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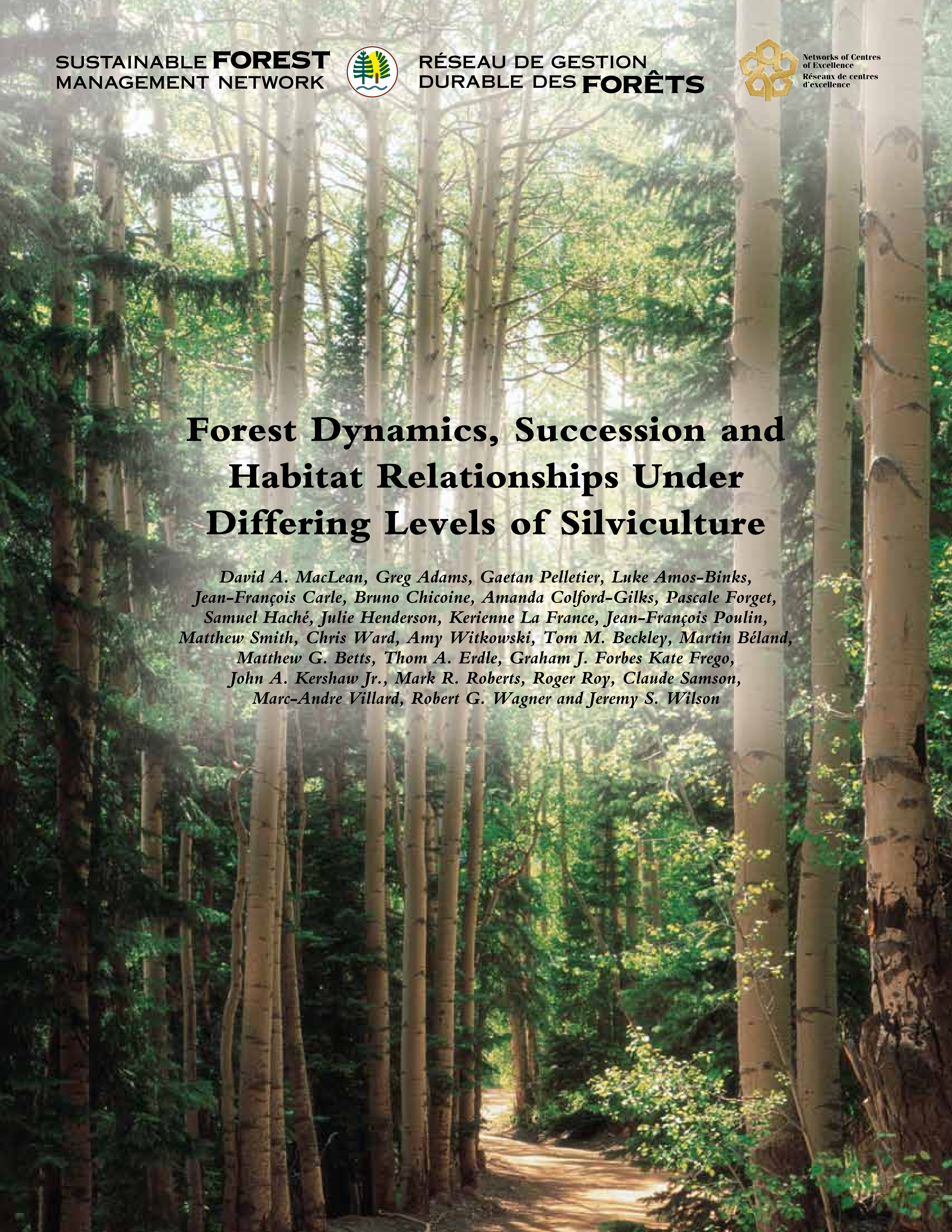

Forest Dynamics, Succession and Habitat Relationships Under Differing Levels of Silviculture

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John A. Kershaw Jr., Mark R. Roberts, Roger Roy, Claude Samson,
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THE SUSTAINABLE FOREST MANAGEMENT NETWORK

Established in 1995, the Sustainable Forest Management Network (SFM Network) is an incorporated, non-profit research organization based at the University of Alberta in Edmonton, Alberta, Canada.

The SFM Network's mission is to:
- Deliver an internationally-recognized, interdisciplinary program that undertakes relevant university-based research;
- Develop networks of researchers, industry, government, Aboriginal, and non-government organization partners;
- Offer innovative approaches to knowledge transfer; and
- Train scientists and advanced practitioners to meet the challenges of natural resource management.

The SFM Network receives about 60% of its $7 million annual budget from the Networks of Centres of Excellence (NCE) Program, a Canadian initiative sponsored by the NSERC, SSHRC, and CIHR research granting councils. Other funding partners include the University of Alberta, governments, forest industries, Aboriginal groups, non-governmental organizations, and the BIOCAP Canada Foundation (through the Sustainable Forest Management Network/BIOCAP Canada Foundation Joint Venture Agreement).

KNOWLEDGE EXCHANGE AND TECHNOLOGY EXTENSION PROGRAM

The SFM Network completed approximately 334 research projects from 1995 – 2008. These projects enhanced the knowledge and understanding of many aspects of the boreal forest ecosystem, provided unique training opportunities for both graduate and undergraduate students and established a network of partnerships across Canada between researchers, government, forest companies and Aboriginal communities.

The SFM Network's research program was designed to contribute to the transition of the forestry sector from sustained yield forestry to sustainable forest management. Two key elements in this transition include:
- Development of strategies and tools to promote ecological, economic and social sustainability, and
- Transfer of knowledge and technology to inform policy makers and affect forest management practices.

In order to accomplish this transfer of knowledge, the research completed by the Network must be provided to the Network Partners in a variety of forms. The KETE Program is developing a series of tools to facilitate knowledge transfer to their Partners. The Partners' needs are highly variable, ranging from differences in institutional arrangements or corporate philosophies to the capacity to interpret and implement highly technical information. An assortment of strategies and tools is required to facilitate the exchange of information across scales and to a variety of audiences.

The KETE documents represent one element of the knowledge transfer process, and attempt to synthesize research results, from research conducted by the Network and elsewhere in Canada, into a SFM systems approach to assist foresters, planners and biologists with the development of alternative approaches to forest management planning and operational practices.

SFM NETWORK PARTNERS AND AFFILIATES AUGUST 2008

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- Manitoba Model Forest
- National Aboriginal Forestry Association

Knowledge Exchange and Technology Extension Program (KETE)
Sustainable Forest Management Network

Forest Dynamics, Succession and Habitat Relationships Under Differing Levels of Silviculture

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Sustainable Forest Management Network

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Introduction

Understanding forest dynamics, succession, and habitat relationships under differing levels of silviculture is the basis of forest management planning. The Acadian forest is comprised of a complex mix of forest communities, including mixedwood stands where boreal softwood and southern hardwoods commingle. This forest is ecologically unique in North America and economically important in northeast North America. The forest provides many ecological services, is biologically diverse, and is the raw material source for the forest industry - a mainstay of the Maritime economy. The succession dynamics of this ecosystem are strongly influenced by natural disturbances, and by a long history of harvest and protection from fire and insects.

This report summarizes the findings of 12 graduate student studies that were funded through the Sustainable Forest Management Network (SFMN) and resulted in the publication of several scholarly articles. The overall goals of the project were to:

a) better understand the succession dynamics of the Acadian mixedwood forest, its value as habitat, and the diversity and habitat implications of current management, and

b) use this understanding to develop and evaluate alternative stand and forest management strategies aimed at maintaining the diversity and habitat values of the forest while supplying an economic supply of industrial raw material.

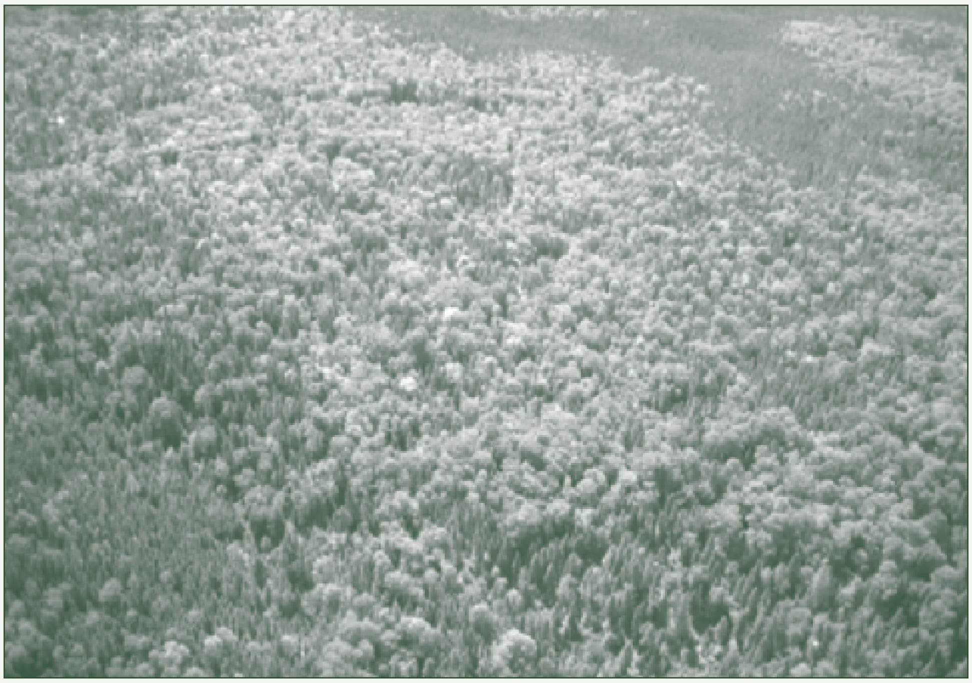


Figure 1. The Acadian mixedwood forest in New Brunswick is comprised of a mix of coniferous and deciduous, boreal and temperate components, with up to 39 different native tree species.

Project overview

This project was initiated by the J.D. Irving, Limited Forest Research Advisory Committee and the Fundy Model Forest, in order to address research needs of these organizations in the Acadian forest. Specific research priorities were to better understand the succession dynamics of mixedwood stands, and the relationship of stand composition and structure to habitat in silviculturally-treated stands (plantations and pre-commercially thinned stands) at the stand and landscape levels.

More specifically there was a need to address how to:

i) define mixedwood stands using ecologically-relevant parameters (rather than the typical, arbitrary, inventory-based definition of hardwood not >75% or softwood not >75%);

ii) manage stand structure variables (e.g., deadwood) to increase the biodiversity value of silviculturally treated stands; and

iii) define habitat windows for species sensitive to forest management.

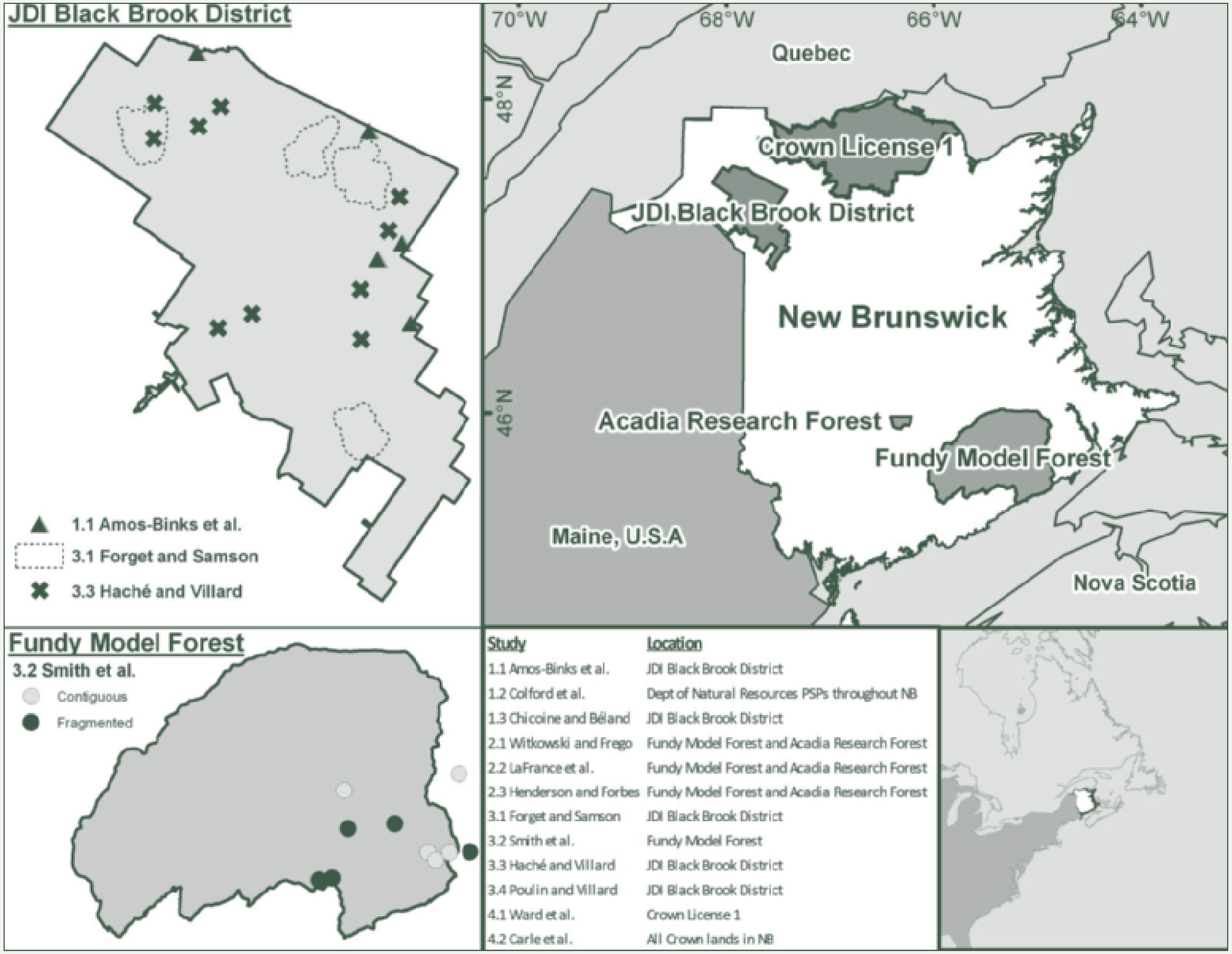
The project brought together collaborators from J.D. Irving, Limited, Fundy Model Forest, University of New Brunswick (UNB) – Fredericton and Saint John campuses, Université de Moncton (UdeM), and University of Maine.

Most of these studies took place in two study areas about 300 km apart, in northern New Brunswick (Black Brook District) and southern New Brunswick (Fundy Model Forest) *(Figure 2).* The Black Brook District is an 189,000 ha privately-owned forest that contains 60,000 ha of spruce plantations and 50,000 ha of high-value shade tolerant hardwood managed for sawlogs and veneer products by selection cutting and patch cuts. The Black Brook District is among the most intensively managed landscapes in Canada, and having been subject to silviculture treatments since 1957, provides a wealth of sites for study. The Fundy Model Forest is a 400,000 ha mix of ownerships (Crown, large industrial, private woodlots, and Fundy National Park) and forest types in southern New Brunswick. The landscape is less intensively managed than the Black Brook District. Both areas contain a mix of softwood and shade-tolerant hardwood forest.

Previous research in the Black Brook District set the stage for this project by:

- quantifying natural and human-caused disturbance (Porter *et al.* 2004; Etheridge *et al.* 2005, 2006),
- determining species of management concern (Higdon *et al.* 2005, 2006; Guénette and Villard 2005),
- simulating the effects of management zoning on timber and habitat values (Montigny and MacLean 2006), and
- determining vertebrate species occurrence and habitat availability (Keppie 2004; Samson 2004; Pelletier 2005).

The studies highlighted in this report build upon those efforts by addressing important outstanding questions and issues raised by previous research, and expanding study and analysis to look at new questions.



Study	Location
1.1 Amos-Binks et al.	JDI Black Brook District
1.2 Colford et al.	Dept of Natural Resources PSPs throughout NB
1.3 Chicoine and Béland	JDI Black Brook District
2.1 Witkowski and Frego	Fundy Model Forest and Acadia Research Forest
2.2 LaFrance et al.	Fundy Model Forest and Acadia Research Forest
2.3 Henderson and Forbes	Fundy Model Forest and Acadia Research Forest
3.1 Forget and Samson	JDI Black Brook District
3.2 Smith et al.	Fundy Model Forest
3.3 Haché and Villard	JDI Black Brook District
3.4 Poulin and Villard	JDI Black Brook District
4.1 Ward et al.	Crown License 1
4.2 Carle et al.	All Crown lands in NB

Figure 2. Map of the various study locations used in individual graduate student projects.

A total of 12 integrated studies were conducted by graduate students that fell under the following four objectives:

Objective 1. Determine succession dynamics of mixedwood stands using historical analysis, stand reconstruction, natural regeneration surveys, and stand growth modeling;

Objective 2. Determine **effects of pre-commercial thinning** (an important silvicultural technique to increase growth of softwoods) on ground vegetation, bryophytes, and small mammals;

Objective 3. Relate **key stand structures and tree species mixtures** of plantations, pre-commercial thinnings, and mixedwoods, **to abundance/occurrence of selected biodiversity indicators** (ground vegetation, bryophytes, birds, American marten, northern flying squirrel, small mammals); and

Objective 4. Determine the **effect of alternate zoning allocations** of reserve, intensive, and extensive management zones on timber and habitat indicators and on forest biomass for potential bioenergy production.

This report first provides an executive summary of the 12 studies organized into sections based on these four objectives. The remainder of the report presents a more detailed account of each study, including background, methods, and implications for forest management. For a detailed listing of individual graduate student projects and advisors organized by report section, please see Appendix 1.

