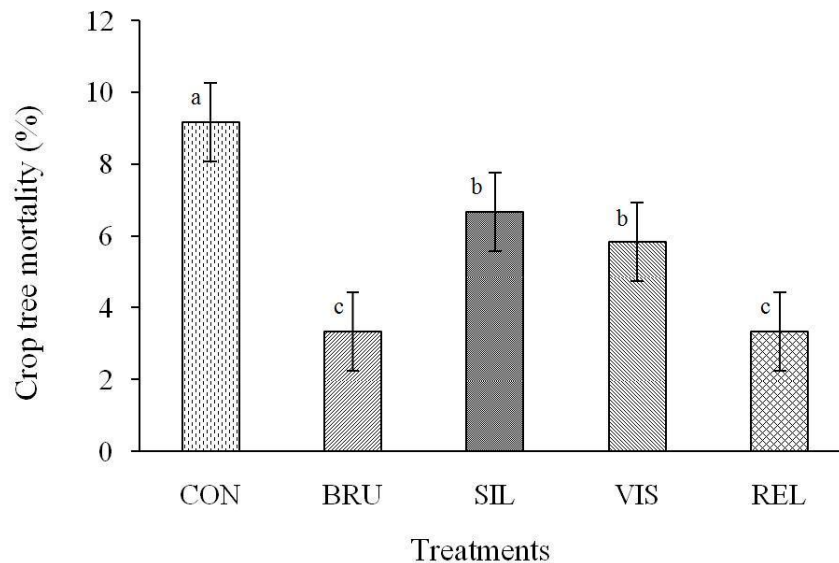
Figure 2.3 White spruce mortality occurring between 7 (2000) and 16 (2009) years after vegetation management treatments (CON – Control, BRU – brush saw, SIL – Silvana Selective, VIS – Vision herbicide, REL – Release herbicide) in northwestern Ontario. Letters above each bar show the significance ($p \leq 0.05$); a is significantly different from b and c, b is different from c; and bars are the standard errors of the mean.

Table 2.2 Volume and value of fibre produced by white spruce following vegetation management treatments (CON – control, BRU – brush saw, SIL – Silvana Selective, VIS – Vision herbicide, REL – Release herbicide) in 2009 (age 20 - measured) and in 2059 (age 70 - projected) compared to that of untreated controls.

Treatment	Gross total volume in 2009 ($m^3\ ha^{-1}$)	Difference in volume (from control in %)	Value of fibre produced in 2009 ($\$\ ha^{-1}$)	Projected				Projected value of fibre in 2059 ($\$\ ha^{-1}$)	Difference in value (from control in %)
				Merch. volume in 2059 ($m^3\ ha^{-1}$)	Lumber (mbf ha^{-1})	Pulpwood (metric ton ha^{-1})	Hogfuel (metric ton ha^{-1})		
CON	14.73	0	294.66[a]	162.95[a]	74.34	29.17	2.65	18,486.76[a]	0
BRU	28.56	94	571.28[b]	198.70[b]	90.82	43.14	3.99	22,838.99[b]	24
SIL	29.16	98	583.26[b]	204.03[b,c]	104.58	21.96	3.03	25,392.04[c]	37
VIS	32.43	120	648.60[b]	207.90[b,c]	104.58	24.94	2.89	25,176.52[c]	36
REL	39.01	165	780.28[c]	229.98[c]	116.24	25.31	1.63	28,209.35[d]	53

Within columns, different letters indicate significant differences among treatments ($p \leq 0.005$)

2.4.2 Total and merchantable volumes: Projected

Observed and projected gross total white spruce volumes at 10-year intervals are presented in Table 2.3. For all projection periods, trees in the REL treatment produced more volume than those in the other treatments, with those in the control plots producing the least volume. Figure 2.4a shows gross total volumes calculated using Honer's equation [Eq. 1] for each treatment for 2009 along with the projected volumes. Merchantable volumes were projected to 70 years using FVS[Ontario], with the same simulation assumptions as GTV, for trees in all treatments using a minimum top diameter of 10 cm and stump height of 30 cm (Figure 2.4b). Trees in the REL treatment had the highest and those in the control plot the lowest merchantable volumes over the projection period.

Table 2.3 Observed (Honer's Equation) and projected (FVS) gross total volume of white spruce trees following vegetation management treatments (CON – control, BRU – brush saw, SIL – Silvana Selective, VIS – Vision herbicide, REL – Release herbicide).

Treatment	Observed volume		Projected volume					
	$(m^3\ ha^{-1})$		$(m^3\ ha^{-1})$					
	1988-89	2009	2009	2019	2029	2039	2049	2059
CON	0	14.73	19.10	53.27	109.69	145.23	181.31	203.69[a]
BRU	0	28.56	32.00	68.22	133.75	177.09	217.32	248.37[b]
SIL	0	29.16	34.88	74.33	137.34	182.10	224.30	255.04[b]
VIS	0	32.43	36.56	79.34	137.94	185.37	227.04	259.87[b]
REL	0	39.01	40.38	83.26	150.8	205.34	256.53	287.47[c]

Within column, different letters indicate significant differences among treatments ($p \leq 0.005$)

a) Gross total volume

b) Net merchantable volume
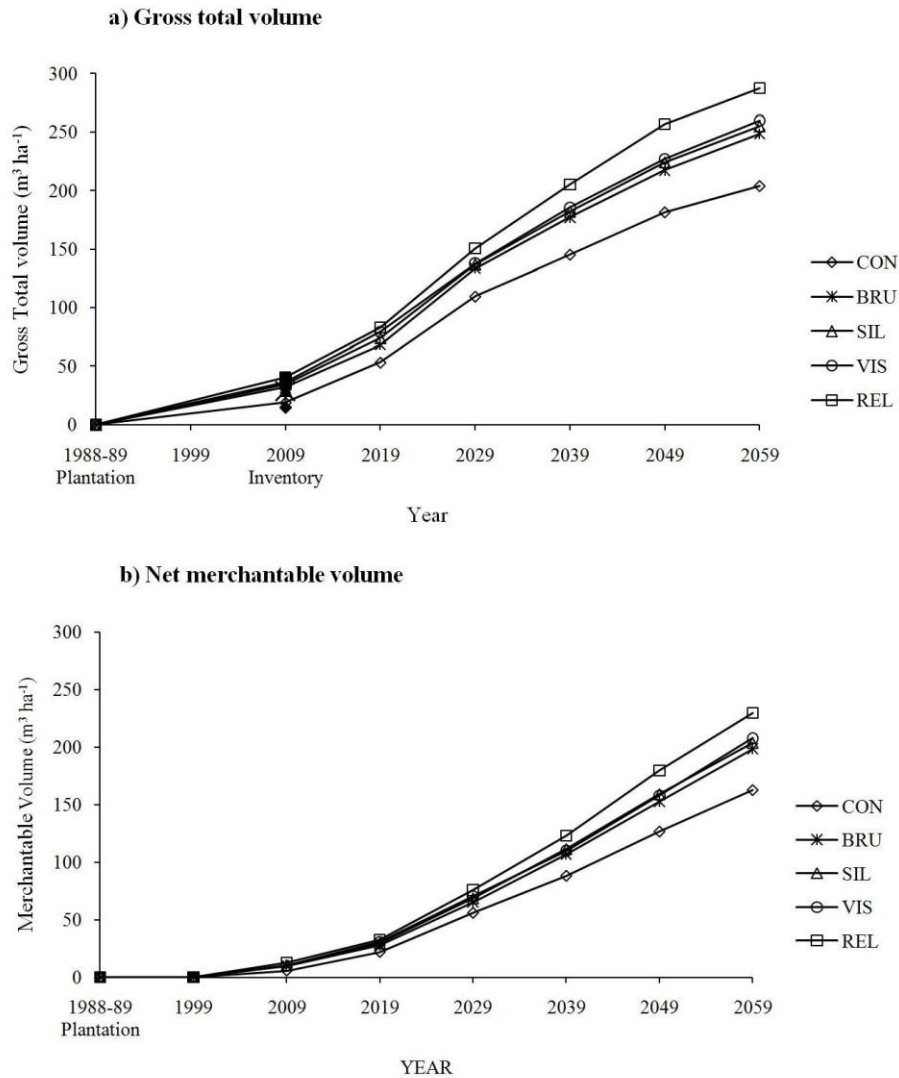
Figure 2.4 Projected volumes (1988 to 2059) for planted white spruce in northwestern Ontario following vegetation management treatments (CON – control, BRU – brush saw, SIL – Silvana Selective, VIS – Vision herbicide, REL – Release herbicide): (a) gross total volume and (b) net merchantable volume. In (a), the mean 2009 measured gross total volumes are indicated using filled symbols.

2.4.3 Stem quality and fibre value: Projected

Crop tree stem quality 16 years (2009) after vegetation management treatments is presented by quality class in Figure 2.5. The percentage of trees in

the Q1 class was significantly higher in treated (p = 0.009) plots than in the control plots, however, differences among treatments were not significant (p = 0.274). About 25% of stems were classified as Q1 and 60% were considered Q2. There was no difference in the number of trees in the Q2 class based on treatment. Only 7% of stems were in the Q3 class and only control plots produced stems classified as Q4 (only 1% of all stems).
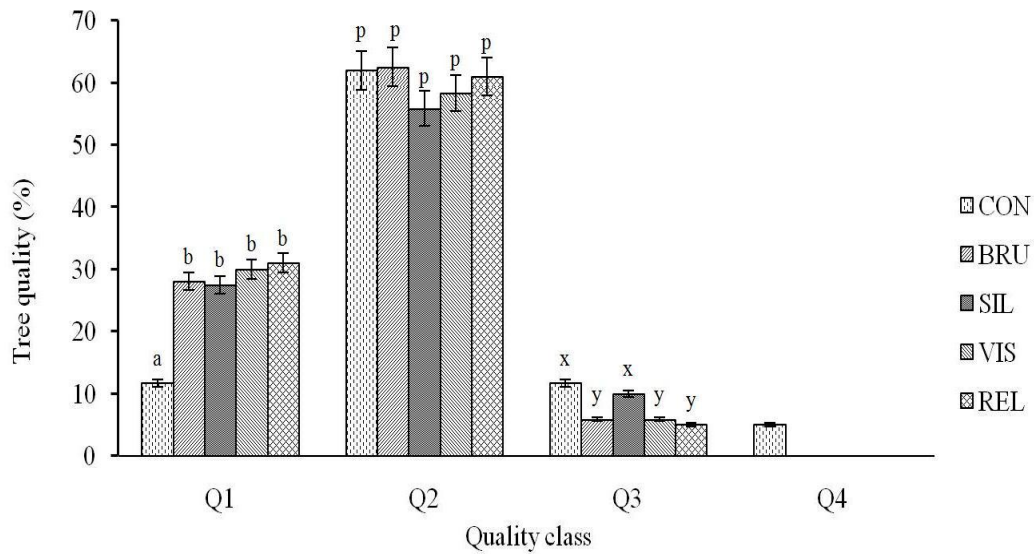
Figure 2.5 White spruce tree quality in northwestern Ontario after 16 years (2009) following vegetation management treatments (CON – control, BRU – brush saw, SIL – Silvana Selective, VIS – Vision herbicide, REL – Release herbicide). Quality grades (Q1 – high quality to Q4 – low quality) were categorized on the basis of visual tree characteristics (height, diameter, taper, crown width, and height to the lowest live branch). Letters above each bar show the significance (p ≤ 0.05); a and b for Q1; p for Q2 and x and y for Q3; and bars are the standard errors of the mean.

Average value of fibre produced ($ ha^{-1}) from the treatments is presented in Table 2.3. As of 2009, trees from REL plots produced the highest value (CDN$ 780.28 ha^{-1}) – albeit for juvenile fibre valued as hog fuel. This value differed sig-

nificantly (p <0.001) from that produced by trees in the VIS, SIL, and BRU treated plots, which in turn produced significantly (p = 0.002) more value than trees in the control plots.

Orthogonal contrasts for analysis of variance of future value of fibre produced per ha after 70 years for each treatment group are presented in Table 2.4. Overall, treatments differed significantly (p <0.001) from one another. Trees in the BRU treatment differed significantly from those in SIL (p = 0.001) and those in the REL treatment differed significantly from those in VIS (p = 0.007). The value of fibre produced by trees in the cutting treatments differed significantly from those in the herbicide treatments (p <0.001) and all treatments differed significantly from controls (p = 0.048). Trees in the herbicide-treated and mechanically cut plots produced significantly more (36-53% and 24-37%, respectively) value based on potential wood products at 70 years than those in control plots (Table 2.2).

Table 2.4 Analysis of variance results with orthogonal contrasts for future (year 70) value of fibre produced ($ ha-1) by white spruce following vegetation management treatments (CON – control, BRU – brush saw, SIL – Silvana Selective, VIS – Vision herbicide, REL – Release herbicide).

Source	df	Type III SS	Mean Square	F-ratio	F-crit (0.05)	*p*-value
Constant	1	8.66E+09	8.66E+09			
Block	2	9.09E+06	4.55E+06			
Treatment	4	1.58E+08	3.96E+07	43.23	3.84	<0.001
BRU vs. SIL	1	2.84E+07	2.84E+07	31.04	5.32	0.001
REL vs. VIS	1	1.19E+07	1.19E+07	13.01	5.32	0.007
Cutting[a] vs. Herbicides[b]	1	1.13E+08	1.13E+08	123.45	5.32	<0.001
CON vs. Treatments[c]	1	5.01E+06	5.01E+06	5.47	5.32	0.048
Error (Block*Treatment)	8	7.32E+06	9.15E+05			
Total	14	1.75E+08				

a=BRU and SIL, b=REL and VIS; and c=BRU, SIL, REL, VIS

2.5 DISCUSSION

We discuss our results in terms of: (i) stem mortality, diameter, height, and volume, (ii) stand level gross total and merchantable volumes, (iii) stem quality, and (iv) stand level value of fibre produced. Our results are directly related to how well the treatments suppressed competitive vegetation when the white spruce trees were establishing.

Stem mortality, diameter, height, and volume were all affected by the vegetation management treatments. Stem mortality was significantly lower, and diameter and height of trees in plots treated with vegetation management alter-

natives were much higher than those of trees in controls, resulting in more gross total volume 16 years after treatment. Our observations that reducing competitive vegetation improves survival, diameter, and height concur with other published results. Sutton (1995) also reported increased survival following control of competitive vegetation. Results from many other studies confirm that white spruce produces more volume following vegetation management treatments (Wagner et al. 2006, Boateng et al. 2006, Boateng et al. 2009).

Although projected gross total volumes calculated using FVS[Ontario] compare with volumes calculated using Honer's equations (Table 2.2) and with volumes presented in Bell et al. (2011a) they are typically lower than those reported for the few other intensive forest management studies focused on white spruce in Ontario. McClain et al. (1994) reported GTV of 208 m^3 ha^{-1} for a 37-year-old plantation near Thunder Bay, Ontario, and Stiell and Berry (1973) reported a GTV of 244 m^3 ha^{-1} in 50 years for trees planted at 2.7 m spacing near Petawawa, Ontario. Similarly, Morgenstern et al. (2006) reported maximum volumes of 287 m^3 ha^{-1} and 216.7 m^3 ha^{-1} for white spruce of Thunder Bay and Kakabeka seed origin in 44-year-old provenance trials established at the Petawawa Research Station. Richer site quality could be one of the reasons for higher GTVs in those studies. It is also plausible that stem densities in the Fallingsnow Ecosystem Project are lower than those in other studies. In this study, white spruce densities were approximately 917 to 1,722 stems ha^{-1} in the control and continuous

removal plots respectively. Whereas other studies found stem densities of 1162 trees ha^{-1} (McClain et al. 1994), 1372 trees ha^{-1} (Stiell and Berry 1973), and 2400 trees ha^{-1} (Morgenstern et al. 2006). The 20-year maximum height in our study was 9 m, which is lower than those reported for the other studies mentioned. The lower projected values in our study could also be the result of our assumption of average site quality (we may have been overly conservative in our estimate of intermediate site quality) and because we included only white spruce in the FVS^{Ontario} simulations although other trees (and thus available volume) were present on site.

Based on external features of individual stems (Table 2.1), our results suggest that vegetation control improved stem quality. Approximately 80% of trees in all treatments were classified as having good stem quality (i.e., Q1 and Q2) 16 years after treatment. However, the proportion of stems in the Q1 class was significantly lower for the control plots. More tests to compare intrinsic tree characteristics, including wood defects and mechanical properties, may help to determine differences among treatments (Wang et al. 2001). The trees are still too immature (20 years from establishment) for destructive sampling for internal wood characteristics, but mechanized non-destructive testing in standing trees could be carried out for basic wood density, ring width, and wood strength.

The average value of fibre produced by trees in herbicide-treated (VIS and REL) and mechanically cut (BRU and SIL) plots were significantly higher ($p \leq 0.05$) than that of trees in control plots. Our value analysis is based on the FVS[Ontario] projections for merchantable volume of crop trees at 70 years, tree quality assessed for measured crop trees, and lumber recovery factors for the various quality grades based on December 2009 average wood prices (Random Lengths 2009). McClain et al. (1994) reported that the net value of 37-year-old pure white spruce established at 2.7 m spacing was CDN $6,891 ha[-1] (at 1994 market price, which is equivalent to about CDN$ 11,544 ha^{-1} at 2009 values compounded at 3.5%). This is the only other boreal Ontario study we could find for which white spruce values were reported. This value is proportionally greater than our estimated average value of CDN$ 10,155 ha^{-1} ($ 9,964 including the controls) per ha at 2009 prices. The difference may be because the McClain et al. (1994) study was an intensive spacing trial on a site of relatively better quality.

2.6 CONCLUSION

In our 16th-year post-treatment assessment of a vegetation management study in northwestern Ontario, we found that, although overall average tree quality classes did not differ significantly among treatments, vegetation management treatments produced higher numbers of larger and thus better quality

– from a potential wood products perspective – white spruce crop trees. Height and diameter growth, gross total volume, and projected value of fibre produced were higher for trees in herbicide-treated and mechanically cut plots than for those in untreated controls. In general, trees in herbicide-treated (VIS and REL) plots produced more volume with higher future value than those in mechanically cut (BRU and SIL) plots. These results suggest that vegetation management treatments result in more volume 16 years post-treatment and have the potential produce much higher future wood values at age 70.

Prior to extrapolating this conclusion beyond this study, we suggest that since we considered only fibre value the cost of the various treatments and all other costs associated with the production of fibre and wood volume need to be compared more thoroughly. Future research could focus on cost-benefit analysis of fibre production at the stand level, comparing results among vegetation management studies as well as with those from other operational tending studies in boreal Ontario, to determine whether the additional volume produced is economically viable.

2.7 ACKNOWLEDGEMENTS

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3. PAPER II

BENEFIT-COST ANALYSIS OF VEGETATION MANAGEMENT ALTERNATIVES: AN ONTARIO CASE STUDY

3.1 ABSTRACT

Vegetation management practices are an integral component of forest management. In this paper, we report results of stand-level benefit-cost analyses of 12 vegetation management treatments applied at 6 study sites in northern Ontario. Forest Vegetation Simulator (FVS^{Ontario}) was used to project gross total and merchantable volumes to 70 years of age, and BUCK-2 was used to optimize potential products. Net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR) were calculated using 2009 constant dollars and variable real discount rates. Aerial herbicide treatments produced the highest NPV, BCR, and IRR. Internal rates of return of 4.32, 2.90, 2.82 and 2.50% for aerial herbicide, manual brush cutting, ground applied herbicide, and brush cutting plus herbicide treatments, respectively, indicated that all of the vegetation management alternatives evaluated are economically viable.

Key words: Aerial herbicides, brush saw, forest economics, Forest Vegetation Simulator (FVS^{Ontario}), ground herbicides, internal rate of return, net present value.

3.2 INTRODUCTION

Ontario's forest sector is a key component of the province's economy (MNDMF 2010). Most of Ontario's productive forest is in the conifer-dominated boreal region where optimization of growth rates of spruce (*Picea* spp.) and pine (*Pinus* spp.) species is a key forest management objective but these species are often outcompeted by hardwoods such as poplar (*Populus* spp.) (Hearnden et al. 1992). Maintaining overall forest composition is a legal requirement under Ontario's Crown Forest Sustainability Act, which states that "large, healthy, diverse and productive Crown forests and their associated ecological processes and biological diversity should be conserved" (Statutes of Ontario 1995). As a result, forest vegetation management practices are an integral component of forest management.

Forest vegetation management practices help to ensure initial plantation[3] survival, accelerate growth of targeted species, and achieve high yields in terms of per unit gross total volume production (Wagner et al. 2006). Forest vegetation management practices include several alternatives (Wiensczyk et al. 2011) and results from experimental studies on growth rates and volume production are highly variable among these alternative treatments (Comeau et al. 1999, Simard

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[3] Plantation is a forest crop established artificially, either by sowing or by planting (NRCan 1995)

et al. 2001, Heineman et al. 2005, Bell et al. 2011a). The costs associated with the various treatments also vary greatly (Bell et al. 1997, Dampier et al. 2006).

In a system where both yields and costs vary, an economic analysis of the efficiency of a silvicultural intervention can only be evaluated based on long-term stand-level growth response data and cost information (McKenney et al. 1997). In a review of the Canadian forest vegetation management research and practice, Thompson and Pitt (2003) report 1,256 scientific publications directly related to forest vegetation management as of 2002, but only 18 (1.4%) of those include components of economic analysis of forest vegetation management treatments, and even fewer are focused on the economics associated with releasing boreal conifers. Therefore, there is a need for stand-level benefit-cost analyses (BCA) that will help decision makers choose the best alternatives for forest vegetation management. BCA is a method of appraising and evaluating an investment decision that includes identification, valuation, and comparison of all costs and benefits during the life of a project (Campbell and Brown 2003). BCA provides the most comprehensive framework for evaluating any economic investment, as it estimates values associated with inputs and outputs for each activity (Nautiyal et al. 2001). Net present value (NPV), benefit-cost ratio (BCR) and internal rate of return (IRR) are the most commonly used measures for conducting benefit-cost analysis. NPV expresses the difference between the discounted present value of future benefits and the discounted present value of fu-

ture costs, whereas BCR is the ratio of discounted present value of benefits to the discounted present value of costs. A positive NPV or a BCR greater than one indicates that the activity being evaluated is economically beneficial. We used both NPV and BCR because for investment decisions related to forestry activities, NPV gives the best comparison when silviculture budgets are not limited and BCR gives the best comparison when silviculture budgets are limited (Willcocks et al. 1997). However, both NPV and BCR depend on the discount rate used for the analysis. Therefore, the benefit-cost analysis is supplemented by finding the IRR, which is the discount rate when NPV is zero. An IRR greater than the existing market interest rates in general indicates a relatively profitable investment (Campbell and Brown 2003). Such analyses provide a management tool to evaluate and compare amongst different release treatments, thereby building a competitive, knowledge-based forest industry that is sustainable under increasing global competition.

In this paper, which is one of a series of papers related to forest vegetation management published in the March/April 2011 issue of *The Forestry Chronicle* (see Bell et al. 2011b), we report the results of stand-level BCA of vegetation management treatments applied at six sites in northern Ontario. The specific objectives of the study were to: (i) calculate costs associated with each vegetation management treatment over almost two decades, (ii) estimate projected yield and value of fibre (timber, pulpwood, and hog fuel) production using a

simulation and an optimization model, and (iii) conduct BCA to compare the economic viability of the vegetation management treatments.