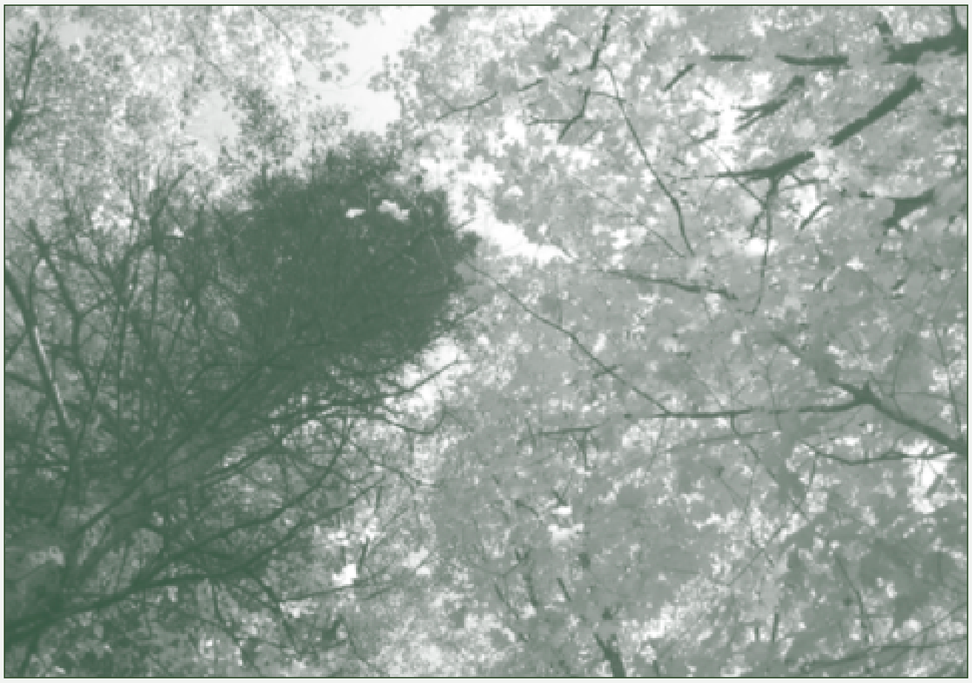


Figure 3. The Acadian forest is a point of confluence where the shade tolerant hardwood forest of the northeastern United States meets the coniferous forest of the Canadian boreal, resulting in a diverse mixture of tree species.

Executive Summary of Project Results

Objective 1. Succession dynamics of mixedwood stands

1.1 Dynamics of mixedwood stands, as influenced by natural disturbance and succession – Luke J. Amos-Binks, David A. MacLean, Robert G. Wagner and Jeremy S. Wilson

Mixedwood composition is highly variable over time and dynamics should be incorporated into management instead of maintaining static stand type proportions over time.

Concerns about the abundance and health of mixedwoods in the Acadian forest have been raised but their long term dynamics are in question. The overall goal of this study was to identify patterns of change in softwood-hardwood content of mixedwood stands and relate them to stand characteristics, succession, and disturbance. Historical information, aerial photographs and growth data were used to reconstruct the dynamics of 32 unharvested mixedwood stands.

Five stand development classes were identified that differed as a function of complex interactions between various disturbances that allowed new tree cohorts to establish. In particular, a significant period of change in species composition occurred between 1946 and 1982, induced by outbreaks of eastern spruce budworm *(Choristoneura fumiferana)* and European spruce sawfly *(Gilpinia hercyniae)* and a period of birch (Betula sp.) dieback. These incidents led to stand re-organization that played out over many years.

Balsam fir *(Abies balsamea)* appears to be an ephemeral component of these mixedwood stands, as its abundance in the canopy is reduced significantly by spruce budworm. In contrast, red spruce *(Picea rubens)* is longer lived, less susceptible to spruce budworm and is more persistent in the canopy. Composition of mixedwoods was highly variable over time and as a result, the dynamics of mixedwoods should be incorporated into management plans instead of trying to maintain static proportions over the long term.

1.2 Effects of spruce budworm on stand dynamics of balsam fir and red spruce mixedwoods – Amanda Colford-Gilks, David A. MacLean, John A. Kershaw Jr., and Martin Béland

Mixedwood stands can mitigate wood supply losses that result during spruce budworm outbreaks.

The presence of multiple species in mixedwood stands results in differential growth, in-growth and mortality patterns. These dynamics are further complicated by periodic outbreaks of spruce budworm. This project aimed to determine the influence of disturbance and stand structure on the development of balsam fir and spruce mixedwood stands in New Brunswick. A total of 154 permanent sample plots (PSPs) were selected from the provincial PSP database, representing spruce and balsam fir mixedwood stands in mature and over-mature age classes, over a gradient of shade tolerant hardwood content.

The amount of mortality in PSPs was significantly related to balsam fir basal area (BA), % hardwood BA, maximum cumulative spruce budworm defoliation from 1973-1977, and location (in three spruce budworm outbreak zones in north, central, and south New Brunswick). Balsam fir mortality was more than double that of spruce but there was little difference in the growth of outbreak survivors between species. Regression analysis revealed that the presence of hardwood in the stand was the most influential on the growth of surviving host species.

Specifically, higher hardwood and balsam fir content at the time of plot establishment were related to greater survivor growth. Findings provide evidence for the promotion of mixedwood stands as a means to mitigate wood supply losses in the event of spruce budworm outbreaks.

1.3 Shade tolerant hardwood natural regeneration 15 years after silviculture treatments on an industrial freehold in northwestern New Brunswick – Bruno Chicoine and Martin Béland

Pre-harvest stand composition influenced sugar maple regeneration, while mineral soil, decayed wood, and transmitted light influenced yellow birch regeneration.

Various partial cutting systems have been used to promote the regeneration of shade tolerant hardwood stands made up of sugar maple *(Acer saccharum),* yellow birch *(Betula alleghaniensis)* and American beech *(Fagus grandifolia).* A total of 1065 (1m^2) plots in 37 stands were used to examine how harvest treatments (selection, shelterwood, strip, and patch) and environmental conditions influenced the abundance and distribution of regeneration 15 years following harvest.

Results indicated that environmental conditions resulting from the silviculture treatments did not differ enough to influence species composition, largely due to competing vegetation. Pre-harvest stand composition appears to have a greater influence on the composition of regeneration, particularly with sugar maple. Mineral soil and decayed wood availability along with transmitted light to the ground were important factors influencing yellow birch regeneration.

Objective 2. Effects of pre-commercial thinning on biodiversity indicators

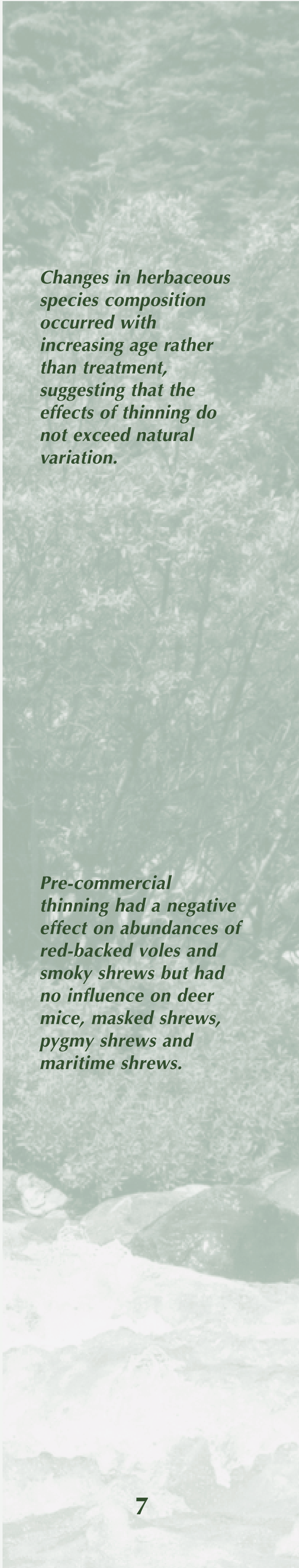
2.1 The effects of pre-commercial thinning on bryophyte communities – Amy Witkowski and Kate Frego

Pre-commercial thinning had negligible effects on bryophytes beyond the initial harvest and conserves more bryophyte species than plantations.

Bryophytes are an important component in forest ecosystems. They are particularly sensitive to physical disruption and microclimatic changes that often occur following forest management activities. This study investigated the effects of pre-commercial thinning on forest floor bryophyte communities, and compared the results to bryophyte responses in plantations (Ross-Davis and Frego 2002). Abundance of bryophyte species was estimated using 1 m^2 sample plots established in naturally regenerated pre-commercially thinned stands, and naturally regenerated un-thinned stands.

Comparisons of pre-commercially thinned stands and un-thinned stands showed similar compositions and suggested that the resulting conditions could sustain these communities. Some bryophyte species known to decline under intensive forest management were present in both stand types, however they were at significantly lower levels in pre-commercially thinned stands.

When compared to bryophyte responses in plantations, bryophytes in pre-commercially thinned stands showed greater similarity to stands that were left untreated following harvest. This indicates that pre-commercial thinning has a reduced impact on bryophytes than plantations. The conclusion is that pre-commercial thinning appears to have negligible effects on bryophytes beyond the initial harvest and conserves more bryophyte species than does plantations.



2.2 The effect of pre-commercial thinning on the abundance of herbaceous species – Kerienne La France and Mark R. Roberts

The herbaceous layer plays a significant role in ecosystem processes and is composed of a diversity of species with varying life history traits. The purpose of this study was to: a) identify changes in stand structure and microsites between thinned and un-thinned stands; b) determine the impact of thinning on the herbaceous layer; and c) determine the long-term influence of thinning on herbaceous species composition. We inventoried stand structures (coarse woody debris volume, tree density, etc.), fine scale environmental features (slash, substrates, ground disturbance) and herbaceous layer vegetation in thinned and un-thinned stands in southern New Brunswick. The stands ranged in age from 16-42 years.

Changes in herbaceous species composition occurred with increasing age rather than treatment, suggesting that the effects of thinning do not exceed natural variation.

Results showed that thinned sites had lower softwood stem density and fewer snags per hectare, while slash height of thinned stands was comparable to un-thinned stands and therefore did not inhibit the growth of vegetation. This suggests that managers should attempt to avoid large slash piles that may inhibit the germination of some species. Although environmental conditions differed between thinned and un-thinned stands, no strong evidence of species composition changes were found. Herbaceous layer species composition tended to change with increasing age rather than treatment, suggesting that the effect of thinning on herbaceous species does not exceed that of natural variation.

2.3 The effect of pre-commercial thinning on the abundance of small mammals – Julie Henderson and Graham J. Forbes

Pre-commercial thinning accelerates height and diameter growth of residual trees by reducing tree density in overcrowded stands. This treatment indirectly increases the amount of woody debris, which is important for small mammals because it can provide cover, travel ways, nesting and burrowing sites, and food.

Pre-commercial thinning had a negative effect on abundances of red-backed voles and smoky shrews but had no influence on deer mice, masked shrews, pygmy shrews and maritime shrews.

The purpose of this study was to determine if pre-commercial thinning influences abundance of small mammals 5, 10, or 20 years after treatment and to examine relationships between habitat components and small mammal abundance. Relative abundance of small mammals was surveyed across 27 sites that represented a chronosequence (5, 10 or 20 years) since treatment. Small mammals were live trapped over seven consecutive nights, weighed, identified for species and gender and marked before release.

Results indicate that pre-commercial thinning had a negative effect on abundances of red-backed voles and smoky shrews *(Sorex fumeus)* but had no influence on deer mice, masked shrews *(Sorex cinereus),* pygmy shrews *(Sorex hoyi)* and maritime shrews *(Sorex maritimensis).* Red-backed vole abundance was 1.8 times higher in control sites compared to thinned sites, but they were still present in 22 of 27 sites. It was expected that micro-debris resulting from thinning activity would benefit small mammals by providing protective cover, leading to higher abundances in thinned stands. However, neither higher abundance nor associations with micro-debris were found. It may be possible that the reduction of canopy cover caused by pre-commercial thinning offsets the benefits of increased woody debris.

Objective 3. Key stand structures and abundance of biodiversity indicators in plantations and mixedwood stands

3.1 *Abundance, age, body mass and spatial distribution of American marten in northwestern New Brunswick – Pascale Forget and Claude Samson*

Plantations 20 years or older contribute to the presence and maintenance of American marten in managed landscapes by providing tall, dense coniferous cover.

American marten *(Martes americana)* is typically associated with old coniferous forest and could be particularly vulnerable to intensive forest management. Previous studies indicate that while softwood plantations 20 years old or greater attained the minimal tree cover, height, and basal area needed to support marten, they may lack the necessary amount of dead wood for marten to complete their life cycle. Using four different sites characterized by age and proportions of plantations present in the landscape, we tested this hypothesis. Marten abundance was determined using the mark-recapture method and survival rates were determined using telemetry.

Results showed that marten appear to look for a combination of plantation stands >20 years old, and mature natural stands in their spatial distribution. However marten were found to be more abundant and males were older and heavier in a landscape where 53% of the landscape was composed of plantations ≥30 years old when compared to a site where plantations greater than 20 years old comprised 78% of the landscape. This indicates that plantations that are 20 years or older can contribute to the presence and maintenance of American marten by providing tall, dense coniferous cover as long as they are interspersed with mature natural stands.

3.2 *Life history parameters and population viability of a forest indicator species (northern flying squirrel) in relation to landscape-scale forest management – Matthew Smith, Graham J. Forbes and Matthew G. Betts*

Flying squirrel numbers were similar in fragmented and contiguous landscapes, and movements were not restricted in landscapes with a matrix of non-mature and mature habitat.

Flying squirrels *(Glaucomys sabrinus)* are mature forest specialists sensitive to forest fragmentation and are often selected as indicators of sustainable forest management. Little research has been conducted on the effects of fragmentation on flying squirrel survival, fecundity and movement. We examined the effects of fragmentation on flying squirrel survival and analyzed whether non-mature forest was restricting flying squirrel movement between mature patches.

Flying squirrels were live trapped, tagged, identified by gender and categorized by one of three age classes (adult, sub-adult, juvenile) to estimate abundance and survival. To determine if non-mature forest was restricting flying squirrel's movement between mature forest patches, individual home ranges were determined by monitoring radio-collared squirrels in small and large patches. We also displaced individuals from their home range by varying distances (180-4000m) and monitored their movements following release.

Preliminary results indicate that flying squirrel numbers were similar in fragmented and contiguous landscapes. Results also suggest that flying squirrel movements are not restricted in forest landscapes made up of a matrix of non-mature and mature habitat because they are able to travel long distances in fragmented habitats and expand home ranges into young forest while using mature patches.

3.3 Demographic response of two songbird species to selection harvesting – Samuel Haché and Marc-André Villard

Partial harvesting is often used to maintain stand structure while harvesting a portion of the merchantable volume. However, the treatment creates a sudden opening in the canopy and can cause significant responses in some song birds by altering their habitat. The mechanisms underlying these responses remain poorly understood. We assessed two of these mechanisms (change in stand structure and abundance of nest predators) on density and productivity of Ovenbird *(Seiurus aurocapilla)* and Black-throated Blue Warbler *(Dendroica caerulescens).* Ovenbirds tend to respond negatively to partial harvesting as they are strongly associated with an open understory and thick leaf litter. Black-throated Blue Warblers respond positively as they utilize low shrubs for nesting and foraging. We also quantified treatment effects on age-specific rate and return of Ovenbird populations.

Alterations to stand structure from selection harvesting and abundance of nest predators influenced habitat selection of Ovenbird and Black-throated Blue Warbler.

Results indicate that alterations to stand structure and abundance of nest predators influenced habitat selection of Ovenbirds and Black-throated Blue Warblers. Ovenbird response to the treatment a year after harvest was less drastic than expected but could be due to an alteration process that is expected to last for up to 10 years post-harvest. The negative response of Black-throated Blue Warblers could be compensated for over time by an increased shrub layer that will provide higher quality habitat. Recruitment is an important process in Ovenbird population dynamics and it was negatively impacted by partial harvesting indirectly by increasing territory size.

3.4 Response of an old forest associate, the Brown Creeper, to forest harvesting at stand and landscape scales – Jean-François Poulin and Marc-André Villard

The Brown Creeper *(Certhia americana)* is strongly associated with large-diameter trees and snags with peeling bark and is sensitive to partial harvesting. We identified stand/landscape structures associated with Brown Creeper nests and successful reproduction, and examined the effect of selection harvesting on demographics. Habitat characteristics were compared at the local (80m) and neighbourhood scales (250m).

Partial harvesting reduces Brown Creeper foraging habitat and pairs compensate by increasing the size of their territory.

Results showed that density of large trees and snags, presence of potential nesting sites, and area of mature forest were important variables discriminating used and unused sites at the neighbourhood scale. Local-scale variables explained more variation in nest site selection than neighbourhood-scale variables. Threshold values for nesting were determined to be 127 large trees/ha, 56 snags/ha or when >53% of the neighbourhood area consisted of mature forest. Single-tree harvesting did not reduce density of snags after harvest but nest density and number of territories was two times lower in harvested plots compared to the mature forest. This suggests that partial harvesting reduces foraging habitat and that Brown Creeper pairs compensate by increasing the size of their territory. Conservation targets are useful but often focus on the availability of nesting substrates. They do not guarantee nutritional requirements will be met following harvest treatments.

Objective 4. Effects of zoning on intensive management

4.1 Triad scenarios on Crown License 1 in New Brunswick – Chris Ward, Tom M. Beckley, Thom A. Erdle and David A. MacLean

Scenarios with more intensive management required less area to meet the same average harvest levels and allowed for increases in reserve area, but had reduced short-term harvest levels.

Triad forest management refers to a way of allocating a portion of forested area to intensive management, with its primary goal being wood production, while the remainder of the landbase is managed for non-timber values. The objective of this study was to test various Triad management scenarios and to evaluate their outcomes based on social, economic and ecological indicators.

Results showed that by varying levels of intensive, extensive and reserve forest, outcomes of some indicators can be maintained in similar states. Management scenarios with increasing levels of intensive forest management required less area to meet the same average harvest levels over the long term and allowed for increases in reserve area. The increased reserve areas resulted in reduced short term harvest levels. However, over the long term increased harvest levels obtained through the availability of forest plantations compensated for those short term reductions.

4.2 Bioenergy production: a case study for Crown lands of New Brunswick – Jean-François Carle, David A. MacLean, Thom A. Erdle and Roger Roy

Conversion of 1.2% of Crown land in NB to willow plantations could offset 26-46% of fossil fuel energy consumption.