3.3 METHODS

The simulations and benefit-cost analyses presented in this paper are based on data from six Vegetation Management Alternative Program (VMAP) studies. In brief, yields were projected beyond the data to age 70 years using Forest Vegetation Simulator (FVS^{Ontario}) (ESSA 2008). BUCK-2 optimization software (Zakrzewski et al. 2010) was used to determine what forest products could be produced at 70 years following treatments. Future benefits were calculated using current Thunder Bay market prices for pulpwood and hog fuel, and lumber prices from Random Length price statistics for 2009 (Random Lengths 2009). A range of real discount rates (2 to 10%) was used to calculate net present value and benefit-cost ratio for each vegetation management treatment. In addition, the internal rate of return for each treatment was estimated to compare changes in NPV over different discount rates. Details of each stage of analysis are provided below following descriptions of the studies from which the data were obtained (for additional details about study sites, see Bell et al. 2011a).

3.3.1 Study areas and vegetation management treatments

Data collected over 10 to 16 years from six research studies in northern Ontario was used for the analysis (Table 3.1). All sites were clear-cut harvested, mechanically site prepared (1986-1988), and planted (1988-1991) with bareroot or container stock of jack pine (*Pinus banksiana* Lamb.) (3 sites), black spruce (*Picea mariana* Mill. BSP) (2 sites), or white spruce (*Picea glauca* [Moench] Voss) (1 site) at approximately 2 x 2 m spacing. In all, 12 vegetation management (release) treatments[4] (plus untreated control) were applied to 97 experimental units (plots) varying from 2 to 12 ha, using randomized complete block designs with single replications. One exception is the Leether lake site, where treatments were completely randomized in four replications. Each site has 3 to 4 blocks and 4 to 7 treatments, but all treatments were not applied at all sites. The level of silviculture implemented at all 6 sites would be classified as 'basic' based on the definitions provided by Bell et al. (2008). Specific site and treatment descriptions are below.

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[4] Vegetation management treatments are sometimes referred as 'release treatments'. These terms are interchangeably used throughout this paper.

Table 3.1 Vegetation management alternative program study areas, treatments, and experimental designs from which data were obtained for the benefit-cost analysis.

Study Site	Location	Year Planted	Crop Species	Year Released	Release Treatments	Exp. Design (Exp Units)
Bending Lake	48°57' N 92°02' W	1988	Jack pine	1992-93	ASg, BS, CON, CRg	RCBD: 4 Blocks (16)
Espanola	46°48' N 82°11' W	Block 1: 1989 Others: 1991	Jack pine	1993	ASg, BBt, BS, CON, CRg, MBg,	RCBD: 3 Blocks (18)
Fallingsnow	48°08' N 89°49' W	1987-90	White spruce	1993	ASg, ASt, BS, CON, CRb, CRg, SIL	RCBD: 3 Blocks (21)
Leether Lake	50°36' N 91°45' W	1988	Jack pine, Black spruce	1993	ASg, BS, CON, CRg	CRD: 3 Blocks (12)
Nipigon Corrigal	49°01' N 88°10' W	1988	Black spruce	1990	BBt, BSg CON, CRg, EZg, RHg	RCBD: 3 Blocks (18)
Nipigon Hele	48°59' N 88°33' W	1987	Black spruce	1990	CON, CRg, SGh, RHg,	RCBD: 3 Blocks (12)

Treatment descriptions:

ASt - aerial application of Release® (triclopyr) from a Bell 206 helicopter

ASg - aerial application of Vision® (glyphosate) from a Bell 206 helicopter

BBt - basal Bark application of Release® (triclopyr) with backpack sprayer (Thin Line)

BS – motor-manual brush saw cutting at 18 cm above ground without herbicide

BSg – brush saw cutting with stump herbicide applicator attachment with Vision® (glyphosate)

CON – untreated control

CRb - continuous removal of vegetation by annual applications of brush saws

CRg - continuous removal of vegetation by annual applications of Vision® (glyphosate)

EZg - EZ-Ject injection of Vision® (glyphosate) into competing basal stem

MBg-Backpack mist blower application of Vision® (glyphosate)

RHg-Reel and hose application of Vision® (glyphosate)

SGh - spot gun application of Velpar-L® (hexazinone)

SIL - mechanical brush cutting at 33 cm above ground with Silvana Selective®/Ford Versatile tractor

The *Bending Lake Project* is located about 54 km north of Atikokan, Ontario (Table 3.1). Jack pine is the crop species at this site. The study includes 4 blocks and 4 treatments: (i) aerial spray with glyphosate (ASg) in late August 1992, (ii) brush saw (BS) between late June and early July 1993, (iii) control (CON) – no release treatment, and (iv) continuous removal with ground applications of glyphosate (CRg) in September 1993 and again in August 1994.

The *Espanola Study* is located approximately 90 km northwest of Espanola, Ontario (Table 3.1). Jack pine is the crop species at this site. The study includes 3 blocks and 6 treatments: (i) aerial spray with glyphosate (ASg) in August 1993, (ii) basal bark/triclopyr (BBt) in October 1993, (iii) brush saw (BS) in October 1993, (iv) control (CON) – no release treatment, (v) continuous removal with ground applications of glyphosate (CRg) in June 1995 and again in June 1996, and (vi) mist blower with glyphosate (MBg) in August 1993.

The *Fallingsnow Ecosystem Project* is located approximately 60 km southwest of Thunder Bay, Ontario (Table 3.1). White spruce is the main crop species at this site. The study includes 3 blocks and 7 treatments: (i) aerial spray with glyphosate (ASg) in mid-August 1993, (2) aerial spray with triclopyr (ASt) in mid-August 1993, (iii) brush saw (BS) in mid- to late October 1993, (iv) control (CON) – no release treatment, (v) continuous removal with brush saws (CRb) in 1994 through 1997, (vi) continuous removal with ground applications of gly-

phosate (CRg) in 1994 through 1997, and (vii) Silvana Selective (SIL) brush cutting between late October to early November 1993.

The *Leether Lake Study* is located about 56 km north of Sioux Lookout, Ontario (Table 3.1). Jack pine is the crop species at this site except in blocks treated with BS, where black spruce was planted. The study includes 4 treatments replicated 3 times: (i) aerial spray with glyphosate (ASg) in August 1993, (ii) brush saw (BS) between early to mid-June 1994, (iii) control (CON) – no release treatment, and (iv) continuous removal with ground applications of glyphosate (CRg) in 1994 through 1996.

The *Nipigon-Hele Study* is located in Hele Township, about 19 km west of Nipigon, Ontario (Table 3.1). Black spruce is the main crop species at this site. The study includes 3 blocks and 4 treatments: (i) control (CON) – no release treatments, (ii) continuous removal with ground applications of glyphosate (CRg) from August 1990 through 1994; (iii) reel and hose application of glyphosate (RHg) in August 1991; and (iv) spot gun application of hexazinone (SGh) in October 1990. All treatments except continuous removal were applied to a 1-m radius around each crop tree.

The *Nipigon-Corrigal Study* is located in Corrigal Township, about 8 km east of Nipigon, Ontario (Table 3.1). Black spruce is the main crop species at this

site. The study includes 3 blocks and 6 treatments: (i) basal bark application of triclopyr (BBt) in October 1990, (ii) brush saw with glyphosate (BSg) in September 1990, (iii) control (CON) – no release treatment, (iv) continuous removal with ground applied glyphosate (CRg) in August 1990 through 1994, (v) EZ-Ject application of glyphosate (EZg) in November 1990, and (vi) reel and hose application of glyphosate (RHg) in August 1991. All treatments except continuous removal, EZ-Ject, and BBt were applied to a 1-m radius around each crop tree.

3.3.2 Data collection

Cop tree plots of approximately 1200 m² (30 m x 40 m) were established in each treatment plot, before applying the release treatment. In each treatment plot, 20 crop trees (at approximately 10 m spacing) were selected for periodic remeasurement. We used the 10th-year post-treatment crop tree measurement data (height, diameter at breast height (dbh) and stocking) presented in Bell et al. (2011a) and additional 16th-year post-treatment data from the Fallingsnow Ecosystem Project collected in 2009 summer for our analyses.

3.3.3 Simulation and optimization models

We used Forest Vegetation Simulator, FVS^Ontario – a non-spatial, individual-tree growth model (for details, see ESSA 2008) – to project expected crop tree volumes to an arbitrary rotation age of 70 years. The model simulates changes in diameter increment of individual trees using current size (diameter

and height) and calibrated values of previous growth. A sub- model accumulates periodic increments over successive time intervals (e.g., 5 or 10 years). For each site, a common forest region (Ontario West), site quality (Site quality II), crop species, and establishment year were used. We simulated total volume assuming equal spacing between existing trees and no additional silvicultural treatments. The existing stand condition was defined using the 10th-year post-treatment measurement data for all sites, except Fallingsnow, for which 16th-year post-treatment data were used. Total tree height, diameter at breast height, number of tree stems per hectare, (SPH), and stocking information were used as inputs to the simulation model, combining the data from all blocks. We projected SPH, gross total volume (GTV), gross merchantable volume (GMV), basal area (BA), quadratic mean diameter (QMD), and top height (TH) of each crop species for each treatment combination.

BUCK-2 (Zakrzewski et al. 2010) was used to optimize the possible product mix and estimate the future value of fibre produced. Projected SPH and GTV, and mean diameter and top height were used as inputs. In this optimization tool, the desired size limits (length and minimum diameter) of roundwood timber products and rankings of log categories (sawlogs, veneer logs, and pulp wood) are user defined. Though BUCK-2 does not account for the price of the output lumber, its objective is to maximize the total monetary value of a sum of the user-defined timber products at the tree level, where the proxy for that

value is a user-defined ranking of the product. In other words, the optimum timber product mix is such that it maximizes volume proportion of the most profitable timber product at the tree level. The constraints are user-defined timber product sizes (constants): minimum top diameters and fixed log lengths. We used 2.44 m (8 feet) minimum length and 30 cm minimum diameter for the first category of sawlog (Rank I), 2.44 m (8 feet) minimum length and 20 cm minimum diameter for the second category of sawlog (Rank II), 1.22 m (4 feet) minimum length and 10 cm minimum diameter for pulp logs (Rank III), and a kerf factor of 1.5 cm (assuming wastage allowance for circular saw), as constraints to optimize the proportion of wood products expected from the projected GMV produced by trees subjected to different vegetation management treatments. Only the merchantable volume of the target crop species was optimized.

3.3.4 Benefit-cost analysis

First, the costs (site preparation, planting, release treatment, harvesting, transportation, and overhead and administration costs) associated with each vegetation management treatment were collected. Because exact costs were not available for each site, data were collected from several sources and averaged. Data sources included individuals (Al Stinson, OMNR, pers. comm. 2010), British Columbia case studies (Boateng 1996, D'Anjou 1996, Thorpe 1996, Comeau and Harper 2009), Ontario case studies (McClain et al. 1994, Willcocks et al.

1997, Bell et al. 1997, Pitt et al. 2000, Pitt et al. 2004, Dampier et al. 2006, Dacosta et al. 2011), and a Quebec case study (Fortier and Messier 2006). Cost estimates for the aerial application of herbicides are based on data previously published from the studies of interest (Bell et al. 1997, Dampier et al. 2006) and current estimates provided by Zimmer Air Services Inc., Thunder Bay and Jack Fish River Forest Management Inc., Hornepayne, Ontario. Herbicide costs for 2009 were collected from E.I. du Pont Canada Company, Engage Agro Corp (a Monsanto Canada dealer), TrueNorth Specialty Products (a Univar company), and Dow Agrosciences Canada Inc. Brush cutting and labour cost estimates came from Haveman Brothers Forestry Services, Kakabeka Falls, Thunder Bay (Dave Haveman, pers. comm., 2010)., and Jack Fish River Forest Management Inc. Hornepayne, Ontario (Jerry Smith, pers. Comm., 2010). Site preparation, planting, and treatment costs were estimated on a 500 ha basis at 2009 values for each site and treatment. Treatment and site preparation costs varied with non-crop stocking, which was based on 10th-year post-treatment stocking data (Pitt and Bell 2005). Harvesting and transportation costs are estimated based on GMV and GMV for each site. A 10% overhead cost was added to offset managerial and administrative costs.

Second, the value of lumber that could be recovered from 70-year projected stem volumes for the different treatments was calculated using forest product market prices and statistics for 2009 (December average) (Random

Lengths 2009). Lumber prices were calculated by averaging prices given for spruce-pine-fir, eastern green lumber for 2 x 4s, precision end trimmed (PET), stud grade, #1 and 2, and random. Pulp wood and hogfuel values were estimated based on current Thunder Bay, Ontario mill gate prices (Buchanan Pulp Sales Office, pers. comm., 2009). The treatment benefits were calculated based on 2009 average prices (CAD $235.5 mbf^{-1} for SPF lumber, CAD $31.34 greenton^{-1} for pulpwood, and CAD $25.07 greenton^{-1} for hogfuel). The non-crop merchantable value were calculated based on hardwood prices, which varied from species to species (ranging from CAD $150 to CAD $300.00 mbf^{-1}). Lumber and other wood product prices in 2009 were low in comparison to the previous 10 years (2000-2009). We also conducted a sensitivity analysis to see the effect of changed wood prices on NPV and BCR using 2005 average prices, which were high for most products during 2000-2009. Since we did not have real future market price and cost information, we discounted benefits and costs estimates to the year 2009, under the assumption that benefits and costs will follow similar trends in the future.

Third, the benefit-cost analysis was conducted using NPV and BCR, as specified in equations [1] and [2], respectively.

$$NPV = \sum \frac{B}{(1+r)^t} - \sum \frac{C}{(1+r)^t}$$
[1]

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$$BCR = \frac{\Sigma \frac{B}{(1+r)^t}}{\Sigma \frac{C}{(1+r)^t}}$$

[2]

where, *B* and *C* are benefits and costs, respectively, associated with each vegetation management treatment over time *t*, and *r* is the discount rate.

Both NPV and BCR depend on the discount rate used for analysis. For private-land forestry situations, the discount rate corresponds to the opportunity cost of capital (Johansson and Löfgren 1985). Several different discount rates, ranging from 0 to 20%, are commonly used to evaluate private forestry investments (Manley 2010) but historical social discount rates range from 3 to 5% (Heaps and Pratt 1989). Given current market competitive interest rates offered by commercial banks, we used a real discount rate ranging from 2 to 10% to assess the sensitivity of NPV and BCR. We also computed the internal rate of return (IRR), which is the discount rate when NPV equals zero and provides a measure of the profitability of an investment excluding environmental factors (Campbell and Brown 2003) for each treatment.

3.4 RESULTS

The results of benefit-cost analyses are presented by site and treatment. Since not all treatments were replicated at all sites, we calculated the averages of benefits and costs from each treatment-site combination. Further we grouped

the results in four treatment groups: aerially applied herbicide (ASg, ASt), ground applied herbicide (BBt, EZg, MBg, RHg and SGh), cutting (BS and SIL), and cutting plus herbicide (BSg). Continuous removal treatments (CRg and CRb) were not considered in the NPV and BCR calculations because costs associated with these treatments are very high and these treatments are neither recommended nor used in practice.

3.4.1 Treatment costs

Costs associated with each treatment at each site are presented in Table 3.2. On average, ASg had the lowest per unit cost (CAD$ 210.50 ha^{-1}) followed by ASt (CAD$ 268.90 ha^{-1}). Costs of continuous removal treatments are always higher as the treatments are repeated for 3 to 5 years; for example, CRb, which was repeated 4 times after the initial treatment, had the highest cost (CAD$ 1,750.00 ha^{-1}). A comparison among the four treatment groups revealed that aerial herbicide treatment was more cost effective than the ground herbicide application, cutting, and cutting plus herbicide alternatives (Figure 3.1a). Average total cost including site preparation, planting, treatment, harvesting, transportation, and overhead ranged from CAD$5,870.40 ha^{-1} (control) to CAD$ 6,663.30 ha^{-1} (cutting) (Figure 3.1b). Interestingly, vegetation management treatment costs accounted for only 8% of the total costs of plantation establishment (Figure 3.1c).

(a) Average treatment cost 2009
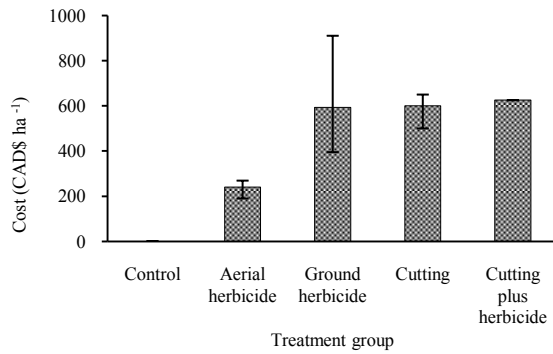
(b) Average total cost 2009
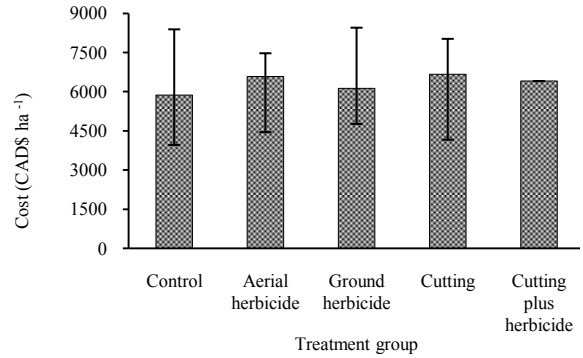
(c) Proportion of costs
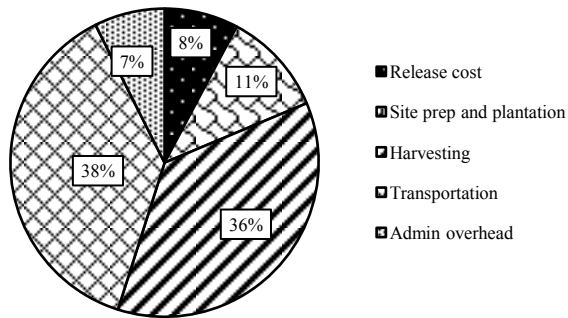
Figure 3.1 Average cost (a), total cost (b) and proportion of costs (c) of vegetation management treatments by treatment groups. Aerial herbicide includes ASg and ASt; ground herbicide includes BBt, EZg, MBg, RHg, SGh; cutting plus herbicide includes BSg; and cutting includes BS and SIL treatments. Treatment details are presented in Table 3.1. Bars show the minimum and maximum ranges in respective treatment groups. All costs are discounted at 2% rate.

Table 3.2 Treatment costs, projected gross total volume and merchantable volume of crop tree species at 70 years by study site and treatment.

Metric	Treatment[1]	Study sites						
		Bending Lake	Espanola	Fallingsnow	Leether Lake	Nipigon-Hele	Nipigon-Corrigal	Average
Costs (CAD$ ha[-1]) [2]	ASg	202.0	240.0	190.0	210.0	-	-	210.5
	ASt	-	-	268.9	-	-	-	268.9
	BBt	-	535.0	-	-	-	455.0	495.0
	BS	550.0	600.0	500.0	550.0	-	-	550.3
	BSg	-	-	-	-	-	625.3	625.3
	CON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CRb	-	-	1750.0	-	-	-	1750.0
	CRg	1124.8	1162.8	2011.8	1132.8	2248.9	2248.9	1655.0
	EZg	-	-	-	-	-	910.3	910.3
	MBg	-	475.3	-	-	-	-	475.3
	RHg	-	-	-	-	426.6	395.0	410.8
	SGh	-	-	-	-	675.3	-	675.3
	SIL	-	-	650.3	-	-	-	650.3
GTV (m³ ha^{-1}) [3]	ASg	205	232	260	208	-	-	226.3
	ASt	-	-	287	-	-	-	287.5
	BBt	-	165	-	-	-	169	167.0
	BS	167	172	248	169	-	-	189.0
	BSg	-	-	-	-	-	177	177.0
	CON	182	181	204	179	131	153	171.6
	CRb	-	-	299	-	-	-	299.0
	CRg	288	280	302	296	180	190	256.1
	EZg	-	-	-	-	-	170	170.3
	MBg	-	251	-	-	-	-	250.7
	RHg	-	-	-	-	196	186	191.1
	SGh	-	-	-	-	169	-	168.7
	SIL	-	-	255	-	-	-	255.0

Metric	Treatment[1]	Study sites						Average
		Bending Lake	Espanola	Fallingsnow	Leether Lake	Nipigon-Hele	Nipigon-Corrigal	
	ASg	173 (5)	186 (5)	208 (51)	185 (157)	-	-	188 (54)
	BBt	-	132 (70)	-	-	-	132 (147)	132 (108)
	BS	159 (3)	138 (6)	199 (114)	142 (72)	-	-	159 (49)
	BSg	-	-	-	-	-	138 (120)	138 (120)
	CON	154 (60)	145 (109)	163 (172)	153 (252)	104 (60)	124 (100)	140 (126)
Merch. vol.	CRb	-	-	260 (9)	-	-	-	260 (9)
(m³ ha⁻¹) [3,4]	CRg	244 (2)	224 (2)	266 (1)	254 (73)	148 (2)	150 (16)	214 (16)
	EZg	-	-	-	-	-	138 (218)	138 (218)
	MBg	-	201 (11)	-	-	-	-	201 (11)
	RHg	-	-	-	-	155 (23)	147 (53)	151 (38)
	SGh	-	-	-	-	133 (91)	-	133 (91)
	SIL	-	-	204 (135)	-	-	-	204 (135)

[1]Treatment descriptions: ASt - aerial application of Release® (triclopyr) from a Bell 206 helicopter; ASg - aerial application of Vision® (glyphosate) from a Bell 206 helicopter; BBt - basal Bark application of Release® (triclopyr) with backpack sprayer (Thin Line); BS – motor-manual brush saw cutting at 18 cm above ground without herbicide; BSg – brush saw cutting with stump herbicide applicator attachment with Vision® (glyphosate); CON – untreated control; CRb - continuous removal of vegetation by annual applications of brush saws; CRg - continuous removal of vegetation by annual applications of Vision® (glyphosate); EZg - EZ-Ject injection of Vision® (glyphosate) into competing basal stem; MBg-Backpack mist blower application of Vision® (glyphosate); RHg-Reel and hose application of Vision® (glyphosate); SGh - spot gun application of Velpar-L® (hexazinone); SIL - mechanical brush cutting at 33 cm above ground with Silvana Selective®/Ford Versatile tractor

[2] Costs are based on non-crop stocking level and distance of the site from the nearest major centre and are calculated on a 500 ha plot basis.

[3]*Volumes were projected using FVS^Ontario;*
[4]*Values in parentheses are the non-crop (hardwoods-mainly poplar) merchantable volumes.*

3.4.2 Total and merchantable volume

Projected GTV and GMV of crop species at 70 years for each site and treatment are presented in Table 3.2. Figures 3.2 and 3.3 show the overall trends in GTV and GMV, respectively for all sites. Compared to other treatments, continuous removal and aerial herbicide treatments produced higher average GTV ha^{-1} followed by mechanical cutting alternatives. Average GTV within treatment groups ranged from 172 m^3 ha^{-1} for the control to 257 m^3 ha^{-1} for aerial herbicide treatments. All treatment groups exhibited a considerable gain (from 3% in cutting plus herbicide to 49.7% in aerial herbicide) in average GTV at age 70 compared to the controls.