In recent years there has been interest in the utilization of forest biomass as a source of energy. This project integrated bioenergy production into management scenarios, and evaluated how various management strategies and actions could impact timber and biomass production on all Crown forest in New Brunswick. Several indicators were developed to evaluate important aspects of biomass harvesting policy.

By converting 1.2% of forested area to fast growing willow plantations, energy production could be increased by 39-56% after 2030 compared to scenarios focused on timber production alone. This could offset 26-46% of fossil fuel energy consumption in New Brunswick. By focusing management on energy production, using 66% of harvest residues and 30% of pulpwood, 44-59% more energy could be produced above levels produced from residues only. This scenario lowered harvest levels by 15-19%.

Project Results

Objective 1. Succession dynamics of mixedwood stands

1.1 Dynamics of mixedwood stands, as influenced by natural disturbance and succession – Luke Amos-Binks, David A. MacLean, Robert G. Wagner and Jeremy S. Wilson

Maintaining stand types native to a region is an important goal of forest management. Recent concerns regarding the abundance and health of mixedwood stands in the Acadian forest (e.g., Betts *et al.* 2003; Etheridge *et al.* 2005; Higdon *et al.* 2005) have highlighted the need for further research into natural stand dynamics. Silvicultural treatments in the Acadian forest often favor either the softwood or hardwood component of mixedwood stands through spacing and partial harvesting. Increased establishment of softwood plantations and high quality hardwood management have further pushed the composition of stands to either softwood or hardwood dominated.

Few silvicultural treatments aim to conserve the unique species assemblages that occur in Acadian mixedwood forest.

Natural stand dynamics and the associated changes in species composition that occur are important sources of information that affect silviculture decisions and provide baseline information used to evaluate the appropriateness of forest management. Etheridge *et al.* (2006) found that the Black Brook District in northwestern New Brunswick showed surprising changes in mixedwood stand types from 1946-2002. Only 16% and 18%, respectively, of harvested and unharvested mixedwood area in 1946 remained as such by 2002. This prompted further research to examine the long-term dynamics of balsam fir – shade-tolerant hardwood mixedwood stands, and the role of natural disturbances in determining changes in species composition over time. Study objectives were to:

1) categorize distributions and patterns of change in softwood-hardwood content for unharvested stands on the Black Brook District from 1946-2006;

2) relate patterns of change in species composition to stand and site characteristics as well as patterns of past disturbance; and

3) examine how natural disturbances have affected composition, stand dynamics and stand development using dendrochronology.

Methods

Sample stands were selected based on comparisons between a 1946 photo-interpreted GIS inventory and the 2006 operational GIS forest inventory. Across the full landbase, mixedwood (MW) stands were classified based on 1946 softwood (SW) content as either 30-60% or 70-80% softwood, and by the degree of change in softwood content from 1946-2006: > -40% SW (i.e., decline by >40%), -20 to -30% SW, -10 to +10% SW or +20 to +30% SW. Unharvested sample stands were selected based on historical harvest records, availability of good quality aerial photographs, and discussions with the district forester to identify areas least likely to have been harvested. Five regions were identified where 32 randomly selected stands were analyzed via detailed photo-interpretation.

For each sample stand, a 50 m by 50 m grid was used to interpret the aerial photos, with each grid cell quantified in 10% classes of SW content, hardwood (HW) content, and total canopy cover. This quantified the species composition of each stand in 1946, 1966, 1982 and 2006. Sample stands were then classified based on change in SW content between 1946-1966, 1966-1982 and 1982-2006. This resulted in five stand development classes reflecting 1946 species composition (SW or MW) and 1946-2006 % SW trend (stable, fluctuating, or declining) *(Figure 4).*

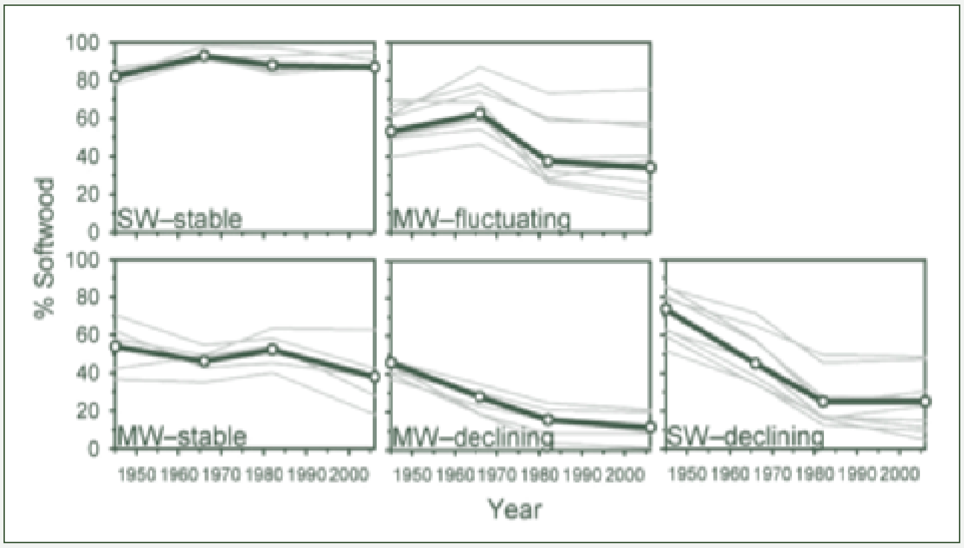
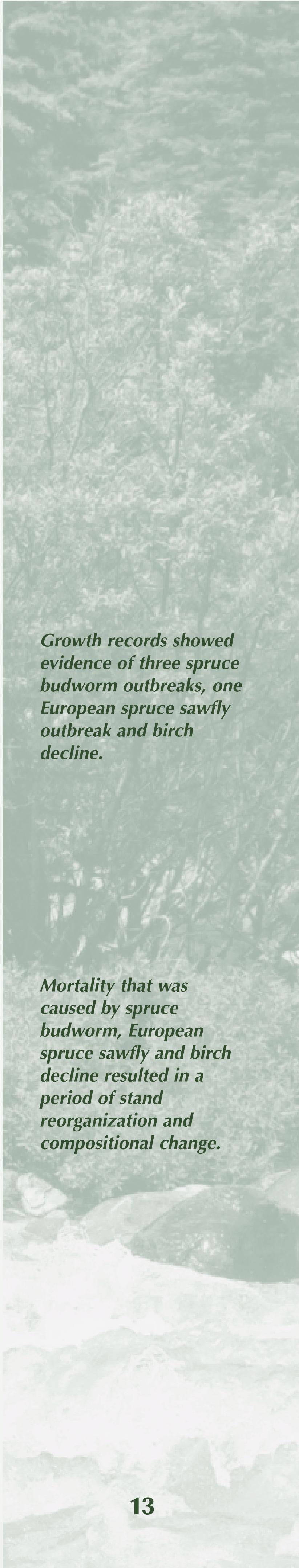


Figure 4. Temporal change in softwood content based on photo-interpretation of images from 1946, 1966, 1982 and 2006, for 32 sampled stands. The stands were grouped into five stand development classes based on softwood content in 1946, and change in % softwood content in three periods from 1946-2006. The bold line represents the average softwood change trajectory for stands in each class, while the grey lines represent trajectories for each stand (from Amos-Binks et al. 2010).

Dendrochronology provides a method to examine past growth trends as influenced by natural disturbance.

A dendrochronological analysis was conducted to examine growth dynamics that lead to the above stand development patterns. Three prism plots were established in each sample stand and increment cores were extracted from every second dominant or co-dominant tree, to a maximum of five trees per species (balsam fir, red spruce, white spruce (*Picea glauca*), eastern cedar (*Thuja occidentalis*), yellow birch, sugar maple and red maple (*Acer rubrum*)). Cores were sanded and measured to determine annual growth, and chronologies for each species and stand were developed using standard dendrochronological methods. Periods of reduced growth caused by natural disturbances and subsequent growth responses were identified, and year of establishment and release of each sampled tree were determined to assess the impact of disturbances on species composition.



Results

Stand development classes

The five stand development classes had varying tree species composition over time (*Figure 4*). SW–stable and SW–declining stands were initially dominated by SW (~80%) in 1946, but subsequently SW–stable stands were fairly stable over time, while SW–declining stands experienced significant reductions (28-60%) in SW cover by 1982. The MW classes had 37-70% SW in 1946 but SW content subsequently varied: MW–fluctuating stands had increased SW from 1946-1966 and declines from 1966-1982; MW–stable stands were relatively stable over time with only slight fluctuations; while MW–declining stands underwent significant declines (20-33%) from 1946-1982.

These varying patterns of SW change were related to variation in disturbance events across the region and stand characteristics among the five classes. SW-stable stands had a large percentage of red spruce, which is less susceptible to defoliation by spruce budworm (Hennigar *et al.* 2008) and is longer lived (Gordon 1985), thereby making it more stable over time.

Disturbances

Growth records can identify periods of below-average growth attributed to natural disturbance and the increased growth (release) that follows canopy mortality. Reduced growth index values for spruce budworm host species (balsam fir and red spruce) during the 1954-1960 and 1975-1984 spruce budworm outbreaks (Baskerville 1975; Royama *et al*. 2005) were evident in dendrochronological results. The red spruce growth index also revealed reduced growth from 1914 to 1921, coinciding with an earlier spruce budworm outbreak. An additional reduction of growth was evident during the 1930s, which may have been caused by the introduction of European spruce sawfly (Balch 1947; Hoyt 1947; Reeks and Barter 1951). Significant reduction in the growth index of yellow birch occurred from 1938-1948, caused by environmental factors prevalent across much of eastern Canada and coinciding with significant mortality, termed 'birch decline' (Gibson 1953; Bourque *et al.* 2005).

Growth records showed evidence of three spruce budworm outbreaks, one European spruce sawfly outbreak and birch decline.

Changes in HW-SW canopy cover differed among stand development classes (*Figure 5*). The most significant periods of change in SW cover varied depending on development class. MW–stable, MW–declining and SW–declining stands experienced their greatest reduction in SW cover from 1946-1966, coinciding with a spruce budworm outbreak during the late 1950s. This pattern may also be related to the decline of a cohort of balsam fir established following a previous, stand-killing 1870s spruce budworm outbreak.

Mortality that was caused by spruce budworm, European spruce sawfly and birch decline resulted in a period of stand reorganization and compositional change.

SW–stable and MW–fluctuating classes showed a different pattern, with their greatest reduction in SW cover occurring from 1966-1982. This decline is attributed to the spruce budworm outbreak that began in the 1970s. Periods of increase in SW cover were uncommon, occurring only in SW–stable, MW–stable and SW–declining classes. It is important to note that all of these stands had < 10% increase in SW content, indicating a lack of softwood recruitment into the canopy.

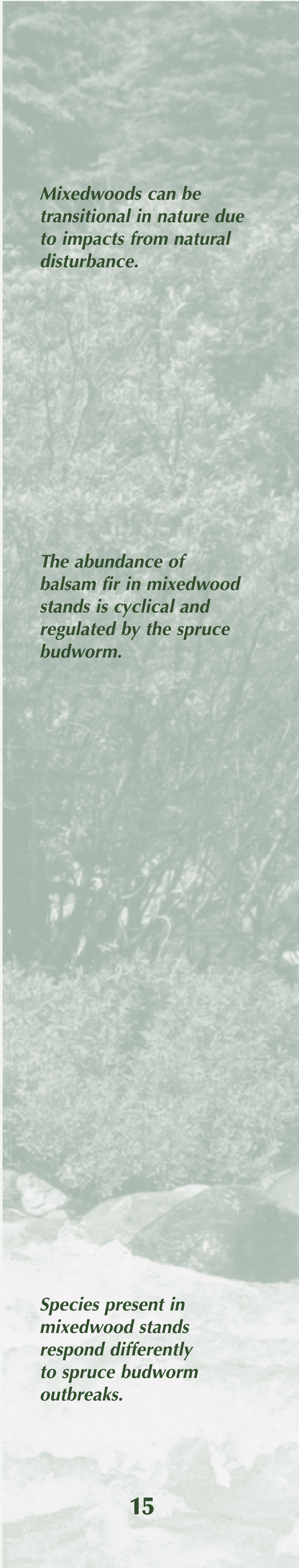
HW canopy cover declined by 8-18% from 1946-1966 in all classes except SW-declining. This reduction in HW canopy coincided with the yellow birch dieback that began in the late 1930s. Between 1966-1982 and 1982-2006, HW canopy cover increased in all classes, with the most significant increases occurring in MW–fluctuating, MW–declining and SW–declining (>19%) classes from 1966-1982.

There were weak indications that ecosite had an effect on differences among stand classes. Sample stands were from two ecosites (5 and 7). Ecosites 5 and 7 both were well-drained, but ecosite 7 had higher productivity. Most stands in MW–fluctuating (75%), MW–declining (100%) and SW–declining (100%) were in ecosite 7, whereas most MW–stable (80%) stands were ecosite 5, and 50% of SW–stable stands were from each ecosite. It is possible that the influence of ecosite on stand development may be stronger with larger sample sizes or improved ecosite discrimination methods.

Figure 5. Average increase or decrease in % softwood and % hardwood cover, by time period, for five stand development classes. Analysis is based on softwood content in 1946 and change in % softwood content from 1946-2006. Overall change in canopy closure (sum of change in softwood and hardwood cover) is shown by the black circle ± 1 standard error of the mean (from Amos-Binks et al. 2010).

Stand dynamics and succession

Differences in the period of release across species and classes were evident. Tree growth in SW-stable and MW-stable stands was gradual up until the 1938-1948 birch dieback. At this time, release of balsam fir and red spruce occurred in SW-stable stands, and release of fir and sugar maple occurred in MW-stable stands. Release in MW-fluctuating, MW-declining and SW-declining stands occurred after the 1910s budworm outbreak and the 1938-1948 birch dieback. This release was made up of mostly sugar maple and yellow birch (62-89%) following the 1910s outbreak, and balsam fir (42-60%) following the birch dieback.



Conclusions and Management Implications

Results suggest that caution should be taken when monitoring mixedwood forest as not all mixedwood stands have the same succession patterns. Differences among the five mixedwood stand development classes resulted from a complex interaction of three disturbance agents (spruce budworm, birch dieback, European spruce sawfly) causing growth reduction and mortality of some tree species, and allowing new cohorts to establish and release. This, in combination with species silvics, led to varying softwood and hardwood composition trajectories. The temporal interactions and legacies resulting from disturbances further complicated the dynamics of mixedwood stands. Changes in species composition that occurred from 1946-1982 likely trace back to between 1914 and 1948, when spruce budworm and European spruce sawfly outbreaks, birch dieback, and age-related mortality in short-lived balsam fir all occurred. The combination of these disturbances led to a period of high species turnover and stand reorganization that lasted for many years.

Mixedwoods can be transitional in nature due to impacts from natural disturbance.

The abundance of balsam fir in all stands and its tendency to establish and release in one main cohort indicates that this species' presence in the canopy is likely cyclical. The cycle is influenced by spruce budworm outbreaks through defoliation-induced mortality and growth loss, and events that allow advanced regeneration to reach the upper canopy. The red spruce component of mixedwood stands differ in that they are less vulnerable to spruce budworm, and also longer lived than balsam fir. This allows red spruce to persist longer, take advantage of multiple disturbance events and maintain their presence in the canopy. It was determined that a significant period of birch dieback played a greater role in the development of mixedwood stands than previously thought. In the absence of birch dieback, changes in species composition would have been exacerbated. Sugar maple's long lived nature and the fact that it was not directly affected by any of the sporadic insect disturbance events allowed it to take advantage of growing space created by mortality of other species.

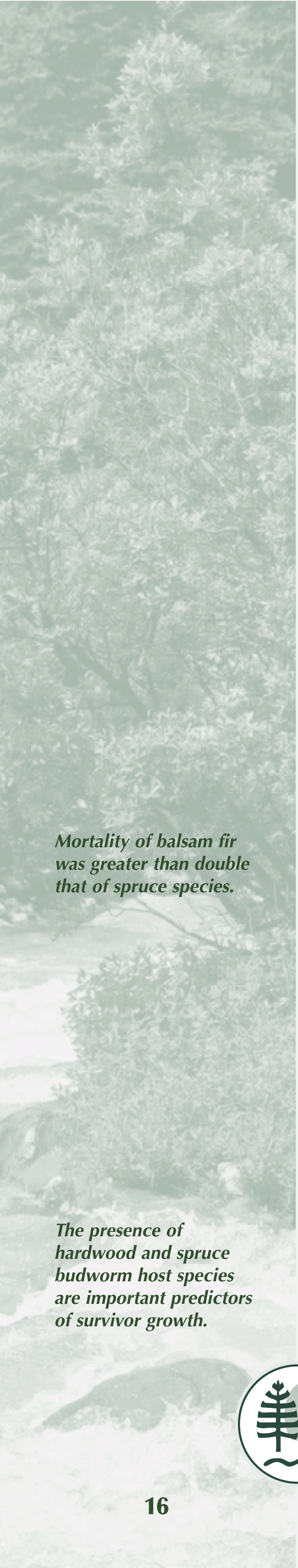
The abundance of balsam fir in mixedwood stands is cyclical and regulated by the spruce budworm.

Given that mixedwood stands are subject to multiple and interacting disturbance agents through time, there are difficulties associated with developing silviculture practices inspired by natural disturbances. Stand dynamics over time have been confounded by the presence of exotic species such as the European spruce sawfly, and the fact that some disturbances are brought on by climate effects (birch dieback). The fact that mixedwood forests can be highly variable in terms of species composition through time, due to variable impacts by disturbances, suggests that managers need to develop new planning techniques. It is likely not sufficient to assume that the current proportions of SW, MW, and HW forest will be maintained over time.

1.2 Effects of spruce budworm on stand dynamics of balsam fir and red spruce mixedwoods – Amanda Colford-Gilks, David A. MacLean, John A. Kershaw Jr. and Martin Béland

Understanding forest dynamics, succession, and habitat relationships under differing levels of silviculture and natural disturbance is the underpinning of forest management planning. Mixedwood stand dynamics (growth and mortality) are strongly influenced by periodic spruce budworm outbreaks that kill spruce and balsam fir but only indirectly affect hardwoods. This can lead to dramatic changes

Species present in mixedwood stands respond differently to spruce budworm outbreaks.



in overstory composition and create canopy openings that lead to a shift in understory species dominance. The presence of multiple species also complicates mixedwood stand dynamics; species respond to site conditions differently and so have dissimilar growth, in-growth and mortality patterns, even in the absence of natural disturbance. A better understanding of mixedwood stand dynamics (mortality, growth and in-growth), and effects of stand structure, ecosite and disturbance is needed to determine the role of these stands in timber production and biodiversity.