A similar trend was observed for average GMV gain in treated relative to control plots. However, herbicide plus cutting (BSg) produced about 2% less GMV than that of the controls averaged across all sites. This treatment (BSg) produced about 8% more merchantable volume than the control of its site (Table 3.2). Non-crop merchantable volumes were always higher in control plots followed by cutting and herbicide groups (Figure 3.4).
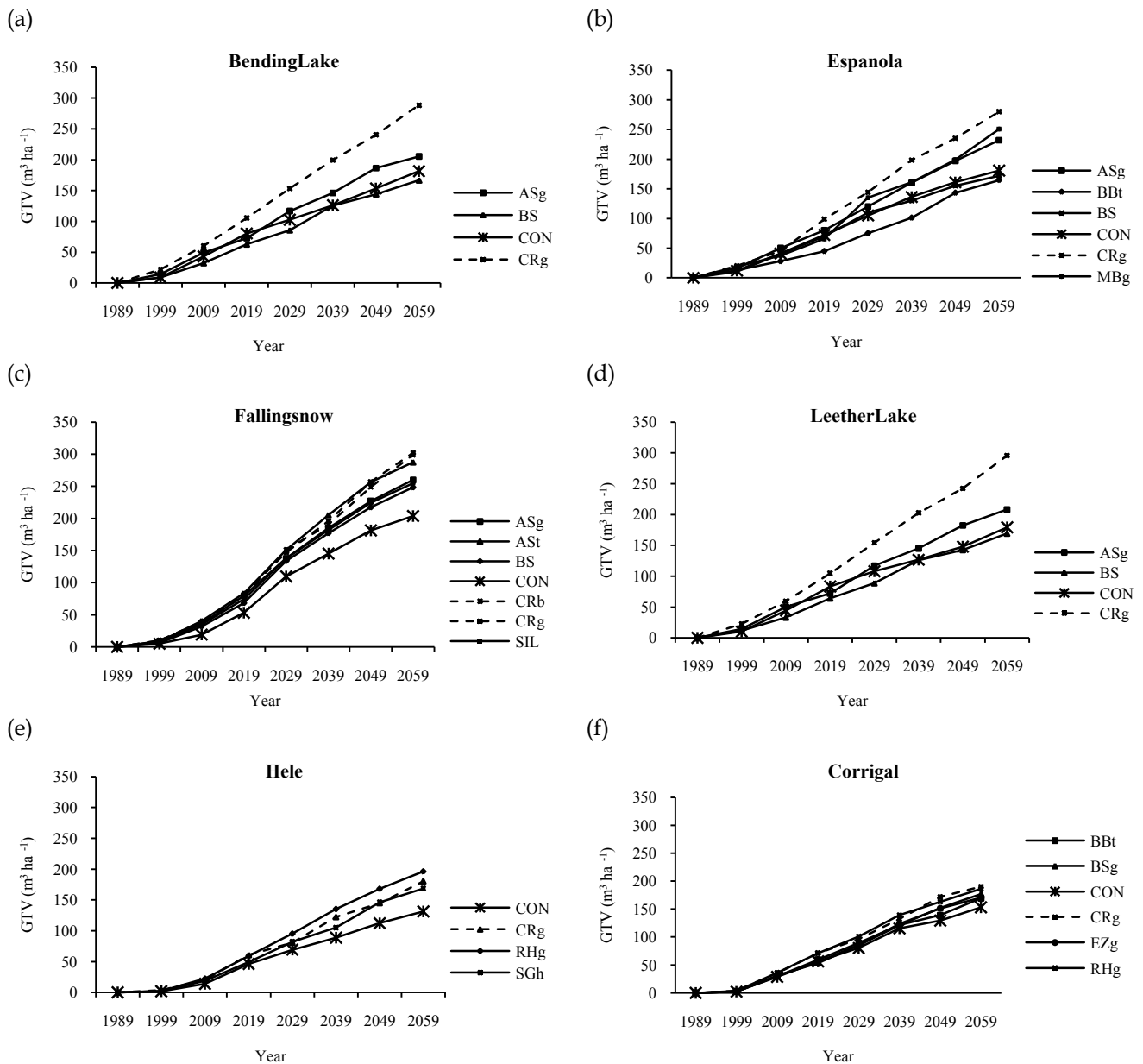
Figure 3.2 Projected gross total volume (GTV; m³ ha⁻¹) of crop trees from various vegetation management studies. Volumes were projected using FVS^Ontario. ASg - aerial spray with glyphosate, ASt - aerial spray with triclopyr, BBt - basal bark application of triclopyr, BS - brush saw, BSg – brush saw cutting with glyphosate, CON - control, CRb - continuous removal by brush saws, CRg - continuous removal by glyphosate, EZg - EZ-Ject injection of glyphosate, MBg - mist blower application of glyphosate; RHg - reel and hose application of glyphosate, SGh - spot gun with hexazinone, SIL - mechanical cutting with Silvana Selective/Ford Versatile tractor. Treatment details are summarized in Table 3.1.

Figure 3.3 Projected gross merchantable volume (GMV; m³ ha⁻¹) of crop trees from various vegetation management studies. Volumes were projected using FVS^Ontario. ASg - aerial spray with glyphosate, ASt - aerial spray with triclopyr, BBt - basal bark application of triclopyr, BS - brush saw, BSg – brush saw cutting with glyphosate, CON - control, CRb - continuous removal by brush saws, CRg - continuous removal by glyphosate, EZg - EZ-Ject injection of glyphosate, MBg - mist blower application of glyphosate; RHg - reel and hose application of glyphosate, SGh - spot gun with hexazinone, SIL - mechanical cutting with Silvana Selective/Ford Versatile tractor. Treatment details are summarized in Table 3.1.

Table 3.3 Crop and non-crop merchantable volumes, product proportions, and value of fibre production at age 70 following vegetation management treatments.

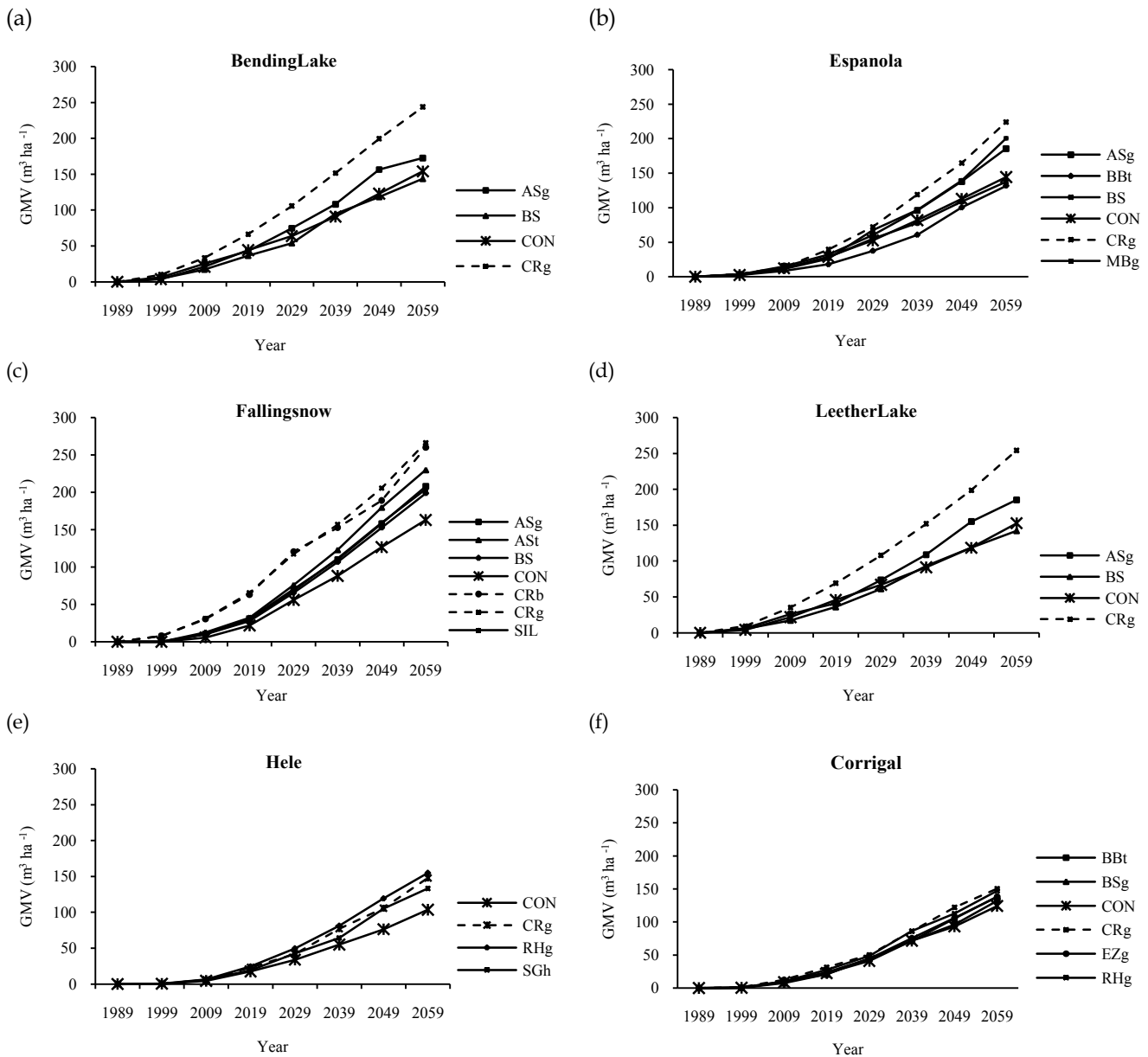| Study site - crop species | Treatment | Crop | | | | Non-crop[a] merchantable volume (m³ ha⁻¹) | Value of fibre production in 2059 (CAD $ ha⁻¹) at 2009 price | Diff. from CON (%) |
		Merchantable volume (m³ ha⁻¹)	Lumber (mbf ha⁻¹)	Pulp volume (metric ton ha⁻¹)	Hogfuel volume (metric ton ha⁻¹)			
Bending	ASg	173	61	20	3.6	4.5	18,373.71	5
Lake-	BS	159	59	25	1.6	3.1	18,127.03	4
	CON	154	53	20	4.2	60.2	17,418.91	0
Jack pine	CRg	244	89	23	4.1	1.9	21,972.07	21
	ASg	186	65	22	4.4	5.0	20,445.92	3
	BBt	132	45	19	1.8	69.7	20,172.27	2
Espanola-	BS	138	46	20	3.7	6.2	20,061.30	2
	CON	145	48	23	2.9	109.3	19,730.54	0
Jack pine	CRg	224	80	25	3.6	1.8	19,843.23	1
	MBg	201	69	26	4.4	10.8	20,954.81	6
	ASg	208	74	25	2.9	51.2	25,176.53	27
	ASt	230	84	25	1.6	96.7	28,209.35	34
Fallingsnow-	BS	199	60	43	4.0	113.6	22,839.00	19
	CON	163	53	29	2.7	172.0	18,486.76	0
White spruce	CRb	260	92	33	3.6	9.0	23,519.30	21
	CRg	266	94	32	3.9	1.0	24,351.49	24
	SIL	204	74	22	3.0	134.8	25,392.05	27
Leether	ASg	185	65	24	2.3	156.5	27,102.68	24
Lake-	BS	142	49	19	3.1	71.6	17,182.74	-19
	CON	153	51	22	4.2	252.1	20,491.29	0
Jack pine and black spruce	CRg	254	89	32	4.1	72.7	27,201.24	25

| Study site - crop species | Treatment | Crop | | | | Non-crop[a] merchantable volume (m³ ha⁻¹) | Value of fibre production in 2059 (CAD $ ha⁻¹) at 2009 price | Diff. from CON (%) |
		Merchantable volume (m³ ha⁻¹)	Lumber (mbf ha⁻¹)	Pulp volume (metric ton ha⁻¹)	Hogfuel volume (metric ton ha⁻¹)			
Nipigon	CON	104	35	14	3.5	60.1	12,973.71	0
Hele –	CRg	148	51	18	3.9	1.9	12,878.50	-1
	RHg	155	52	22	3.3	23.3	14,773.93	12
Black spruce	SGh	133	44	20	3.4	91.1	17,545.13	26
	BBt	132	44	18	5.5	146.8	21,327.17	19
Nipigon	BSg	138	46	23	0.3	119.5	20,046.93	13
Corrigal-	CON	124	41	19	3.5	99.6	17,370.92	0
	CRg	150	49	18	5.3	16.2	17,012.61	-2
Black spruce	EZg	138	49	17	1.2	218.3	27,401.07	37
	RHg	147	48	23	5.0	52.7	15,767.31	-10