The overall goal of the study was to compare the development of balsam fir and spruce mixedwood stands in New Brunswick, and determine the influence that disturbance and stand structure have on these two stand types. No previous studies have directly contrasted the spruce-fir component of the two stand types.

Methods

Provincial permanent sample plots (PSPs), with data collected from 1987 to 2004, were selected based upon the forest unit categories of New Brunswick Department of Natural Resources (NBDNR) (2004) to obtain plots with a range of balsam fir (BF), spruce (SP), and shade tolerant hardwood (TH) content. PSPs were limited to naturally growing, mature and overmature age classes. A total of 154 PSPs, with 35 BF-TH, 50 SP-TH, 31 TH-BF and 38 TH-SP throughout New Brunswick were analyzed. Stand mortality, survivor growth and in-growth were determined for five periods spanning 1987-2004 for the 154 stands. These variables were then related to BF-SP content, past spruce budworm defoliation, TH content (%), and a wide range of stand and site characteristics.

Results

Mortality of balsam fir was greater than double that of spruce species.

As shown in *Figure 6,* strong differences in mortality occurred between the mixedwood stand types, with balsam fir sustaining higher mortality and lower periodic annual increment (PAI where PAI = survivor growth + in-growth - mortality) values. Little in-growth occurred and no substantial survivor growth differences were apparent between the two stand types. Cumulative mortality across the hardwood content range revealed that mortality of balsam fir was more than double that of spruce *(Figure 6).*

Regression analyses determined that variables significantly related to mortality included balsam fir basal area (m^2/ha), total basal area, % hardwood basal area, black spruce *(Picea mariana)* basal area, location (one of three spruce budworm outbreak zones in northern, middle, or southern New Brunswick), forest unit, and depth to water table (m). The final model included four variables to determine amount of mortality: balsam fir basal area, % hardwood basal area, maximum cumulative spruce budworm defoliation from 1973-1977, and location.

The presence of hardwood and spruce budworm host species are important predictors of survivor growth.

An analysis of growth determined that the presence of hardwood and spruce budworm host species (balsam fir and spruce species) at the time of plot establishment were most influential in determining host species survivor growth. Increases in stand hardwood content along with increases in balsam fir (relative to spruce) presence resulted in increased host survivor growth *(Figure 7).*

Conclusions

This study is unique in examining development of a large number of mixedwood stands (66 fir- and 88 spruce-tolerant hardwood) representing a gradient of 12-82% tolerant hardwood content. Results indicated a strong effect of spruce budworm defoliation on host spruce-fir species, even with the known effect of hardwoods in reducing defoliation. Balsam fir-tolerant hardwood plots had 4-5 times higher host post-outbreak cumulative mortality rates (3.7-13.3 m^2/ha) than spruce-tolerant hardwood plots (1.0-2.9 m^2/ha) from 1990-2006. Stands experienced a post-budworm outbreak legacy effect, as blowdown, stem and top breakages were responsible for 46-100% of tree death from 1990-95 in balsam fir-tolerant hardwood stands. Spruce-fir growth rates were similar among balsam fir-tolerant hardwood and spruce-tolerant hardwood plots, at 0.0-0.5 m^2/ha/yr and 0.1-0.5 m^2/ha/yr from 1987-2004, respectively.

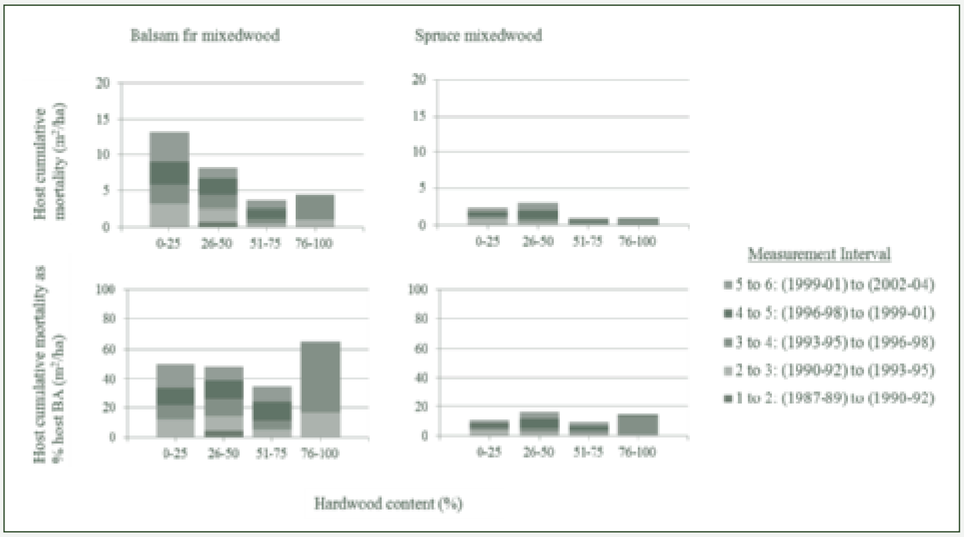


Figure 6. *Cumulative mortality of host species (m^2/ha) by % hardwood content, measurement period (3-5 year periods spanning 1987-2004), and stand type.*

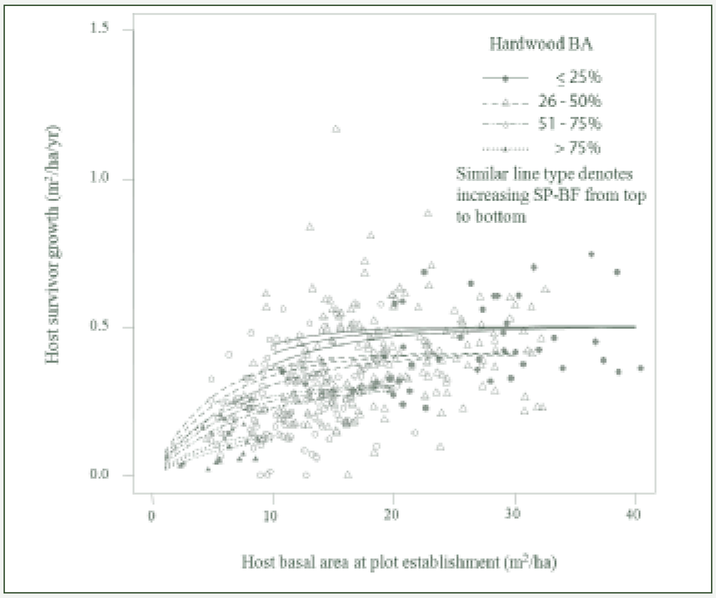


Figure 7. *Spruce budworm host species (i.e., balsam fir-spruce) basal area survivor growth (m^2/ha/yr) as a function of host basal area per hectare, amount of balsam fir relative to spruce, and hardwood class.*

1.3 Shade tolerant hardwood natural regeneration – Bruno Chicoine and Martin Béland

Adequate regeneration must be achieved in order to maintain sustainable resource extraction.

Forest stands must be adequately regenerated in order to provide all the ecological, social and economic benefits to society. As a result, various partial cutting systems (selection, shelterwood, patches, strips) have been used for more than 15 years to regenerate shade tolerant hardwood stands dominated by sugar maple, American beech, and yellow birch on freehold land of J.D. Irving, Limited in northern New Brunswick. However, few studies have looked at the applicability of these treatments from an industrial perspective, and despite the multiple factors influencing regeneration in shade tolerant hardwood stands, there has been no formal monitoring of natural regeneration following hardwood management.

Four partial cutting treatments have been in use for many years in hardwood stands of eastern North America: selection, shelterwood, patch, and strip cutting. Shade tolerance (Burns and Honkala 1990) is commonly recognized as one of the main factors driving the dynamics of forest succession (e.g., Kimmins 1997), and will influence competition for light over time. Because yellow birch is less shade-tolerant than its main competitors (sugar maple and American beech) (Farrar 1995), its probability of mortality is higher with decreased light levels.

The distance of seed dispersion differs between species (Johnson 1988). This may affect regeneration patterns of some species (Ribbens *et al.* 1994), especially sugar maple, because it regenerates only from seed over short distances. Meanwhile, beech regenerates from roots and stumps by sprouting, and yellow birch disperses seeds to such great distances that the density of its regeneration is not related to proximity of the parent tree (Houle 1998). Another factor influencing hardwood regeneration is beech bark disease, which may affect stand dynamics (Houston 2001). In addition, the indirect effect of the disease on regeneration (Hane 2003; Hane *et al.* 2003) hinders development of more commercially desirable species such as sugar maple and yellow birch.

Methods

Sampling of 1065 plots ($1m^2$) in 37 harvested (selection, shelterwood, strips, patches or control) stands allowed a retrospective study. The 37 stands studied were selected to cover the array of silvicultural treatments used in shade tolerant hardwood stands treated during the last 15 years. All stands sampled (except control stands) received partial cutting treatments performed with feller-bunchers and grapple skidders. Selection cuts and shelterwood cuts were performed in the winter to avoid damage to advanced regeneration and to recover maximum value from quality sawlogs. Strip and patch cuts were performed in the summer and fall in stands where beech dominated, in order to maximize soil disturbance and assist regeneration.

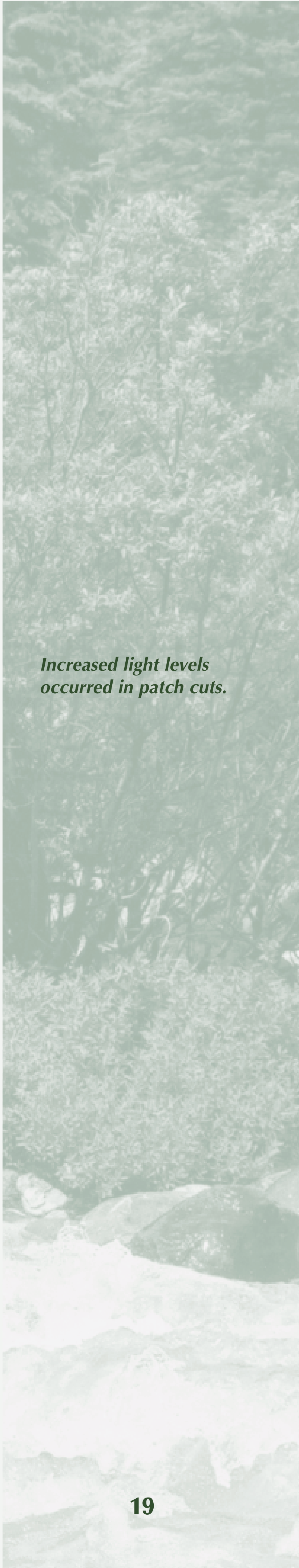
Data reflecting the environmental conditions affecting abundance and distribution of natural regeneration, and recruitment dynamics in hardwood stands of the Black Brook District were collected and analyzed. Data collected included residual composition of sampled stands, regeneration (tallied by species and height class), percentage cover of competing vegetation (herbs, graminoids, shrubs, trees), average height of shrubs and tree regeneration, and thickness of soil organic layer. In addition to the above, other measurements in recently treated stands and in controls, included light interception, distribution of substrates for germination and relative soil moisture.

Data analyses included ANOVAs to compare treatments, with repect to species proportions in the residual stands, densities of seedlings by species, and a variety of environmental variables. Simple linear regressions were performed to explain dependent variables as a function of independent variables at the stand scale, and to identify pertinent co-variables. Multiple regressions were performed, at the plot scale, for 1) seedling abundance as a function of plot level % herb cover, % shrub cover, mean shrub height and thickness of organic matter; and 2) stand-level variables measured in all stands and those only measured in recent cuts and in control plots. Linear regression was used to test the effect of distance to an edge on seedling abundance in patch and strip cuts.

Results

Stand conditions

Environmental conditions were similar among treatments, with a lack of mechanical soil disturbance and competing vegetation control. Less than 5 years after treatment, total proportion of transmitted light reaching the soil was higher in patches (19%) than in control stands (9%).



Increased light levels occurred in patch cuts.

Density in residual stands varied among treatments (*Table 2*). Basal area was lower after shelterwood cutting than after any other treatment. The proportion of yellow birch in residual stands was significantly higher in selection cuts than in patch or strip cuts (*Table 2*).

Table 2. Residual species proportions (%) and total basal area for each treatment, for all age classes combined.

Treatment	**Sugar maple (%)**	**Yellow birch (%)**	**American beech (%)**	**Basal area (m^2/ha)**
Control	58.2	20.0	15.4	18.8
Selection	50.3	30.8	5.5	15.8
Shelterwood	65.1	27.6	16.9	9.6
Patch	49.0	19.2	20.7	19.2
Strip	42.7	18.5	25.8	12.4

Beech regeneration

An age × harvest treatment interaction was significant for the proportion of beech in the residual stand. The largest proportion of beech was observed in patches recently cut, in shelterwood cuts for the second age class (6 to 10 years) and it was largely dominant in strips for the third age class (*Table 3*). Variances were, however, heterogeneous.

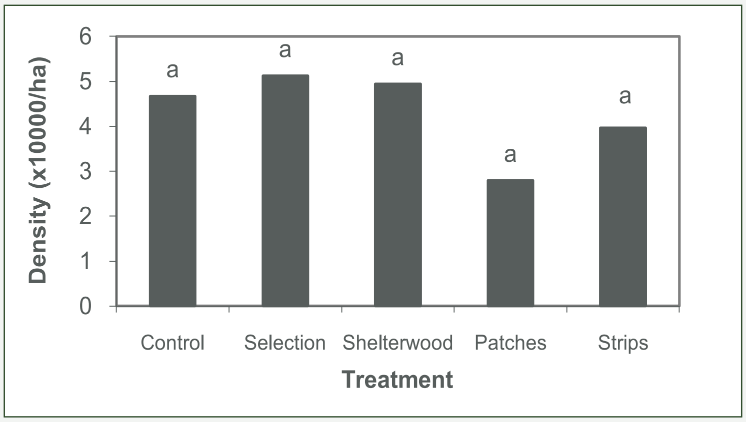
Table 3. Residual proportion (%) of beech in basal area by treatment and age class.

Treatment	**Age class (years)**			
	Control	**1 to 5**	**6 to 10**	**11 to 15**
Control	19.3			
Selection		26.0	12.7	7.0
Shelterwood		19.5	39.5	17.0
Patch		27.3	14.0	
Strip			13.0	45.0

Species have competitive advantages in some stand conditions.

Beech regeneration was more abundant after patch cutting than any other treatment, and yellow birch seedlings were more abundant after shelterwood cutting. Sugar maple regenerated best after selection cutting. Regeneration of commercially desirable species (yellow birch and sugar maple) was relatively good in all treatments, greater than or equal to 40 000 stems/ha, except in patch cuts where it was 28 000 stems/ha (*Figure 8*).

Figure 8. Average density of sugar maple and yellow birch seedlings per ha after various treatments.



Species composition and treatment influence

Initial stand composition influenced regeneration more than harvest method.

Results suggest that initial stand composition influenced regeneration composition more than harvest method. Stand level regressions showed that sugar maple recruitment was positively influenced by its pre-harvest proportion in the stand, and negatively influenced by the presence of both herbaceous and shrub competitors. Yellow birch regeneration, at the stand scale, was mainly affected by shrub layer competition. Plot level analyses demonstrated that availability of substrates such as mineral soil and decayed wood, and transmitted light to ground level, were determining factors for yellow birch regeneration.

Beech is likely to persist in stands due to its ability to reproduce vegetatively.

The study suggests that beech-dominated stands are likely to regenerate to beech. Mechanical harvesting operations stimulate vegetative reproduction of beech and summer harvesting probably enhances production of new suckers, leading to dense beech understories in harvested patches. The high density of beech in the study area is similar to a general shift in the composition happening everywhere in the region, a phenomenon related to sugar maple decline (Duchesne *et al.* 2005).

The results also suggest that different environmental conditions created by the various silvicultural treatments are not substantial enough to influence the species composition of natural regeneration. This is primarily due to high intensity and invasion by competing vegetation. On one hand, selection and shelterwood cuts seemed too intense to restrict regeneration to shade tolerant species and, on the other, competing vegetation decreased light availability after patch cutting.

Indeed, the small residual basal areas after selection (12-15 m^2/ha) and shelterwood (9 m^2/ha) suggest that the partial cutting practices in the study area offer different environmental conditions than usually found after most present-day partial cuts. The cutting intensity in partial cuts is thus possibly higher than in other jurisdictions. The private tenure of the forest land leaves all the latitude for the company to practice silviculture that achieves company goals consistent with the rich soil and high growth rates of this landbase.

Objective 2. Effects of pre-commercial thinning on biodiversity indicators

2.1 Bryophytes in plantations and pre-commercially thinned stands – Amy Witkowski and Kate Frego

In order to maintain native biodiversity within a forest managed for timber extraction, there is a need to understand how organisms respond to forest management. Conservation of native species is most probable under conditions in which forest management activities are similar to natural disturbance events to which these species are adapted. For instance, clearcut harvesting would be considered more intense and spatially extensive, but less frequent, than naturally occurring tree blowdown events. However, the severity (i.e., impact) is likely to vary among species, depending on whether they are more sensitive to disturbance intensity or frequency. Some organisms are naturally resistant to a range of disturbance types (i.e., individuals persist during long low-intensity events) while others emphasize resilience (i.e., they are able to quickly reproduce and re-colonize after a more extensive and devastating event).

Bryophytes play important roles in the forest ecosystem.

Few studies have addressed the impacts of forestry treatments on bryophytes (mosses, liverworts, and hornworts). These relatively tiny (<15cm) non-vascular plants often form thick carpets on forest floors and tree trunks alongside lichens. They play important roles in the forest ecosystem, influencing water and nutrient cycles (Schofield 1985; Longton 1984) and seedling germination (Keizer *et al.* 1985).

Site preparation prior to tree planting is often associated with changes in bryophyte communities.

Bryophytes have been shown to be particularly sensitive to changes in their microclimate (Frisvoll and Presto 1997; Söderström 1988), as well as to direct physical disruption - both of which are associated with forest management. Fenton *et al.* (2003) found significant changes in bryophyte community composition four years after clearcut harvest, especially where substrates were disrupted. With no further disturbance, these bryophyte communities may eventually return to their pre-harvest compositions (Mathieson, unpublished). But if the harvested area is left untreated, natural regeneration often results in tree densities that are either above or below the optimum for growth of high quality timber. One solution is to use plantation forestry to optimize spacing and ensure the supply of target species. Unfortunately, the site preparation treatments preceding planting are associated with the greatest changes in bryophyte communities: increased loss of susceptible species with negligible recolonization by some species (Ross-Davis and Frego 2002).

Natural regeneration followed by thinning may conserve forest floor bryophyte communities.

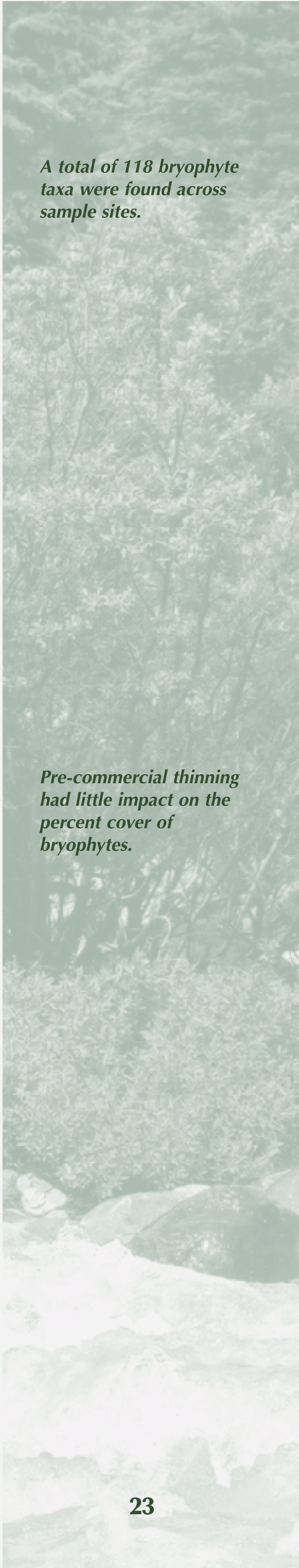
Another management tactic to improve tree spacing is a combination of natural regeneration and thinning. After harvest, the trees are left to regenerate naturally for approximately 15 years, at which point a series of thinning at various intervals occur. The biomass removed during the first thinning is not merchantable (pre-commercial thinning (PCT)). Later thinning extracts merchantable timber, and constitutes commercial thinning. This approach does not involve the high intensity soil disturbance associated with plantations and is expected to avoid severe impacts on forest floor bryophytes. However, it is difficult to predict the response of bryophytes to the higher frequency of disturbance associated with multiple stand entries and repeated changes to the tree canopy.

This study assessed the impacts of PCT on forest floor bryophytes relative to (a) the preceding clearcut harvest, and (b) plantation management in the Acadian forest of southern New Brunswick. This is a companion study to those of La France and Roberts (Section 2.2) and Henderson and Forbes (Section 2.3). These three studies used the same sample stands.

Methods

The study took place in two areas: Coles Island in the Fundy Model Forest, and the Acadia Research Forest in southern New Brunswick. Eighteen stands were deemed comparable based on similarity in five criteria: age, canopy cover, ecosite, soil, and drainage class. In Coles Island, nine experimental stands had been harvested 26 to 37 years previously, and experienced PCT 15 years after harvest. In the Acadia Research Forest, nine reference (unthinned) stands had been harvested 26 to 36 years previously (no untreated stands were available within the same geographical area). Data were collected from May to October in 2005 and 2006. Each stand was sampled using 45 to 50 1m^2 quadrats placed at randomly generated intervals of 20 to 25 m on 4 parallel transects. In total there were 417 quadrats in 9 PCT stands, and 440 quadrats in 9 unthinned stands.

Abundance of each bryophyte species was measured as ground cover, including vertical surfaces up to 1 m from the ground. Specimens of each bryophyte species were collected and the identification of those from the five oldest stands in each treatment were confirmed in the laboratory using Ireland (1982) and Crum and Anderson (1981) for mosses, and Schuster (1966-1992) for liverworts, and were checked against the County checklist of the Mosses of New Brunswick (Bagnell 2002).



Approximately 118 taxa were found within the study area, however, specimens that were difficult to identify to species were collapsed to genus or taxonomic group. This resulted in 83 working taxa, hereafter referred to as “species” for simplicity. Four groupings of species were analyzed in the study:

1) bryophytes - all working taxa,
2) mosses,
3) liverworts, and
4) species of interest.

A total of 118 bryophyte taxa were found across sample sites.

Species of interest were defined as: **a) species of concern in plantations** (all taxa shown by Ross-Davis and Frego (2002) to decline in plantations) and/or **b) species associated only with substrates of concern in plantations** (all taxa shown by Mathieson (2008) to have strong statistical associations with substrates and shown to decline in plantations by Ross-Davis and Frego (2002)).

The data was analyzed to compare PCT and unthinned stands in terms of total % cover of bryophytes in all 18 stands over time. Data for plantations and naturally regenerated (equivalent to unthinned) stands collected by Ross-Davis and Frego (2002) were also analyzed using similar methods for comparative purposes.

Results

Bryophytes - general

There was little difference in % cover of bryophyte communities between PCT and unthinned stands. The total cover of bryophytes (i.e., all species pooled) was highly variable, with no significant difference between treatments detected at the stand or quadrat scales. Stand age did not account for this variability: neither linear regression nor ANCOVA tests detected significant linear trends in bryophyte cover over time between treatments.

Pre-commercial thinning had little impact on the percent cover of bryophytes.

Detrended Correpsondence Analysis of quadrat-level species data reinforced the similarity of species compositions between PCT and unthinned treatments (*Figure 9*). Treatment centroids were very close, and the spread of quadrats from the two treatments overlapped, on the first two axes. The range of quadrat scores on both axes (>4 units) indicated high species turnover among quadrats regardless of treatment, whereas the axis eigenvalues (0.668 and 0.515 for axes 1 and 2, respectively) showed relatively weak pattern capture.

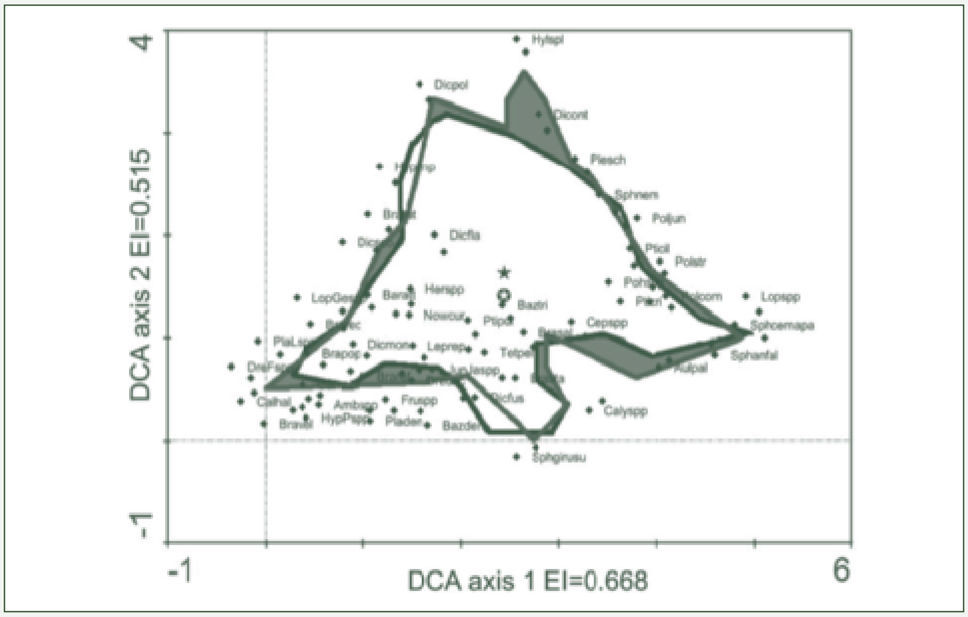


Figure 9. *Scatterplot of species (diamonds) on first two axes of Detrended Correspondence Analysis. * = treatment centroids; outlines show spread of quadrats of unthinned quadrats (open polygon, n=215) and PCT (shaded polygon, n=196). Total inertia = 7.830, EI= eigenvalue for each axis.*

Of the total 83 species, 60 (72%) occurred in both treatments; 16 (19%) were found only in PCT stands and 7 (8%) only in unthinned stands. Jaccard's similarity index was 72.29% at the treatment level, with a mean (±SE) of 68.64% ±0.01% at the stand level. Mosses comprised 67 taxa; 16 were liverworts (no hornworts were found). PCT stands contained 60 moss and 16 liverwort species, while the unthinned stands contained 53 moss and 14 liverwort species. At the treatment level, Jaccard's index indicated 69% and 88% similarity in moss and liverwort composition, respectively.

PCT and unthinned stands had similar ranges and means of species richness, with no significant difference at quadrat or stand scales. Moss richness was significantly higher in PCT quadrats ($p = 0.0378$) but was not significantly different at the stand scale, whereas liverwort richness was not significantly different at either.

Bryophytes – groups of interest

Within the five oldest stands of both treatments combined (10 stands total), 33 taxa (~40%) had less than six occurrences and were considered to be "infrequent." Twenty-four of the infrequent taxa also had an average cover <0.5% and are considered to be "inherently uncommon" in the study area. It was noted that 12 of the 38 taxa in this study classed as "of concern" or "associated with a substrate of concern" in plantations (Ross-Davis and Frego 2002) were found to be "infrequent" or "inherently uncommon." Additional comparisons of these species showed a striking difference in total cover but much less in composition. Overall cover of this group was significantly greater in unthinned than PCT at both stand and quadrat scales. However, species richness was not significantly different at either scale, with high mean Jaccard species similarities of 76.6 ± 1.3 % between unthinned and PCT at the stand scale, and 82.0% at the treatment scale.

Comparison of PCT to plantations

According to Jaccard's index of similarity, plantations were less similar to naturally regenerated stands (59% similarity) than PCT stands were to unthinned stands (72%). This pattern was particularly evident in the liverworts. Of a total of 96 species, 6 were found only in plantations, 33 were found only in naturally regenerated stands, and 57 species were found in both treatments. Similarity of moss and liverwort composition was lower between plantation and naturally regenerated stands than between PCT and unthinned stands (Table 4).

Liverworts were particularly sensitive to plantation forestry.

Table 4. Jaccard's species similarity (%, treatment level) between (a) PCT and unthinned (naturally regenerated) stands (this study), and (b) plantations (PL) and naturally regenerated stands (unplanted) (Ross-Davis and Frego 2002).

Treatments compared	**Moss**	**Liverwort**	**Overall**
(a) PCT vs. unthinned	70%	88%	72%
(b) PL vs. naturally regenerated	60%	50%	59%

Plantations had higher total bryophyte cover and lower species richness than naturally regenerated areas at both the stand and quadrat scales (*Figure 10a*), while those in PCT and unthinned treatments were not significantly different at either scale (*Figure 10b*).

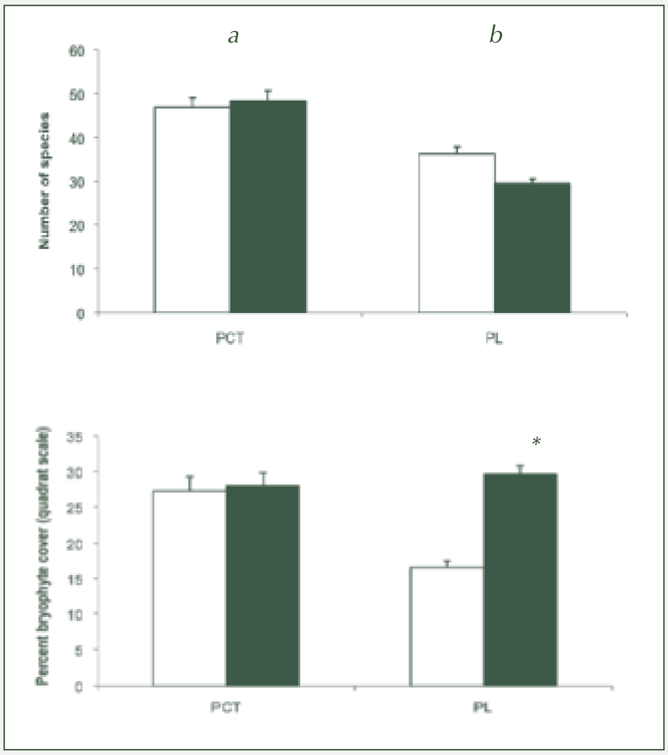
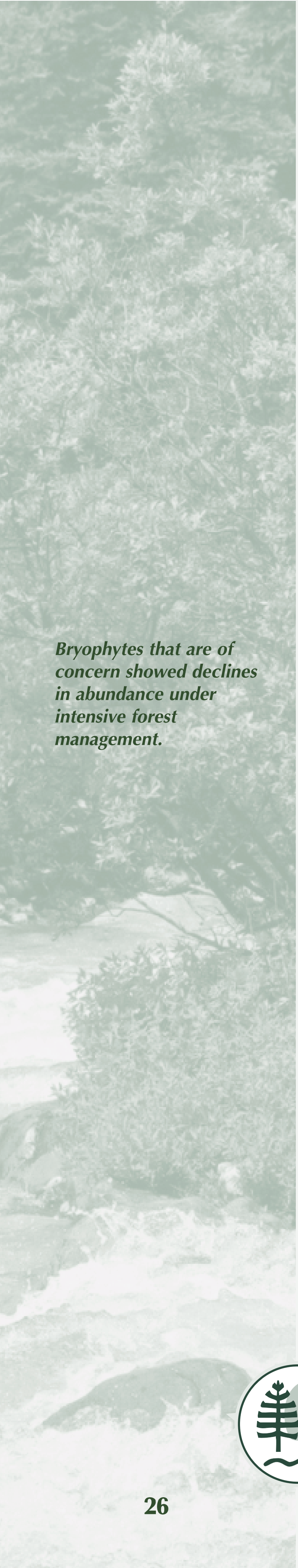


Figure 10. Comparison of treatments mean species richness + SE at the stand scale and mean total bryophyte cover + SE at the quadrat scale (below). Open bars = untreated (unthinned and naturally regenerated), solid bars = treated (pre-commercially thinned (PCT) or plantations (PL)). Plantations differed significantly from naturally regenerated stands (*) in both cover (p=0.0217) and richness (p=0.0374).



Management implications

Forest floor bryophyte composition is diverse and variable

Forest floor bryophytes constitute a rich taxonomic component of Acadian forests in southern New Brunswick, with high variability at a fine scale (i.e., there are numerous species with patchy distribution that varies as much (or more) over a distance of a few meters than among forest stands). A relatively high proportion of species, especially liverworts, are inherently uncommon. This may make them more vulnerable to disturbance, but they occur so infrequently and in such small patches that this is difficult to assess quantitatively.

Most common bryophytes show negligible response to PCT

In terms of conserving biodiversity, bryophyte communities in unthinned stands were similar in composition to those in PCT stands. This suggests that conditions imposed by the PCT treatment may be able to sustain these communities. It is important to note that this analysis only looked at one year's data. As such it is not possible to determine whether populations of species in either treatment are declining, increasing, or being maintained within the habitat provided.

Species of interest, though still present, were lower in abundance.

Bryophyte species that have been shown to decline, or are associated with substrates that decline under intensive forest management, persisted after PCT, however their abundance was significantly lower. This suggests that there are losses throughout the PCT stand, and/or that growth is reduced in PCT stands. Either could be attributed to microclimatic changes following canopy thinning, and either could be serious if these effects are cumulative with subsequent thinning events.

Bryophytes that are of concern showed declines in abundance under intensive forest management.

It is particularly interesting that liverworts showed higher similarity between treatments than did mosses. Liverworts have generally been found to be more sensitive to disturbance than mosses, so it was expected that they would show greater differences. The status of liverworts must still be considered with caution. Differences may have been underestimated as a result of collapsing taxa or of sampling error (the tiny liverworts stand a greater chance of being missed while sampling than the more robust mosses). Liverworts constitute many of the inherently uncommon species for which we lack sufficient data to detect changes. However, it is also possible that the impact on liverworts was principally from the initial harvest.

Overall, bryophytes show less response to PCT than to plantation forestry.

In all variables tested, PCT exhibited greater similarity to clearcut and naturally regenerated stands than did plantations. This indicates that the impact (severity) of disturbance associated with plantations is higher than that associated with PCT. For the single PCT event, the increased frequency of disturbance (one additional canopy thinning) had negligible impact on forest floor bryophytes relative to the increased intensity of disturbance associated with plantation management. However, PCT management strategies may involve a number of thinnings, and impact of frequency of disturbance, in terms of subsequent (commercial) thinnings, remains to be assessed.

Conclusions

PCT appears to have negligible additional impact on forest floor bryophytes beyond that of the initial clearcut harvest. At 37 years post-harvest, PCT also appears to conserve relatively more bryophyte species than plantations.

Bryophytes appear to be less sensitive to pre-commercial thinning than to plantation forestry.

Future studies must examine the bryophyte responses after subsequent commercial thinnings, in order to better evaluate consequences of this strategy. Tracking of permanent plots from before harvest, through the full rotation, would provide more reliable results. The absence of controls (comparable but unmanaged stands) further restricts our ability to assess conservation goals. It is recognized that there will be a blend of silviculture and harvesting treatments across the landscape. For conservation of bryophyte communities, there is value in having areas of natural regeneration managed by PCT.

2.2 The effect of pre-commercial thinning on the abundance of herbaceous species – Kerienne La France and Mark R. Roberts

Pre-commercial thinning is an intermediate treatment used in naturally regenerating stands following harvest and is usually applied when trees are young, before canopy closure occurs. PCT has become an important tool in wood production and is widely applied across the Maritime Provinces. In addition to wood production, forest managers have become increasingly concerned with maintaining biodiversity in managed stands. Thus, it is important to understand impacts of PCT on other ecosystem components.