[a] Non-crop volume was obtained from Bell et al. (2011a) and includes commercial softwoods and hardwoods including poplar. Crop volumes were projected using FVS^{Ontario}. Treatment descriptions are provided in Table 1. Proportions of lumber, pulp, and hog-fuel volumes for crop trees were optimized using BUCK-2 (Zakrzewski et al. 2010).
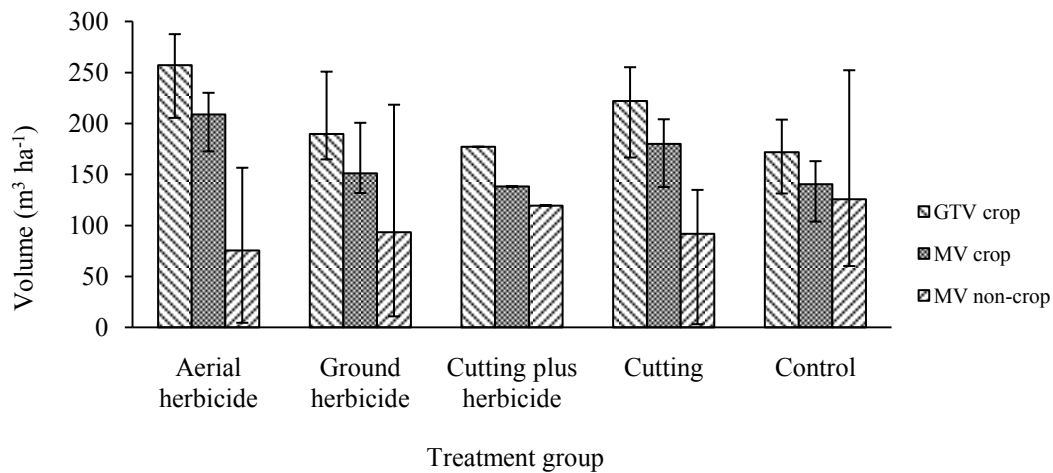
Figure 3.4 Projected average gross total (GTV) and merchantable volume (MV) (m³ ha⁻¹) of woody vegetation at 70 years (2059) following vegetation management alternative treatments by treatment group. Volumes were projected using FVS^Ontario. Aerial herbicide includes ASg and ASt; ground herbicide includes BBt, EZg, MBg, RHg, SGh; cutting plus herbicide includes BSg; and cutting includes BS and SIL treatments. Treatment details are presented in Table 3.1. Bars show the minimum and maximum ranges in respective treatment groups. Non-crop merchantable volumes were obtained from Bell et al. (2011a).

3.4.3 Value of fibre production

The estimated values of fibre produced by crop and non-crop species at 70 years following treatments are presented in Table 3.3. The expected value at crop rotation includes both crop and non-crop merchantable volumes and values associated with potential products as optimized by BUCK-2. The aerial herbicide treatment group had the highest average value (CAD$ 25,492 ha⁻¹) compared to the controls (CAD$ 17,745 ha⁻¹). However, all treatments did not produce higher values than the controls at all sites. For example, BS at Leether Lake and RHg at Nipigon-Corrigal produced 19% and 10% less value per hectare, respectively, than the control group. A comparison of the average value of fibre

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produced at different sites indicated that, on average, fibre value was higher for Fallingsnow than for the other study sites.

3.4.4 Net present value and benefit-cost ratio

Net present values and benefit-cost ratios for different vegetation management treatment groups computed at different discount rates with sensitivity analysis of 'high' and 'low' lumber prices are presented in Figures 3.5 and 3.6. In general, the aerial herbicide group had the highest NPV and BCR for all discount rates followed by cutting and other herbicide groups. As expected, NPV was always higher for all species combined than for crop species alone (Table 3.4). However, at lower discount rates crop species produced higher BCR than that for all species combined. At a 2% discount rate, aerial herbicide applications produced more than double (for crop species) and more than triple (for all crop and non-crop species) the NPV than other treatment groups. The NPV for trees in the aerial herbicide treatment group was positive up to a 4% discount rate whereas trees in the other treatment groups had negative NPV for discount rates from 3% and above. At the highest discount rate (10%), all NPV values were negative; the aerial herbicide group had the highest NPV followed by cutting and ground herbicides. However, at the lowest discount rate (2%) ground herbicides had higher NPV than the cutting treatment.

Figure 3.5 Net present values (NPV; a-d) and benefit-cost ratios (BCR; e-h) at different discount rates and low lumber prices for alternative vegetation management treatments. Aerial herbicide includes ASg and ASt; ground herbicide includes BBt, EZg, MBg, RHg, SGh; cutting plus herbicide includes BSg; cutting includes BS and SIL treatments. Treatment details are presented in Table 3.1.
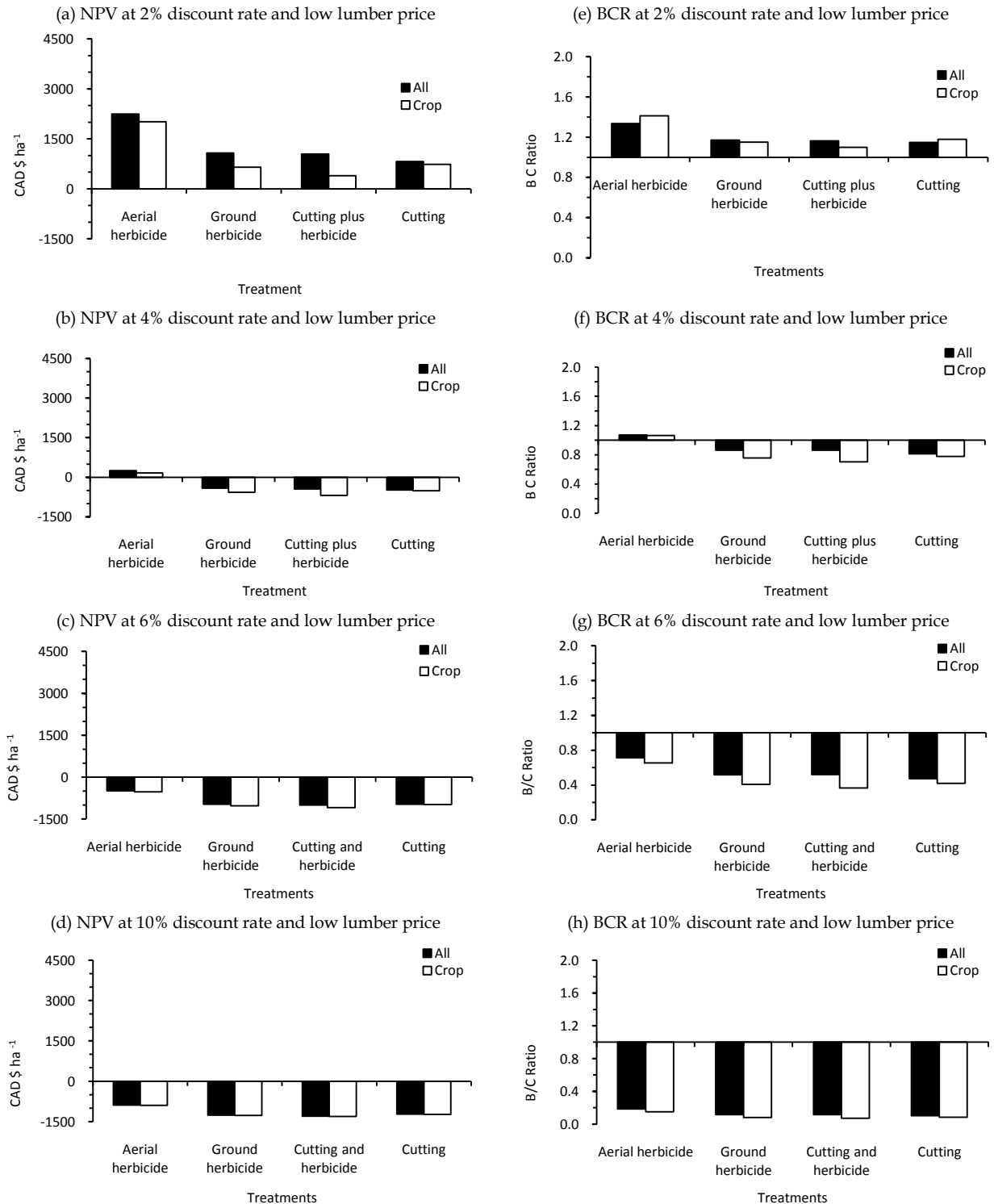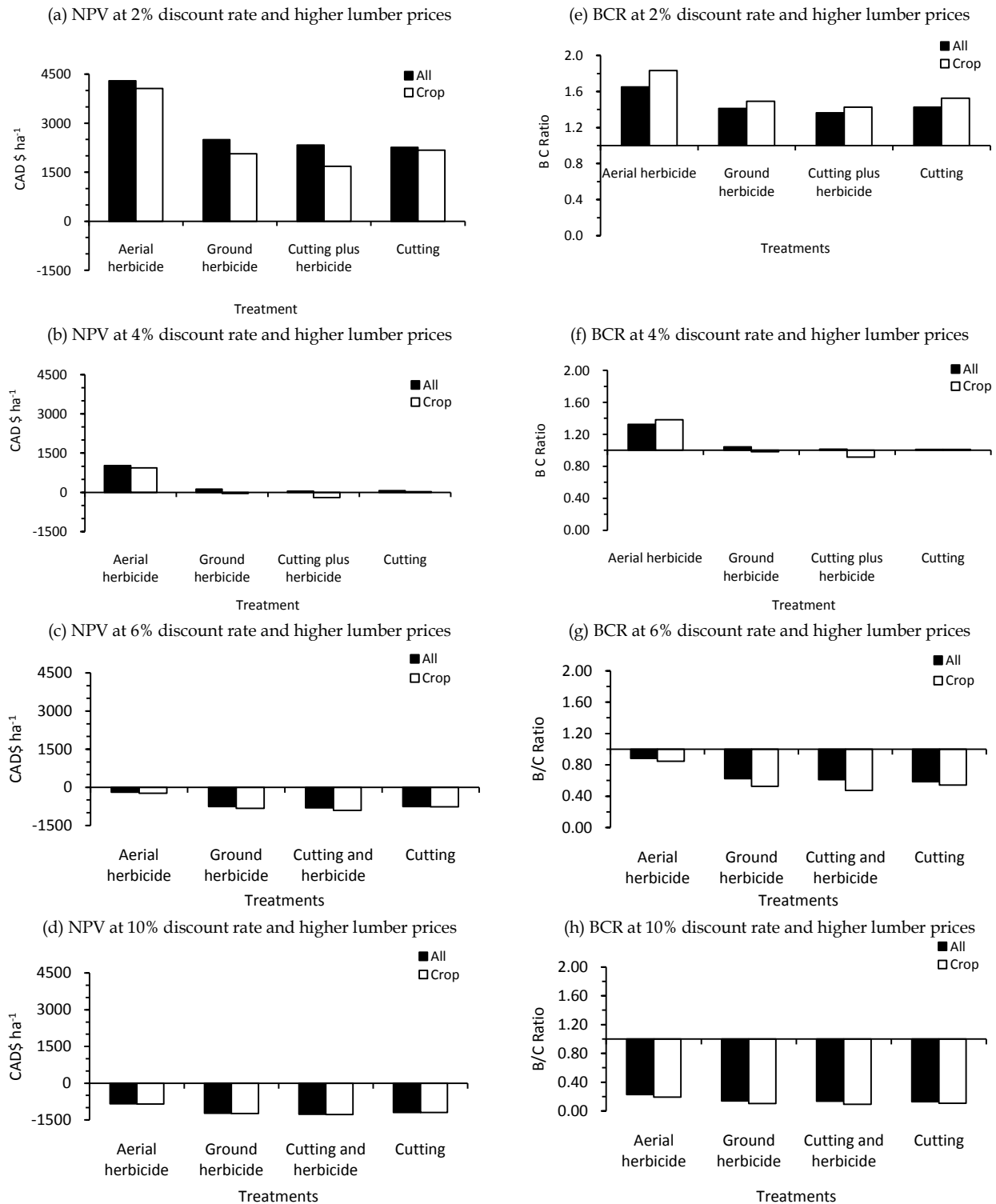
Figure 3.6 Net present values (NPV; a-d) and benefit-cost ratios (BCR; e-h) at different discount rates and high lumber prices for alternative vegetation management treatments. Aerial herbicide includes ASg and ASt; ground herbicide includes BBt, EZg, MBg, RHg, SGh; cutting plus herbicide includes BSg; cutting includes BS and SIL treatments. Treatment details are presented in Table 3.1.