The herbaceous layer refers to all vascular herbs and shrubs less than 1 m in height. The herbaceous layer is of particular interest because it plays a significant role in ecosystem processes and is composed of a greater variety of species and life-history traits than overstory trees. This diversity makes the response of this group of species to disturbance more difficult to predict. The objectives of this study were to:

The herbaceous layer contains a high diversity of species and life history traits.

1) identify differences in stand structure and microsite environmental features between PCT and unthinned stands;

2) document changes in stand structure and microsite features over time in PCT and unthinned stands; and

3) determine the initial impact of PCT on herbaceous species and the long-term influence on species composition.

Methods

Study sites were the same as those used by Witkowski and Frego (Section 2.1). Stand-level characteristics that were assessed included coarse woody debris (CWD) volume, tree density, species, diameter, height, fine-scale environmental conditions (slash, substrates, and ground disturbance), ground cover and canopy cover for each stand. Individual species data were used to calculate several measures of species diversity including species richness, evenness, Shannon-Wiener diversity index, and Simpson's index of diversity.

Results

Stand-level environmental variables

Total softwood stem density was initially significantly higher in unthinned sites than in PCT sites, because stems are removed during the thinning operation. This trend is supported by the stand-level Principal Components Analysis (PCA) which showed unthinned sites being more closely associated with increasing softwood density, while PCT sites were associated with decreasing softwood density (*Figure 11*).

PCT resulted in different stand structure characteristics.

Stump density was expected to be significantly higher in PCT than in unthinned sites; however, regression analysis revealed that stump density was initially the same between the two treatments, and significantly higher in mid-aged PCT sites. There were significantly more snags in unthinned sites than in PCT sites, most likely due to high inter-tree competition and subsequent tree mortality. The stand-level PCA showed a similar pattern, with control sites being more closely associated with snag density than PCT sites (*Figure 11*).

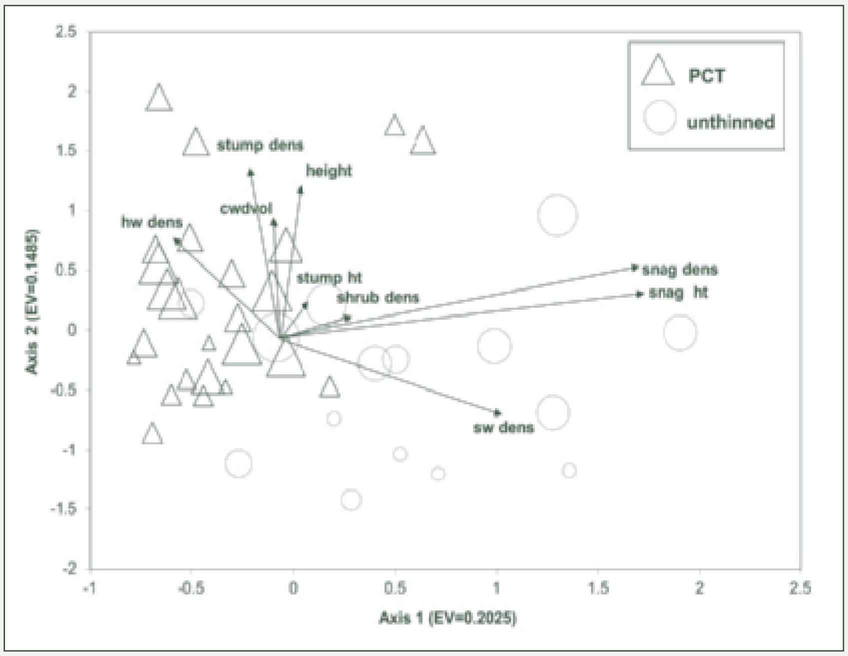


Figure 11. Principal Components Analysis (PCA) of stand-level environmental variables and sample centroids. Symbol size corresponds to stand age; smaller symbols represent younger stands while larger symbols represent older stands.

Fine-scale environmental variables

Slash cover was consistently higher in PCT sites than in unthinned controls, which was expected since cut stems are left on site during the treatment. This observation is supported by the fine-scale environmental PCA (not shown), which showed that most unthinned sites were associated with decreasing slash/CWD cover. While there was more slash in PCT sites, slash height was similar between the two treatments, suggesting that slash was more or less evenly distributed throughout the stands.

Hardwood litter was initially higher in PCT stands than in unthinned stands but then decreased to be lower in unthinned stands over time. This may be due to a decrease in hardwood density (at the stand level) or hardwood canopy cover; however, density and canopy cover did not differ significantly between treatments due to high variation among sample sites.

The fine-scale environmental analysis showed that older sites were associated with an increase in softwood litter and softwood canopy cover in both treatments. Conversely, younger sites were associated with decreasing softwood canopy cover and increasing hardwood litter.

Individual species and diversity

The cover of some species (wild sarsaparilla, lily of the valley, and starflower) was higher in PCT sites compared to unthinned sites; however, these differences in percent cover were very small, less than 1%. While this was statistically significant, a difference of less than 1% cover of relatively common species may not be ecologically significant when considered at the landscape level, which is the scale used in most forest management activities.

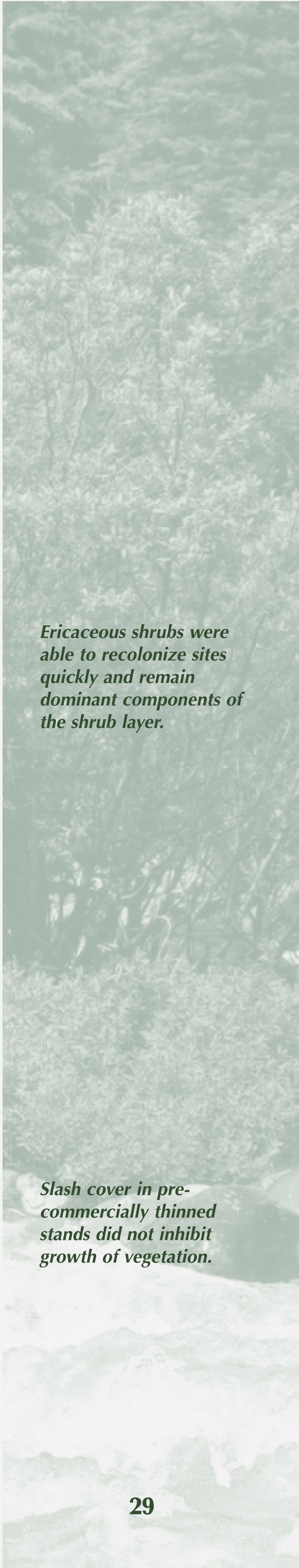
Several species, including sheep-laurel, low sweet blueberry, velvet-leaf blueberry and wild raisin, were not significantly different between treatments, but showed a significant decline in % cover over time. These species are mostly ericaceous shrubs that likely established soon after the clearcut harvest. The ability of these species to quickly colonize a site has allowed them to remain dominant components of the understory in young, regenerating sites. They do however decrease in cover over time as canopy closure occurs and available light decreases. There were no significant differences between treatments or over time for any of the diversity measures except Shannon-Weiner diversity. It showed that diversity was higher in young and old PCT stands compared to unthinned stands, and was lower in mid-aged PCT stands.

Associations between fine-scale environmental variables and species composition

The analysis showed that some species (mainly ericaceous shrubs) were associated with decreasing canopy cover and younger sites. Meanwhile, other species (mainly forest herbs) were associated with increasing canopy cover and older sites, regardless of treatment. Slash/CWD cover seemed to account for some of the differences between young PCT and control sites, supporting the results of the regression analyses.

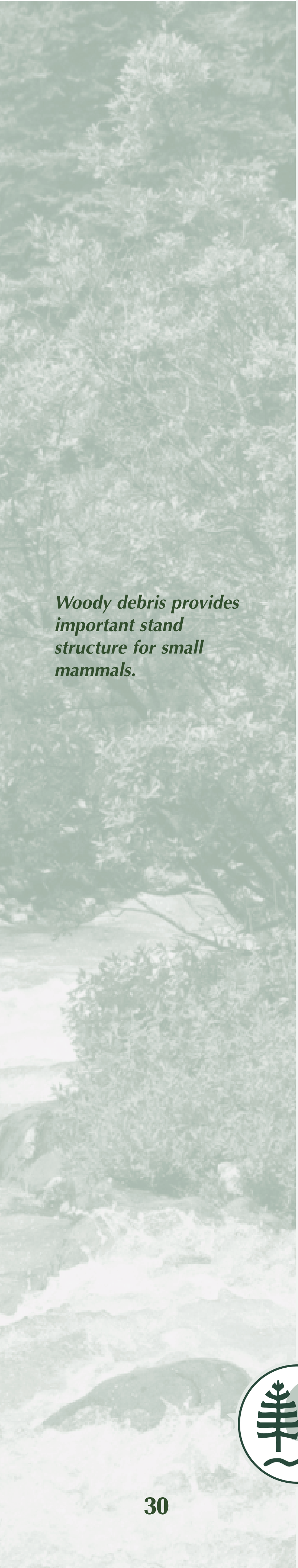
Conclusions and Recommendations

PCT sites differ from unthinned sites in that they initially have lower stem density (softwood density in particular) and fewer snags per hectare (reduced tree mortality). At the quadrat level, the environmental condition that characterizes PCT stands best is increased slash cover, which is expected since cut stems are left on the site following treatment. In this study, slash height in PCT sites was comparable to that of unthinned controls and did not appear to inhibit growth of vegetation in PCT sites. Therefore, managers may consider distributing slash evenly throughout PCT stands to avoid large slash piles that may potentially inhibit germination of some species.



Ericaceous shrubs were able to recolonize sites quickly and remain dominant components of the shrub layer.

Slash cover in pre-commercially thinned stands did not inhibit growth of vegetation.



Despite differences in some environmental conditions between PCT and unthinned stands, regression analyses of individual species and ordinations did not provide any compelling evidence to suggest that the initial or long-term patterns of species composition were significantly different between the two treatments. Changes in species composition appear to be more closely associated with increasing stand age rather than treatment, suggesting that effects of PCT on herbaceous species do not exceed the range of natural variability found in these study areas.

2.3 The effect of pre-commercial thinning on the abundance of small mammals – Julie Henderson and Graham J. Forbes

Pre-commercial thinning is a silvicultural treatment used to increase growth of desired tree species and enhance timber production. While the response of crop trees to PCT is fairly well known, there has been little study of the influence of PCT on other habitat characteristics and the response of wildlife, both short and long term.

Woody debris provides important stand structure for small mammals.

Since the thinned trees have limited merchantable value they are typically left on site. This temporarily increases the amount of small and intermediate diameter woody debris (microdebris) on the forest floor. Downed woody debris is important to small mammals because it can provide protective cover, travel ways, nesting and burrowing sites, moist microclimates and food in the form of fungi, plants, and invertebrates (Carey and Johnson 1995; Loeb 1999; Fuller *et al.* 2004). Much research on the contribution of CWD has been published but our understanding of the role of microdebris is limited. Although individual pieces offer minor cover, piles of slash remaining after PCT may create a significant source of protective cover for small mammals, at least for several years after treatment.

The purpose of this study was to examine the long-term response of small mammals to PCT. Our objectives were:

1) to determine if PCT influenced abundance of small mammals 5, 10, and 20 years after treatment; and

2) to examine relationships between habitat components and small mammal abundance.

Methods

The study was conducted in the same sample plots described by Witkowski and Frego (Section 2.1, this report). Study sites were classified as ecosite 2, characterized by moist soil, and dominated by softwood trees - typically black spruce (NBDNR 2003). Sites also had lesser components of balsam fir, white pine (*Pinus strobus*), red maple, white birch (*Betula papyrifera*) and speckled alder (*Alnus incana*). A chronosequence of age categories was used in the study design to allow observation of longer-term effects within the time frame of a short-term study. We sampled 27 PCT treatment stands (either 5 years, 10 years, or 20 years after treatment) and 18 unthinned control stands.

The relative abundance of small mammals in each site was surveyed using 16 Sherman (H. B. Sherman Inc., Tallahassee, FL) live traps and 16 pitfall traps, spaced at 20m intervals along one 300m transect. Traps were set for seven consecutive nights in each site. Captured animals were weighed, identified to species and gender and marked before being released at the trap site. Abundance was expressed as number of individuals captured per 100 trap nights (1 trap night = 1 trap left open for one 24-hour period), correcting for sprung traps and number of captures (Nelson and Clark 1973). Two-way ANOVA ($\alpha = 0.05$) tests were used to determine if abundance differed significantly between treatments (thinned vs. unthinned) and age classes (5, 10 and 20 years) for each species.

Results

During summers 2005 and 2006, 807 masked shrews, 260 red-backed voles, 96 deer mice, 87 pygmy shrews, 54 smoky shrews, and 21 maritime shrews were captured. The abundance of red-backed voles was significantly higher in unthinned stands than in PCT stands. Red-backed voles were also influenced by stand age and were more abundant in stands 10 years post-treatment than 5 and 20 years post-treatment.

Red-backed voles were more abundant in unthinned stands.

Abundance of smoky shrews was significantly higher in unthinned stands than in PCT stands (*Table 5*). Abundance of deer mice was over 3 times higher in stands 10 and 20 years post-treatment than in stands 5 years post-treatment. Abundance of pygmy shrews in stands 5 years post-treatment was significantly higher than in stands 20 years post-treatment (*Table 5*). Maritime shrews were 9 times more abundant in stands 5 years post=treatment than those 10 years post-treatment. There were no maritime shrews captured in stands 20 years post-treatment (*Table 5*).

Table 5. *Comparison of mean (S.E.) abundances of small mammals in pre-commercially thinned (n=27) and similar unthinned control stands (n=18), at 5 years (n=15), 10 years (n=16) and 20 years (n=14) after treatment. Significant differences among PCT vs. unthinned or among age classes are shown in bold font.*

	Species of small mammal					
	Red-backed vole	Deer mouse	Masked shrew	Pygmy shrew	Smoky shrew	Maritime shrew
Treatment						
PCT	**4.00 (0.63)**	2.15 (0.47)	7.48 (1.09)	0.96 (0.16)	**0.26 (0.13)**	0.22 (0.12)
Unthinned	**7.11 (1.09)**	2.11 (0.61)	8.72 (1.17)	0.83 (0.15)	**1.11 (0.46)**	0.33 (0.14)
Years since treatment						
5 years	**4.47 (0.78)**	**0.87 (0.35)**	9.07 (1.09)	**1.27 (0.20)**	0.40 (0.21)	**0.67 (0.23)**
10 years	**7.19 (1.13)**	**2.75 (0.75)**	9.19 (1.64)	**0.81 (0.21)**	0.75 (0.45)	**0.13 (0.09)**
20 years	**3.86 (1.09)**	**2.79 (0.64)**	5.43 (1.12)	**0.64 (0.13)**	0.64 (0.37)	**0.00 (0.00)**

Species abundance

PCT negatively affected the abundance of red-backed voles and smoky shrews but had no significant influence on abundance of deer mice, masked shrews, pygmy shrews and maritime shrews. Abundance of red-backed voles was 1.8 times higher in unthinned control stands than PCT stands in our study area from 5-20 years after treatment. This finding is consistent with results from Quebec (Etcheverry *et al.* 2005) but contradicts results from Maine where thinning resulted in increased abundances of red-backed voles (Homyack *et al.* 2005).

Red-backed vole abundance was also influenced by age class, with the highest abundance in stands 10 years post-treatment. Deer mice were not influenced by thinning but showed a positive response to stand development, with lowest abundance in stands 5 years post-treatment. In Maine, the abundance of deer mice was similar among PCT and unthinned stands and showed a positive response to stand development (Homyack *et al.* 2005).

In this study, abundance of deer mice was positively associated with hardwood canopy closure and negatively associated with herbaceous plant cover below 1 m in height. The amount of herbaceous cover decreased with age in both thinned and unthinned stands. Deer mice have been reported to be more abundant in stands with lesser vegetation cover (Miller and Getz 1977). Amount of hardwood canopy cover did not differ significantly between thinned and unthinned stands or between age classes, which suggests that amount of hardwood trees in the regenerating study sites was sufficient to benefit deer mice populations.

Masked shrews were the most abundant species captured within the study area and were present in 44 of the 45 sampled sites. PCT had no significant effect on abundance of masked shrews from 5 to 20 years after treatment. In Maine, Homyack *et al.* (2005) found that in stands previously treated with herbicide, PCT increased the relative abundance of masked shrews from 1 to 11 yrs after treatment. Herbicide can have lasting effects on composition and structure of stands (MacLean and Morgan 1983), therefore, discrepancies between this study and results from Maine may be due to the influence of herbicide application prior to thinning.

Pygmy shrews were not influenced by thinning but showed decreasing abundance as the stand aged. For smoky shrews, however, we found that abundance was 4 times higher in unthinned stands than in PCT stands. Maritime shrews were not influenced by PCT but we detected differences in abundance between age classes. Abundance was higher in stands 5 years post-treatment than in those 10 years post-treatment, and no maritime shrews were captured in stands 20 years post-treatment.

The collection of 21 maritime shrews is noteworthy because this species is thought to be associated with wetlands and therefore restricted to moist grasslands and bogs (Perry *et al.* 2004). The locations of collected maritime shrews in this study may extend the range currently known for this species.

Stand structure

The microdebris left from thinning was expected to benefit small mammals in the short term after PCT as it would provide a source of protective cover. We did not observe higher abundance in stands shortly after PCT stands compared to unthinned stands. Nor did we find any associations between small mammals and microdebris. It is possible that the reduction of canopy cover in PCT stands outweighs any perceived benefit from microdebris cover.

Although red-backed voles were less abundant in PCT sites, voles were still present in 22 of the 27 PCT stands sampled. Unfortunately we were unable to produce predictive models for smoky shrews, possibly due to the rarity of this species or because variables important to this species were not measured. We recommend future work exploring relationships between smoky shrews and habitat variables in order to gain a better understanding of the influence of pre-commercial thinning on this species. Further investigation of existence of maritime shrews outside of wetland habitats is also worthy of future study.

The impact of the reduced canopy cover following PCT may outweigh the benefits of increased microdebris.

Objective 3. Key stand structures and abundance of biodiversity indicators of plantations, and mixedwood stands

3.1 Abundance, age, body mass and spatial distribution of American marten in an industrial forest of northwestern New Brunswick – Pascale Forget and Claude Samson

Intensive silviculture can improve forest productivity and fibre yields, providing important economic and social benefits. However, this management approach can cause significant ecological impacts on forest ecosystems. Intensive silvicultural practices usually simplify forest structures by reducing the prevalence of dead wood in managed stands, providing an even age structure of trees, and reducing tree species diversity. Over the long-term and at larger scales, intensive management may also reduce the prevalence of old coniferous forest.

Figure 12. American marten were live trapped in four different study sites, to determine abundance using the capture-mark-recapture method.

Pine marten is an old coniferous forest associate but plantations can contain the stand structure they need.

In Canada, some species, like the American marten, may be particularly vulnerable to intensive management if they are generally associated with old coniferous forests. Old forests are generally recognized as optimal habitat for marten, as marten prefer high and dense coniferous cover for hunting, and a large amount of dead wood for reproduction and resting. However, marten are also found in other forest types, mainly forests with complex horizontal and vertical structures. In fact, Payer and Harrison (2003) proposed that most marten habitat requirements would be met in stands with a mean tree cover height ≥9 m, live-tree basal area ≥18m^2/ha and a volume of large snags ≥10 m^3/ha.

While marten are known to inhabit industrial forest in New Brunswick where intensive management has occurred since the 1950s, uncertainty remains regarding the contribution of plantations to their habitat. Previous studies (Laurion 2005; Pelletier 2005; Villeneuve 2007) showed that coniferous plantations ≥20 years old usually reach the minimal tree cover, height, and live-tree basal area needed by marten, but were usually lacking dead wood. Given this information we tested three main hypotheses:

1) That marten distribution can be predicted by the prevalence of mature natural stands, and perhaps by the prevalence of plantations ≥20 years old,

2) That habitat quality of landscapes for marten is influenced by the age and proportion of plantations present in those landscapes (based on previous knowledge that stands containing a large amount of dead wood are needed to complete their life-cycle), and

3) That relative abundance of marten, age structure and mean body mass of marten is higher in managed landscapes where plantations were ≥20 years old and interspersed with a substantial proportion of natural stands.

Methods

The study was conducted in the Black Brook District in northwestern New Brunswick. Four different sites were studied (*Table 6*), characterized by the age and proportion of plantations present in the landscape. Tree composition of plantations was mainly white and black spruce, with some Norway and red spruce plantations. Balsam fir and trembling aspen were naturally present in various proportions. Commercial thinning usually occurs when plantations are 25 years old and continues every 10-15 years, until the stand matures at 55-75 years old. Even after thinning, plantations ≥20 years old have tree cover height ≥9 m, basal area ≥18m^2/ha, and winter crown closure ≥50%. However, abundance of woody debris and snags are generally low in these plantations compared to natural stands (respectively <10 m^3/ha and <5 m^3/ha in plantations, compared to >25m^3/ha and >35 m^3/ha in natural stands (Laurion 2005)).

We sampled marten abundance in the four study sites, using the capture-mark-recapture method. Marten were captured, anaesthetized, sexed, aged, and weighed. Five to ten adult marten were fitted with a radio-collar every year and located at least once a month by telemetry. From telemetry data, annual survival rates were determined. Fur snagging was also used to determine marten distribution in winter, using modified squirrel live traps.

Table 6. Stand composition in the four different study sites.

	% of the surface area[a]				
Study sites	Deciduous stands	Mixed stands	Coniferous stands	Plantations	Age of most plantations
Skin Gulch	11	22	10	53	≥30 years old
Jardine	1	8	8	78	20-30 years old
Clair Brook	32	14	11	38	0-10 years old
Castonguay	7	14	11	58	10-20 years old

[a] Surface areas established from 400 m buffers around trap sites

Simple repeated-measures ANOVA was used to compare relative abundance of marten between sites and factorial ANOVA was used to compare mean body mass of marten in relation to age. To characterize trap sites, we derived habitat information using GIS data from J.D. Irving, Limited. We established 400 m buffers around every trap site, and determined the proportion of area covered by natural stands and by plantations in two age classes (<20 years old or ≥20 years old). Logistic regressions were used to compare habitat characteristics of used vs. unused trap sites, and linear regressions were used to compare trapping success and proportion of area covered by natural stands.

Results

Marten demographics

Between 2001 and 2006, 119 different marten were live trapped in autumn, in 172 different trap sites, during 4612.5 trap nights. Relative abundance varied between 0 and 8.9 martens/100 trap nights in the four different study sites (*Figure 13*).

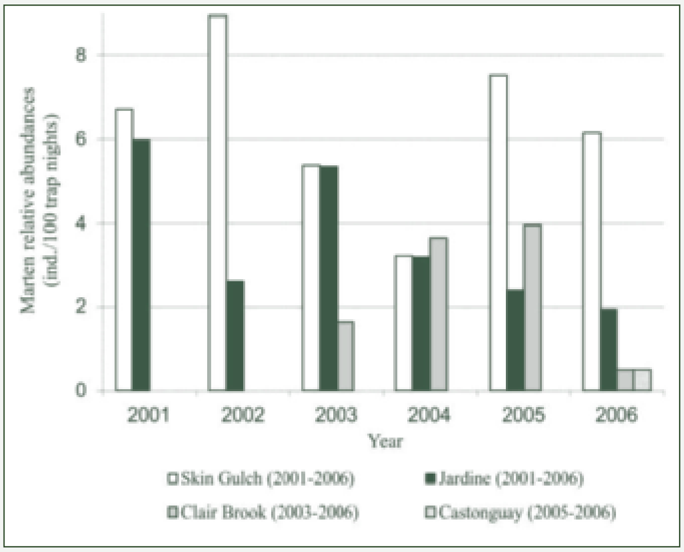


Figure 13. Relative abundance of marten in an industrial forest of northwestern New Brunswick.

Mean ages of resident (≥1.5 year old) marten were similar to those reported in other managed forests, but lower than in unmanaged forests (males 2.3±0.2 years, n = 31; females 2.6±0.3 years, n = 19). A total of 29 marten were fitted with radio-collars and tracked between 2002 and 2004. Annual survival rates of marten varied between 0.23 and 1.0 in two different study sites and were not different between sites. Body mass of males was systematically heavier in the Skin Gulch site (53% ≥30 year old plantations), compared to the Jardine site (78% 20-30 year old plantations) (*Figure 14*).

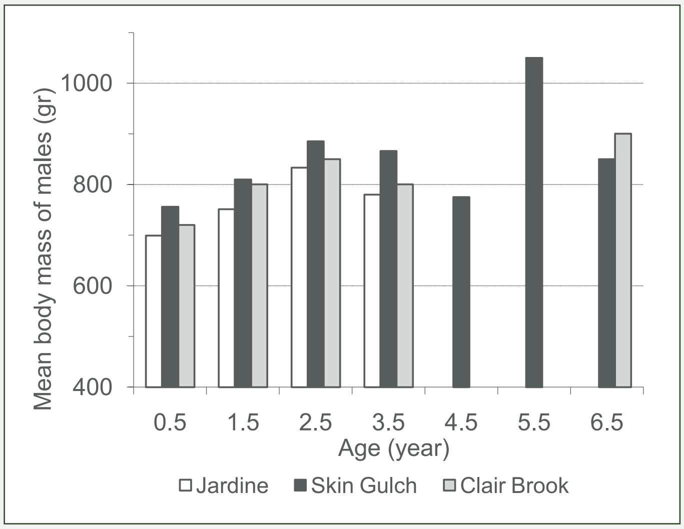


Figure 14. Mean body mass of male marten in relation to age in the three principal study sites, Jardine, Skin Gulch and Clair Brook.

In the study area, proportions of used trap sites were 91% in Skin Gulch, 61% in Jardine, 30% in Clair Brook, and 2.5% in Castonguay. In Skin Gulch, 34% of captures were located in natural stands, compared to 68% in Jardine, while 43% of the trap sites were in natural stands for both sites.

Although coarse woody debris may be lacking in managed stands, marten are able to utilize structure in nearby stands.

Habitat use

Considering the spatial distribution of marten in the study area, logistic regression showed that both proportion of plantations ≥20 years old, and proportion of natural stands around trap sites positively predicted marten occurrence. Surprisingly, trapping success of marten was positively associated with proportion of natural stands surrounding trap sites in the Jardine landscape (covered with 78% plantations ≥20 years old). Meanwhile trapping success was negatively associated with proportion of natural stands surrounding trap sites in the landscape with 53% coverage of plantations ≥20 years old (Skin Gulch).

These results suggest that in an industrial forest where natural stands would be mainly deciduous and mixed stands, and consequently, plantations would be the main coniferous cover available, marten would prefer a combination of both cover types in their spatial distribution, even if the amount of dead wood is limited in plantations.

Conclusions and Management Implications

In the study area, the two landscapes covered with ≥20 year old plantations supported relatively abundant populations of martens. Regression analysis revealed that old plantations and mature natural stands were positively related to marten distribution. However, marten were more abundant and males were older and had heavier body mass in the landscape with 53% plantations ≥30 years old, compared to the landscape where plantations were younger and covered a higher proportion of the landscape.

Landscapes dominated by plantations 20 years or older can support populations of pine marten but mature natural stands are an important source of dead wood for this species.

Despite a relatively low sample size, plantations ≥20 years old can contribute to presence and maintenance of American marten in managed forests of northwestern New Brunswick. These plantations provide high and dense coniferous cover for marten and a relatively high abundance of hares and squirrels. However, we strongly recommend retention of mature natural stands interspersed with plantations on >20% of the landscape, in order to provide a large amount of dead wood for martens.

Intensive silviculture has occurred in the study area for about 50 years, and we were able to investigate impacts of these practices on marten habitat over this time period. Longer-term effects of repeated silvicultural practices on the American marten, and at larger scales, remain to be assessed.

3.2 Viability of northern flying squirrel in relation to landscape-scale forest management – Matthew Smith, Graham J. Forbes and Matthew G. Betts

The amount of mature forest in New Brunswick has declined by 1% per year since 1970 (Betts *et al.* 2007). Increased harvest intensity on remaining mature forests, with recommendations to decrease conservation targets on public land from 30% to 20% (Self Sufficiency Task Force 2007), could lead to increased isolation of mature forest, smaller patches of mature forest, reduced structural complexity, and a decline in amount of mature forest on the landbase to 12% (Erdle and Sullivan 1998).

Mature forest is declining and becoming increasingly fragmented, which could have negative effects on flying squirrel populations.

The northern flying squirrel is often cited as a mature forest specialist (Gerrow 1996; Carey 2000; Vernes *et al.* 2004; Ritchie 2006; Holloway 2006) that is sensitive to forest fragmentation due to its arboreal nature, preference for gliding as a means of locomotion, and relatively large territories (male:12.5 ha (Gerrow 1996)). Throughout their range in North America, flying squirrels have been selected as indicators of sustainable forest management (McLaren *et al.* 1998; Carey 2000; NBDNR 2000). Despite the suggestion that northern flying squirrels are sensitive to mature forest loss and fragmentation, there has been little research on the effects of fragmentation on flying squirrel survival, fecundity, and movement.

To study effects of fragmentation on survival, we conducted a mark-recapture study over 4 years (2005-2008). We predicted that flying squirrel density, survival and fecundity would be lower in landscapes with lower amounts of mature forest due to barriers to movement and dispersal. To understand the impacts of fragmentation on reproduction, we counted total number of young in fragmented and contiguous sites. Final survival and fecundity parameters are not yet complete.

Translocation was used to determine if non-mature forest is limiting flying squirrel movement.

The second goal of this study was to determine if non-mature forest (<60 years) restricted flying squirrel movement between mature habitat patches. This was studied in two ways. First we followed nightly movements of flying squirrels in small and large patches and estimated home range sizes. We predicted that squirrels in small patches would have smaller home range sizes compared to squirrels in larger patches. Secondly, we conducted homing trials where flying squirrels were moved across varying distances and levels of fragmentation. During short translocations, flying squirrels were tracked continuously to observe movements in relation to mature forest corridors and clearcuts. We predicted that flying squirrels would be less likely to return home and take longer to return home in fragmented landscapes. Only a preliminary analysis of the movement data will be presented in this report.

Methods

This study was conducted in the Greater Fundy Ecosystem (GFE) in southern New Brunswick (*Figure 15*). Fundy National Park is located in the centre of the GFE and covers 207 km^2. The surrounding landscape is intensively managed by industrial forestry (provincial and private ownership) and is a mosaic of clearcuts, plantations, and mature forest patches. The amount of mature forest on the landscape ranges from 20%-90% with a mean of 40%.

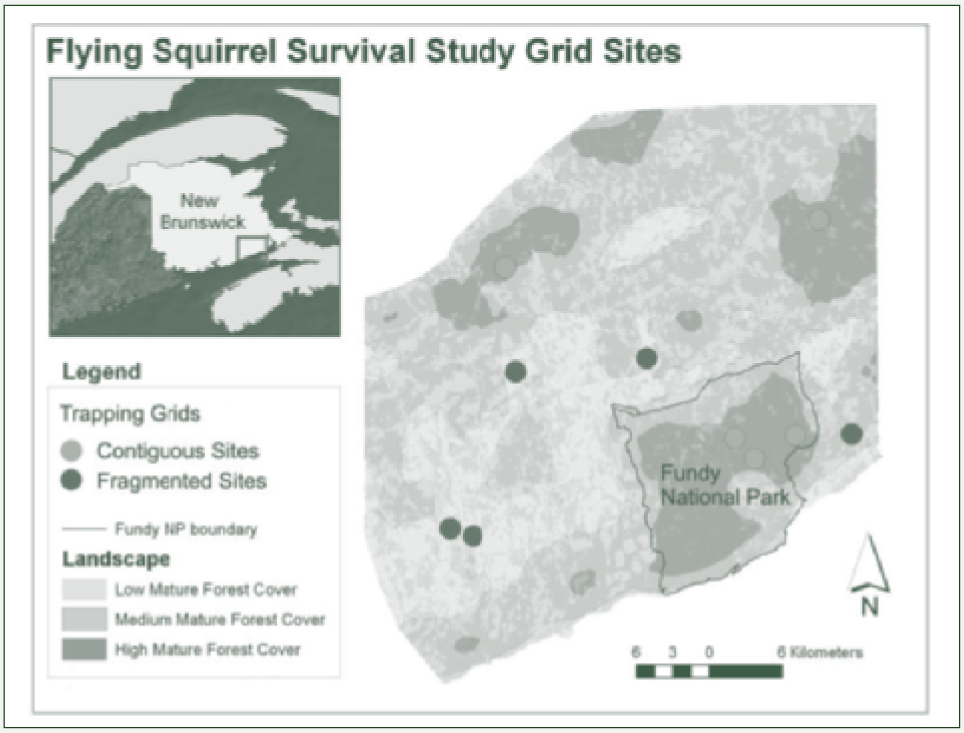


Figure 15. Location of survival grids 2006-2007.

The landscape was classified according to the amount of mature forest habitat in a 2 km radius (the median dispersal distance of a flying squirrel) and recorded as low, medium or high cover (*Figure 15*). In the low and high cover landscapes, potential sites for the trapping grids were identified from forest inventory maps and air photos. From the list of potential sites, several sites were picked at random to establish permanent sample grids. We established trapping grids as recommended by Carey *et al.* (1999).

Traps were set at 40 m intervals. Each flying squirrel captured was ear tagged, sexed, and placed in one of three age classes (adult, sub-adult, or juvenile) based on weight, colour, and evidence of sexual activity (e.g., enlarged teats). Abundance was estimated for each trapping grid and landscape using the Lincoln-Petersen (LP) index and a simple index of true abundance based on the number of individuals captured/100 trap nights (corrected for closed traps and captures of non-target species). The effective trapping area was determined using maximum home range dimension derived from the minimum convex polygon (Bondrup-Nielson 1983).

Survival was estimated between trapping sessions using Cormack-Jolly Seber (Cormack 1964; Seber 1982) and robust design (Kendall *et al.* 1995) within Program Mark (Couch and White 2006). Robust design uses the secondary and primary trapping sessions to estimate capture probability and survival. Temporary emigration of animals (animals that are temporarily unavailable for capture) can also be estimated using robust design.

In small and large forest patches, 30 flying squirrels were fitted with radio collars and home range was estimated from nest sites and night movement location data, collected using the ‘homing technique’, where technicians would track flying squirrels from a distance of 20-50 m and mark observed locations with a GPS. During times when the flying squirrel could not be followed closely, locations and error ellipses were estimated by triangulation and individual home range size was calculated.

A total of 75 individuals were displaced from their home range to investigate ability of flying squirrels to move through contiguous and fragmented landscapes. These data were combined with 44 experimental trials conducted using similar methods (Bourgeois 1997). Only adults and non-lactating females were moved. After initial capture we tracked the individual for a few days to roughly estimate home range. Then the individual was recaptured, held until after dark with food and water, and then displaced from its home range from a predetermined distance (180-4000 m). For the first two weeks, we located the individual daily to determine if the flying squirrel had returned home. Subsequently the flying squirrel was tracked 3-7 days a week until the end of the study.

A subset of experimental trials was conducted across young clearcuts (< 10 years). In all cases, flying squirrels were released in mature forest with a forested detour route back to their home range. For short distance trials, flying squirrels were tracked continuously by triangulation (3 stations) to record which route was selected to return home.

Results

Survival and fecundity

Trapping success in the low cover landscape was greater than in the high cover landscape.

During 28,856 trap nights a total of 438 individual flying squirrels were captured 1,482 times. Capture success was highly variable between plot and year. Within-session capture success for an individual plot ranged from 0 to 21.9 individuals /100 traps. Mean capture probability was 20% over the 4 years of the study. The overall capture mortality rate was 4.5%. The sex ratio of captured squirrels was relatively even with 174 females captured to 181 males and was not significantly different in any of the 4 years. The total number of individual captures (corrected for closed traps and non-target species) was higher for the low cover landscape compared with the high cover landscape (*Table 7*). Flying squirrel abundance estimated using the Lincoln-Peterson and Robust Design estimators gave similar estimated abundances (highly correlated) and showed large annual changes over the 4 year period.