3.4.5 Internal rates of return

The IRR for each treatment group for crop and all (crop and non-crop) species are presented in Table 3.4. Figures 3.7a (crop species) and 3.7b (crop and non-crop species combined) illustrate the NPV at different discount rates. The aerial herbicide treatment group produced the highest IRR (4.32% for crop species and 4.49% for all species), whereas treatments that involved cutting plus herbicides had the lowest IRR (2.50%) for crop species, and cutting alone had the lowest IRR (3.02%) for all woody species combined.

Table 3.4 Net present value (NPV; CAD$ ha^{-1}), benefit-cost ratio (BCR), and internal rate of return (IRR; %) compared with average projected revenue at age 70 for vegetation management alternatives by treatment groups.

Treatment groups	Crop species			All species			Average revenue at age 70 (CAD $ ha^{-1}) in 2009 prices
	NPV[a]	BCR[a]	IRR%	NPV[a]	BCR[a]	IRR%	
Aerial herbicide	2,249	1.33	4.32	2,016	1.41	4.49	25,492.03
Ground herbicide	1,077	1.17	2.82	647	1.15	3.18	20,384.27
Cutting plus herbicide	1,042	1.16	2.50	392	1.10	3.20	20,046.93
Cutting	819	1.15	2.90	733	1.18	3.02	22,472.28

[a] *NPV (2009) and BCR (2009) are discounted at 2%. Aerial herbicide includes ASg and ASt; ground herbicide includes BBt, EZg, MBg, RHg, SGh; cutting includes BS and SIL; cutting plus herbicide includes BSg treatments. Treatment details are presented in Table 3.1*

(a) IRR of crop species

(b) IRR of all species
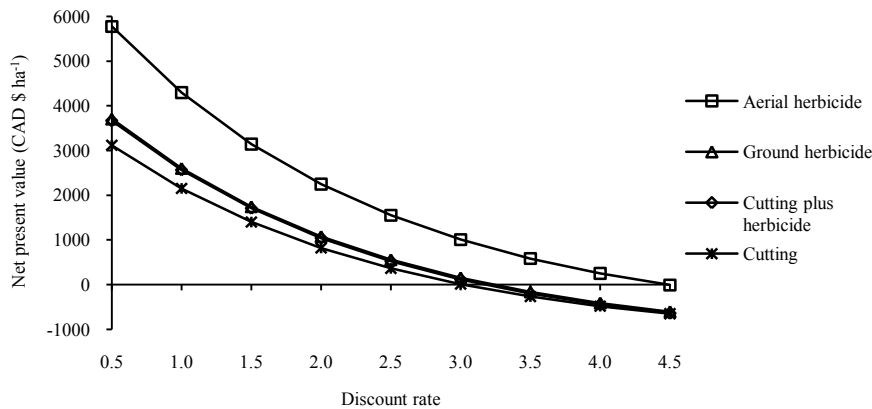
Figure 3.7 Net present values of vegetation management treatment groups plotted against discount rates for internal rate of return (IRR) sensitivity analysis. Aerial herbicide includes ASg and ASt; ground herbicide includes BBt, EZg, MBg, RHg, SGh; cutting plus herbicide includes BSg; and cutting includes BS and SIL treatments. Treatment details are presented in Table 3.1.
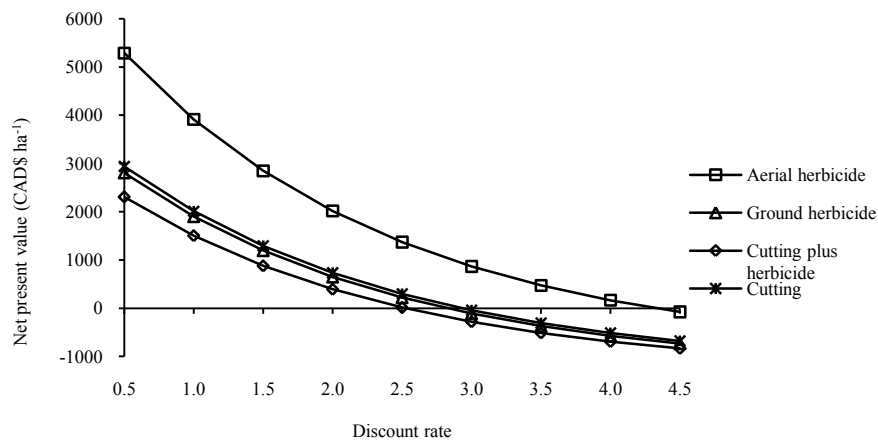
3.5 DISCUSSION

The study results indicate that the aerial herbicide treatment group pro-

vided the most cost-effective treatments, resulted in the highest GTV and GMV,

highest average value of fibre produced, and highest NPV, BCR, and IRR when

compared to ground herbicide application, cutting, and cutting plus herbicide

treatments. Although herbicides are cost effective, their use in forest manage-

ment continues to be contentious affecting operations in the forestry sector

(Wyatt et al. 2011). At the same time, the need for forest vegetation management

to favour certain species and increase the productivity of Crown forests is also

recognized (*see* Wiensczyk et al. 2011).

Silvicultural ground rules (SGRs) and regeneration standards are used

throughout Canada as tools to assess the sustainability of forest management

and to help determine if desired objectives are being met (Armson 2005, Buda

and White 2007). Vegetation management treatments are included in SGRs to

ensure conifers are sufficiently released from competitive vegetation to ensure

that regeneration standards are met. Currently, herbicide and cutting with

brushsaws are commonly applied in Canadian forests; however, evidence sug-

gests that herbicides are the more effective treatment. A survey of plantations

not treated with herbicides, conducted by the Nova Scotia Department of Natu-

ral Resources indicated that only 2.7% of surveyed areas met provincial planta-

tion success criteria (Nicholson 2007). Therefore, herbicide-free forest vegetation

management strategies which have been implementing in Quebec since 2001

when the province banned the use of forest herbicides in commercial forestry,

pose major challenges to intensive silviculture, especially where high volumes

of lumber and fibre are expected. To deal with these challenges, in Quebec, four

alternative strategies are being implemented. These are: preventive silviculture

and natural regeneration; mechanical site preparation; early planting of size-

adapted stock; and use of mechanical release where and when needed (Thiffault and Roy 2010).

The common alternative to herbicides is cutting either by motor-manual or mechanical means (Wiensczyk et al. 2011). We found that applying a cutting treatment once, although not as profitable as aerial application of herbicides, is economically viable. However, in some scenarios a single cutting operation may not be sufficient to suppress the competition (MacDonald and Fiddler 1993, Heineman et al. 2005) and repeated cutting operations are not cost effective (Comeau and Harper 2009). Although job creation was a major goal of implementing these labour intensive methods on a large scale, companies now frequently report a shortage of available (willing) workers to carry out mechanical release treatments (Thiffault and Roy 2010; Wyatt et al. 2011). Risks of gasoline and oil spillage, and inhalation of exhaust emissions from brush saws pose potential environmental and health risks (Dubeau et al. 2003). Additionally, mechanical cutting can damage up to 7% of planted seedlings (K. Ride, OMNR, unpubl. data). Swift and Bell (2011) discuss additional environmental consequences of using these and other forest vegetation management alternatives.

Costs for cutting treatments are highly dependent on the average stocking of competing vegetation during the treatment. The treatment costs also depend on the terrain, machine efficiency, and fuel costs. Variable treatment costs have been reported. For example, Comeau and Harper (2009) estimated treatment costs of $547 to $617 ha^{-1} for manual cutting and $743 ha^{-1} for ground ap-

plied herbicide. We found that treatment costs represented only 8% of total costs. Therefore, better indicators of relative costs (in comparison to benefits) were needed, for which we resorted to NPV, BCR, and IRR.

Results from NPV and BCR both favour the vegetation management treatment alternatives up to a 3% discount rate, which is common in long-term investments where no intermediate risks are involved. An IRR greater than 3% indicates that investment in vegetation management alternatives is not only economically justifiable, but also leads to increased forest industry competitiveness (Baker and Powel 2005). The crop tree species focused on in this study (black spruce, jack pine, and white spruce) cover 52% of managed Crown forest land, or 94% of managed forest land in Ontario (OMNR 2006). Since 1991, about 30 to 40% of harvested area is treated annually (once) using forest vegetation management and 97% of those treatments are aerial application of herbicides to release desired conifer species from hardwood and herbaceous weed competition (NRCan 2010). Therefore, the most economical treatment is being used in most cases. Although, the results of our studies are applicable to the VMAP study sites only, Dacosta et al. (2011) have modelled the landscape-level effects of reduced herbicide use in two forests in northern Ontario and found that herbicide reduction would negatively affect the overall wood supply of both softwoods and hardwoods; increase costs of wood transportation and silviculture; and increase the active road network.

We recommend that additional analysis be carried out to determine the effects of adding environmental or social costs or modifying overhead costs, rotation ages, yields, input costs, and stem defect on NPV, BCR and IRR. In our analysis, we did not consider any environmental or social costs or risks associated with these treatments. We assumed 10% overhead cost in the analysis, which may have influenced NPV and BCR more so than IRR. We used an arbitrary rotation age of 70 years, assuming that managed conifer crop species will reach maximum productivity by this age; however, Willcocks et al. (1997) and Bell et al. (2011a) suggest that lower biological rotation ages are possible. Our assumptions for forest vegetation simulator may also have some implications for the projected values of total and merchantable volumes. Higher yields are possible through the use of more intensive site preparation, planting genetically improved stock, and increasing density and dispersion; however, such gains are associated with higher initial costs resulting in minimal influence on the economic benefits. Finally, we used the assumption of zero defects in trees and no intraspecific competition or natural disturbances (i.e., losses to mortality over the 70 years) in the optimization software, which might have resulted in overestimating the value of fibre production. More information about costs and consequences of various vegetation management treatments would also help to refine these assumptions to improve future stand-level economic analyses.

3.6 CONCLUSIONS

Economic benefit-cost analysis is an effective tool for investment decision making and policy formulation. We used stand-level benefit-cost analyses of 12 vegetation management treatments applied at 6 study sites in northern Ontario to evaluate net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR) for the resulting tree crop at 70 years following treatments. Under the assumptions used in this case study, we found that crop trees in treated plots produced higher projected gross total and merchantable volumes and value of fibre produced than did those in untreated control plots. Net present value and BCR for trees in aerial herbicide treatment groups were higher than those for the other treatments, however, all vegetation management alternatives showed positive NPV for up to a 3% discount rate. Trees in aerial herbicide treatment groups had more than double (for crop species) and more than triple (for crop and non-crop species) the NPV of other treatment groups. Trees in aerial herbicide treatment groups had the highest IRR followed by those in the ground herbicide, cutting, and cutting plus herbicide treatment groups. Values of IRR greater than 3% indicate that investment in vegetation management alternatives is economically profitable for the forest industry and may help to improve its competitiveness in forest products markets.

3.7 ACKNOWLEDGEMENTS

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4. CONCLUSION AND MANAGEMENT IMPLICATION

4.1 SYNTHESIS

Forest vegetation management is an integral component of boreal forest management. Successful regeneration and enhanced crop productivity are the most common silvicultural considerations for the application of different treatments in any specific stand. Vegetation management treatments are not necessarily applied to all stands but on a 'when needed' basis after an assessment survey. We compared 12 alternatives from six sites. The most common treatment groups are: Aerial spray of herbicides, ground spray of herbicides, herbicide plus cutting, manual and mechanical cutting using brush saws and control (no treatment). No treatment, which may not lead to the right result, is always a cost effective alternative and it is considered only when vegetation management treatment is not possible or not necessary.

Economic considerations in making vegetation management alternative treatment decisions are important for policy makers and forestry practitioners. This thesis analyzed the 10 to 16 year post treatment data on different sites and assessed the productivity, quality and future value of fibre production. Furthermore, a detailed benefit cost analysis was performed and the alternatives were compared with the following conclusions:

First, vegetation management alternative treatments produced trees with higher average diameter, height and gross total volume. Herbicide treatments in general produced higher stem volume than cutting treatments and control. Herbicide treated plots produced up to 165% more volume and mechanical cutting produced up to 98% more volume than control plots. The gross volume production in the control plots was the lowest.

Second, treated plots produced higher quality trees than control plots. Tree qualities did not differ among treatments. Control plots also produced quality trees but in lower proportions as compared to treated plots. Crop tree mortality was highest in control plots.

Third, the projected future value of fibre production was up to 53% greater in herbicide treated plots and up to 37% greater in cutting treatment than in control plots.

Fourth, aerial spraying of herbicide was found to be the most inexpensive treatment alternative followed by ground spray, cutting, cutting plus herbicide and continuous removal treatment alternatives.

Fifth, projected total and merchantable volumes are also greater in herbicide treated plots than in cutting and control plots. Cutting plots also produced greater gross and merchantable volumes than control plots.

Sixth, the aerial herbicide treatment group had the highest net present value and benefit-cost ratio for all discount rates. Cutting produced the second highest NPV and BCR. At lower discount rates, crop species produced higher BCR than that for all species combined. At a 2% discount rate, aerial herbicide treatment produced more than double NPV as compared to other treatment groups. The NPV for trees in the aerial herbicide treatment group was positive up to a 4% discount rate, whereas other treatment groups had negative NPV for discount rates 3% and above.

Seventh, the internal rates of return from all treatments within the study showed that all treatments are economically viable. The aerial herbicide treatment group produced the highest internal rates of return. The IRR is 4.32% and 4.49% respectively for crop species and all species in herbicide treatment groups. In the case of crop species, the cutting group produced 3.02% and cutting plus herbicide group produced 2.50% IRR which all are greater than the current market interest rate.

4.2 MANAGEMENT IMPLICATION

4.2.1 Vegetation management methods and critiques

Vegetation management can be accomplished using any method that can suppress the growth or reproduction of undesirable plants and encourage the growth and reproduction of desirable plants. In forestry, this can occur by selecting the method and timing of a range of operations. Site preparation generally involves the use of large machines, prescribed fire, or herbicides to prepare a site for natural or artificial regeneration. Because so many options are available, site preparation offers one of the best opportunities to accomplish vegetation management objectives. After desired tree species have been introduced to a site, options for vegetation management become more restricted due to the need to avoid damage to desired tree seedlings. Vegetation management treatments during this phase may include: ground and aerial application of herbicides, individual tree applications of herbicide, manual cutting, mechanical cutting, animal grazing, mulching, prescribed burning, cover cropping and use of biological plants and fungi. However, the most common and operational release methods used in Ontario are: aerial and ground spray of herbicides, manual or mechanical cutting, and/or a combination of both. In Ontario, 95% of release treatment is done with herbicides and Glyphosate is used in 97% of the cases (CCFM 2010).

Use of herbicides in crop management has a long history in agriculture. Over the past several decades, the use of herbicides has become a dominant method of forest vegetation management. The aerial application of herbicides is especially prominent in remote northern forests; it is being used almost exclusively for vegetation management in the boreal forest. Among Canadian provinces, Ontario has historically had the largest forest herbicide program (CCFM 2010) averaging about 70,000 ha per year. Controversy about the use of forest herbicides has increased since the 1980s across Ontario. A 1989 national survey indicated that 71% of Canadians opposed the use of chemicals in the forest and most believed that pesticides are harmful to wildlife and people (Environics Research Group 1989). Similarly a 1994 survey revealed that 82% of the public found the aerial application of herbicides to be unacceptable (Decision Research 1995). Despite this strong opposition to herbicides, the majority (82%) of the Ontario public support controlling unwanted vegetation to improve the survival of tree seedlings, but are quite selective about the vegetation control methods they find acceptable (Decision Research 1995). All alternative methods are more socially acceptable than aerially applied herbicides, with some alternatives such as manual cutting, animal grazing and cover cropping being acceptable to more than three quarters of the public, and others like heavy machinery, mulching, and prescribed burning being acceptable to more than half.

4.2.2 Arguments for and against herbicide use

Forest vegetation management, based on herbicides, has been and continues to be a contentious silvicultural practice. One of the arguments put forward in favour of herbicide use is its minimal human health risk as compared to other intensive agricultural herbicide use. The general consensus is that there is no serious indication of any direct human health concern (Walstad and Dost 1984). Studies also indicate that active persistence of herbicide in forest soils and watersheds after aerial application is 45 to 60 days (Feng and Thompson 1990, Feng et al 1990, Thompson et al. 2000). On the other hand, studies claim that herbicides like glyphosate may pose potential risks to human reproduction and foetal development as a result of herbicide's exposure in the presence of adjuvant (Richard et al. 2005, Benachour et al. 2007, and Benachour and Séralini 2009). However, these studies tend to focus on agricultural use of glyphosate which generally use higher concentrations and as such are of limited relevance in the forestry context. It is often argued that herbicides are attractive from an environmental point of view as they would allow accrued yields in intensively managed sites to meet increasing demand, thus reducing pressure on other sites which could be set aside for conservation (Bell et al. 1997, Franklin et al. 1994, Flueck and Flueck 2006, Little et al. 2006). However, this viewpoint assumes that the public supports increasing wood production to meet anticipated demands, which may not be the case. It also supposes that as more land is being inten-

sively managed, there would be an increase in land set aside for conservation, which is also not necessarily the case.

Another important consideration towards the use of herbicide in forestry practice is that it is effective, productive and affordable as compared to other treatment alternatives. Chemical spray treatments are recognized to be an effective and affordable vegetation management tool (Franklin et al. 1994, Bell et al. 1997, Guynn et al. 2004, and Wagner et al. 2004) as compared to other alternatives. Effective management of forest vegetation, which includes suppressing competition through selective herbicide use, has led to wood volume yield gains ranging from 30% to 450% (Miller and Miller 2004, Wagner et al. 2004), and annual sustainable harvest levels increase by 31% in comparison to no forest vegetation management (Wagner et al. 2004). Daggett (2003) also found softwood volumes increased by 264% for herbicides (glyphosate and triclopyr) treated plots as compared with untreated plots. Aerial herbicide treatments costs are approximately $250-$300 per ha, compared to $600-$700 for manual weeding. Furthermore, manually weeded vegetation will often coppice again after cutting, thus requiring multiple treatments before preferred species outgrow competition (Dunster 1987).

Many claims about the impact of herbicides on biodiversity in forest systems exist. A substantial effort has been made to assess these claims. The general view is that the effects of forest herbicides on biodiversity are almost negli-

gible (Boyd et al. 1995, Sullivan et al. 1998, Guynn et al. 2004, Lautenschlager 2004, Wagner et al. 2004). Studies indicate that herbicides may have deleterious effects to wildlife species, but these are restricted to relatively small spatial and temporal scales (DeCalesta et al. 2002, Lautenschlager 1993, Lautenschlager and Sullivan 2002, Lautenschlager and Sullivan 2004, Miller and Miller 2004). Although glyphosate does not appear to have short-term negative impacts on biodiversity, it tends to be closely associated with intensive plantation forest management, which has been shown to negatively impact biodiversity (Charbonneau and Simpson 2010). Dampier (2006) assessed the species diversity in the boreal plantations in northern Ontario using percentage of theoretical species maximum (%TSM) method and reported that only one out of 94 experimental units developed into a tree level monoculture.

Although many studies show that herbicides have negligible effects on biodiversity, a few studies have suggested that herbicide use over longer periods of time might provide different results (Lautenschlager and Sullivan 2002, Lautenschlager and Sullivan 2004). Indeed, herbicides can alter plant communities and successional trajectories (Freedman 1991, MacKinnon and Freedman 1993, Brooks et al. 1995, Miller and Miller 2004) thus affecting plant and wildlife species in the long term. Direct effects of herbicides on plant communities are generally short-term (Miller and Witt 1990, O'Connell and Miller 1994, Lautenschlager and Sullivan 2004, Miller and Miller 2004), but long-term changes in

successional trajectories could influence future wildlife occupancy of herbicide-treated habitats (MacKinnon and Freedman 1993, Sullivan and Sullivan 1982). Although changes in forest community structure can decrease habitat quality for some species, it can also increase habitat quality for other species. As such, the literature contains examples of the overall impacts of community changes due to herbicide use ranging from negative (Borrecco et al. 1979, Santillo et al. 1989a, Santillo et al. 1989b, Lautenschlager 1993) to neutral (Savidge 1978, Gruver and Guthery 1986, Freedman et al. 1988, Sullivan 1990, Hood et al. 2002), and even to positive (Landes 1975, Anthony and Morrison 1985, Hurst 1987, Lautenschlager 1993, Jones and Chamberlain 2004).

4.3 CONCLUDING REMARKS

Treatment efficacy, survival and establishment of crop species, crop productivity over the rotation period, comparative benefit-costs, and social and environmental concerns are major management perspectives when deciding vegetation management alternatives. This thesis is a part of a bigger picture of forest management decisions, covering economic analysis of different vegetation management alternatives in Ontario. Ontario's Crown Forest Sustainability Act - 1994 (CFSA) states that "*large, healthy, diverse and productive Crown forests and their associated ecological processes and biological diversity should be conserved.*" This study only addresses the economic benefit-cost analysis in terms of external tree

qualities and projected future value from different vegetation management alternatives. Ecological process and biological diversity are closely related to environmental services provided by the forest ecosystems, which are very difficult to quantify. When such values are quantified and evaluated, these can be part of a more comprehensive social benefit-cost analysis. It is important for a decision maker (manager) to consider the most economic but socially and environmentally acceptable alternative while making investment decisions. Vegetation management treatment costs account for only a fraction of total cost of commercial forestry operation. However, these are initial investments for a long return period and may build a significant capital in future. Since future values and interest rates (and even inflation) are hard to predict, available economic study indicators and comparisons can help decide on the best possible treatment decisions for silviculture investments. Economics, society and the environment are the three foundations of any sustainable system (Munasinghe and Shearer 1995) and natural resource managers and policy makers should always look for the most comprehensive knowledge base to make better informed decisions.

4.4 LIMITATIONS OF THE STUDY AND SUGGESTIONS FOR FUTURE RESEARCH

This study is the first of its kind and restricted to only six study sites of northern Ontario. The overall research design was done in early 1990 and I had

no control on the design at this point. Among the alternative treatments studied not all treatments were applied at all sites and the replications were also limited. Some treatments were applied only once at a single site.

Extrinsic tree qualities were assessed on the basis of external tree characteristics only. The true value of fibre production is, however, directly related to the internal tree characteristics and defects. We assumed similar internal characteristics and zero internal defects across all treatments for valuation. The internal characteristics (quality) have been found to vary with spacing. In this study, the crop trees were planted at approximately 2 m spacing in all sites. Therefore, more closely-spaced plantations should be tested for yield and quality differences in future.

I used a non-spatial individual tree growth model (FVS^{Ontario}) and projected the gross and merchantable volumes of targeted crop trees for the arbitrary rotation age of 70 years assuming that this coincides with the biological rotation of conifer crop species in the study area. The use of BUCK-2 for product optimization and assumptions made during its run were also a limitation of this study.

Lumber prices in 2009 were the lowest for the decade. All the costs and benefits were calculated for the base year 2009. Sensitivity analysis was only conducted for high and low lumber rates and for discount rates ranging from 2

to 10%. More sensitivity analysis for cost and projected volume variability will provide a much better picture.

Future research should, therefore: (i) focus on the above mentioned limitations and in particular on internal wood characteristics, (ii) cover more sites, and (iii) include more replications. Growth models could be updated using the same study plot data and future projections should be more site and species specific.

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