Table 7. Total number of individual captures/100 traps (corrected) for two landscape types in southern New Brunswick, 2005-2008.

Landscape Type	2005	2006	2007	2008	Mean
Low cover landscape	2.1	2.8	3.7	3.3	2.4
High cover landscape	1.6	2.1	3.1	2.7	1.9
Mean	1.8	2.5	3.4	3.0	2.1

A common problem with mark-recapture studies is how to distinguish between resident and transient individuals. Not accounting for transients causes survival estimates to be biased low. We suspected that a high proportion of our captured animals were transients based on the large number of sub-adults (< 1 year) captured only once. In the final analysis, survival for sub-adults will be estimated separately from adults.

To study fecundity of flying squirrels, 21 nests were located by tracking radio-collared pregnant females. An additional four nests were located in nest boxes. The average litter size was 3, with a range of 1-5. Several of the juvenile flying squirrels were radio tagged and dispersal from natal patches was observed. One female flying squirrel dispersed 2.5 km from home, covering this distance in only a few days.

Home range size in small and large patches

A total of 615 night tracking points were taken for 38 individual flying squirrels in 2007 and 2008. Flying squirrels were sighted 20% of the time. Home range size ranged from 1.3 to 10 ha for females (mean=5.6) and 3.1 to 48 ha for males (mean=8.9). The sizes of male and female home ranges were similar to those found in other studies (Gerrow 1996; Martin and Anthony 1999; Holloway 2007).

Fragmented landscapes may increase travel distances.

The home range sizes of males were much larger than for females. In the spring, male squirrels were observed making large movements (>1.5 km) to nearby patches and then containing their later movements to one mature patch. Long distance inter-patch movements seemed to coincide with the breeding season. Other studies have suggested that movements of flying squirrels are more related to foraging than breeding (Gerrow 1996). Our results indicate that males are moving farther during the breeding season than females and that these movements may be longer in more fragmented landscapes.

The second objective of this study was to observe habitat use around small forest patches. We found that 17 of 21 animals in small patches used younger forest (<30 years) surrounding mature forest patches. However, the majority of den sites (~80 %) were found within mature forest patches. Several flying squirrels were located foraging in younger forests and 25 year old plantations (*Figure 16*). This was unexpected for a mature forest species, but could be the result of individuals supplementing their small mature forest patch with resources from the surrounding younger forest (e.g., foraging on Norway spruce cones).

Short distance gap crossing experiments

A total of 30 individuals were translocated across clearcuts. In comparison to long distance translocations these were quite short (minimum distance = 60 m, maximum = 800 m). All squirrels except for one were able to return within one evening. Of the 30 individuals translocated, 11 flying squirrels crossed regenerating clearcuts rather than using the longer forested corridor. The largest gap distance that a flying squirrel crossed was 300 m. The strongest predictor of gap crossing was detour efficiency (ratio of the forested detour length to the direct crossing distances). These results are similar to those found with red squirrels (Bakker and VanVuren 2006).

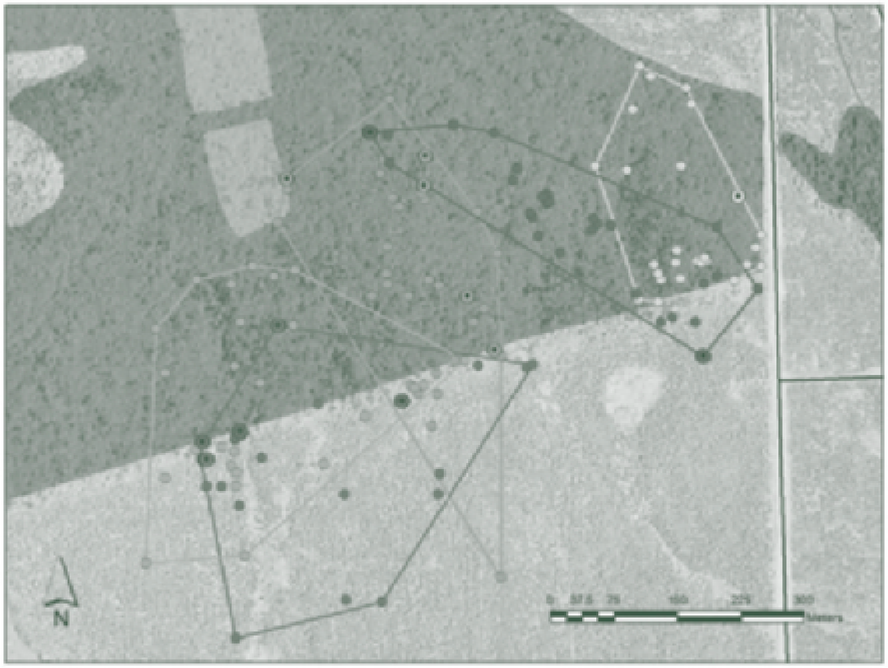


Figure 16. Minimum Convex Polygon calculated for five flying squirrels in a small mixedwood patch (dark grey). The younger forest (light grey) is a 25 year old Norway and black spruce plantation. The larger circles indicate den or nest sites and the small circles indicate night tracking locations.

Male squirrels were most likely to return home, from farther distances.

Long distance gap crossing experiments

To study the effects of fragmentation on movements of flying squirrels we translocated 119 individuals across fragmented and contiguous landscapes. Overall, 68% of squirrels were able to return home, however the probability of returning was much lower with increased distance (*Figure 17*). The ability to return home was strongly influenced by sex and distance. Males were much more likely to return home from farther distances than females. No females returned home beyond 1.2 km (*Figure 17*). The final analysis of the data will compare landscape metrics (mean nearest neighbour, amount of mature forest, and amount of connected habitat) with probability to return home and time to return home.

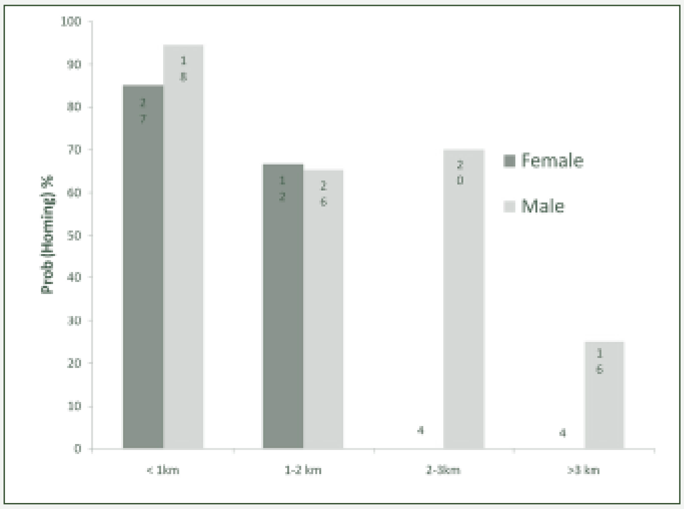


Figure 17. Probability of returning home by distance, shown for female and male flying squirrels. The numbers of squirrels translocated are shown. The probability of homing for females for the last two categories was 0.

Conclusions

A better understanding of effects of habitat loss and fragmentation on mature forest indicator species like the northern flying squirrel is critical to conserving native biodiversity in managed forests. In order to parameterize a population viability model, survival parameters were estimated using a 4 year mark-recapture study in fragmented and contiguous landscapes. The analysis of these data is ongoing; however preliminary results indicate that flying squirrels numbers were similar in fragmented stands and contiguous landscapes. It is important to note that these results are from large mature patches imbedded in landscapes with high amounts of young forest (<60 years) in the matrix.

Flying squirrels may have a better ability to utilize young forest than previously thought.

Experimental trials conducted with flying squirrels in fragmented and contiguous forests show that flying squirrels can return over long distances in fragmented habitats. These results along with the home range study indicate that flying squirrel movements may not be restricted in forested landscapes that have a matrix composed of younger forests rather than non-habitat.

Final demographic parameters (survival and fecundity) and movement data will be used in a population viability analysis to predict how populations will do under a wide range of future forest harvest scenarios.

3.3 Demographic response of songbird species to selection harvesting – Samuel Haché and Marc-André Villard

Partial harvesting aims to manage uneven-aged stands by maintaining stand structure and composition while harvesting part of the timber (Thompson *et al.* 1995). The treatment creates a sudden opening of the canopy, which induces rapid shrub growth (Anders *et al.* 2005) and many other ecological events. For example, a reduction in the volume of overstory foliage, combined with increases in solar energy and wind intensity reaching the ground tends to reduce litter moisture. This facilitates displacement of the leaf litter and ultimately causes a reduction in litter depth (Haskell 2000). Many songbird species respond significantly to such alterations of their habitat (Guénette and Villard 2005; Vanderwel *et al.* 2007), but mechanisms underlying such responses remain poorly understood.

This study aimed to identify processes taking place when a stand is opened through a first-entry selection cut. The first objective of the study was to assess the influence of two potential mechanisms (i.e., alteration of stand structure and shifts in abundance of potential nest predators) underlying post-treatment changes in density and productivity of two species of passerine birds: Ovenbird (*Seiurus aurocapillus*) and Black-throated Blue Warbler (*Dendroica caerulescens*). According to the literature, these species show contrasting short-term responses to this type of harvesting. Using low shrubs as nesting and foraging substrates, Black-throated Blue Warbler responds positively to selection harvesting (Bourque and Villard 2001). The Ovenbird is strongly associated with open understory with thick leaf litter (i.e., nesting and foraging substrate), and responds negatively to selection harvesting this and other partial harvest treatments (Bourque and Villard 2001; Holmes and Pitt 2007; Vanderwel *et al.* 2007).

Little is known with respect to the mechanisms behind songbird responses to habitat change.

The second objective of the study was to quantify treatment effects on age-specific recruitment rate and return rate in individually-marked Ovenbird populations. Recruitment is an important demographic parameter, especially in short-lived species (Saether *et al.* 2002). However, it has rarely been measured in forest songbirds even though it may yield critical information on local habitat suitability and functional connectivity. Post-disturbance movements and especially natal dispersal are very difficult to track, but examining recruitment into marked populations provides an efficient alternative.

We hypothesized that returning migrants of each target species respond to alteration of stand structure according to their niche “gestalt” (James 1971). Canopy opening resulting from partial harvesting was expected to increase shrub cover and decrease litter depth, and these changes were expected to have a negative effect on Ovenbird density and productivity, and a positive effect on Black-throated Blue Warbler. Based on the ideal despotic distribution model (Fretwell and Lucas 1970), experienced males (after second year, hereafter ASY) can outcompete inexperienced ones (second year, hereafter SY) and settle in higher-quality territories. Hence, we predicted that, compared to controls, Ovenbird males in treated plots would have lower return rates and recruitment rates of ASY males, and accordingly, the age structure would be biased toward first-time breeders. We did not make specific predictions about response to single-tree selection harvesting of two potential nest predators surveyed, red squirrel (*Tamiasciurus hudsonicus*) (Reitsma *et al.* 1990), and eastern chipmunk (*Tamias striatus*) (Morton 2005), because little is known on this topic.

Increased shrub cover was expected to have negative effects on Ovenbird productivity, while positively affecting Black-throated Blue Warbler.

Methods

The study was conducted in the Black Brook District in northwestern New Brunswick. We used a before-after, control-impact pairs (BACIP) experimental design with five pairs of study plots (25 ha each; 1 treatment-1 control). The study included 1 year (2006) pre-harvest and 1 year post-harvest (2007). The experimental treatment was single-tree selection harvesting, which removes 30-40 % of the basal area at approximately 20 year intervals via a network of skid trails (5 m wide) spaced 20 m apart. Harvesting of the trails themselves removes approximately 20% of the basal area, while the remaining 10-20% is harvested between trails. For this study, the treatment was set at 30% or 40% basal area removal in order to obtain post-harvest stand structure as similar as possible across study plots.

Prior to harvesting, we individually marked territorial Ovenbird males in four pairs of study plots and monitored their response in the first year post-harvest. Return rate was estimated as the proportion of males banded in the pre-harvest year that returned to the same plot in the first post-harvest year, while recruitment rate was the proportion of recruits per 25 ha. Individuals were aged as second- or after-second year males based on the wear pattern of the third rectrix (Donovan and Stanley 1995). Density (number of territorial males/ 25 ha) was estimated by mapping territories of all territorial males (Bibby *et al*. 2000) and number of young fledged per 25 ha was estimated by finding nests and family groups (Pérot and Villard 2009). When mapping songbird territories, we also recorded all visual and auditory detections of eastern chipmunks and red squirrels, and estimated their abundance as mean number of individuals detected per visit. Each plot was divided into 400 cells (25 m × 25 m) at the center of which we measured canopy closure, litter depth and shrub density.

We quantified treatment effect on demographic parameters (density, productivity, return and age-specific recruitment rate), stand structure, and abundance of nest predators using linear mixed models, with study plot and landscape context as random variables (McCulloch and Searle 2001). Significant causal relationships among density, productivity and stand structure, and abundance of nest predator variables were identified using partial correlation and standardized regression coefficients produced by least-squares regressions to obtain path coefficients (Vázquez and Simberloff 2004).

Results

Stand structure

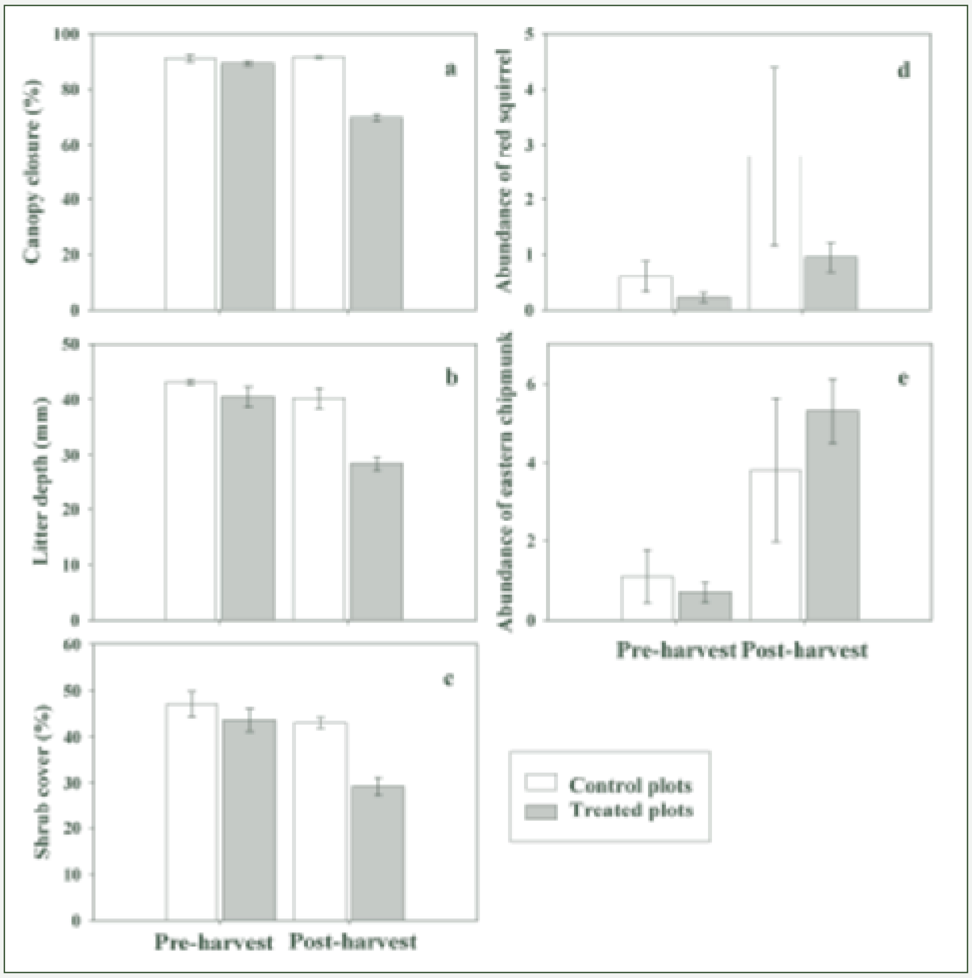
Following treatment, canopy closure, litter depth and shrub cover significantly decreased by 23, 29 and 32 %, respectively (*Figure 18a-c*). Abundance of the two nest predators increased in the study area during the post-harvest year. However, only the eastern chipmunk responded significantly to the treatment (*Figure 18e*).

Species abundance

Mean Ovenbird density and productivity were similar in plots (future treatments vs. controls) prior to harvesting. In the first year post-harvest, density and productivity significantly decreased in treated plots relative to controls, by 41% and 45%, respectively (*Figure 19a,b*). Ovenbird density was the only significant predictor of productivity, and was positively related to litter depth and negatively related to the abundance of eastern chipmunk. Of the 98 males banded in the pre-harvest year, 58 returned to the same plot the following year. Contrary to our prediction, mean return rate was not influenced by the treatment. However, consistent with the prediction, mean proportion of recruits was considerably lower in treated plots than in controls (18% vs. 49%; *Figure 20a*). This can be attributed to a significantly lower proportion of ASY male recruits in treated plots (*Figure 20b*). Indeed, there was no significant treatment effect on recruitment rate of SY males (*Figure 20c*).

Mean recruitment of Ovenbirds was lower in harvested stands.

Figure 18. Mean (±SE) canopy closure (a), litter depth (b), shrub density (c) (n = 4, 4, 2, 4, respectively), abundance of red squirrel (d) and abundance of eastern chipmunk (e) (n = 5) in treated and control plots during pre- and post-harvest years.



Significant decreases occurred in Black-throated Blue Warbler density and productivity following harvesting.

For the Black-throated Blue Warbler, contrary to our prediction, the treatment was followed by a significant decrease in density and productivity (*Figure 19c,d*), the latter being 61% lower in treated plots than in controls. Treatment effects appeared even greater considering that productivity increased by 31% in control plots during the post-harvest year. The density of the Black-throated Blue Warbler increased with shrub cover and was significantly negatively related to red squirrel abundance. However productivity increased with shrub cover.

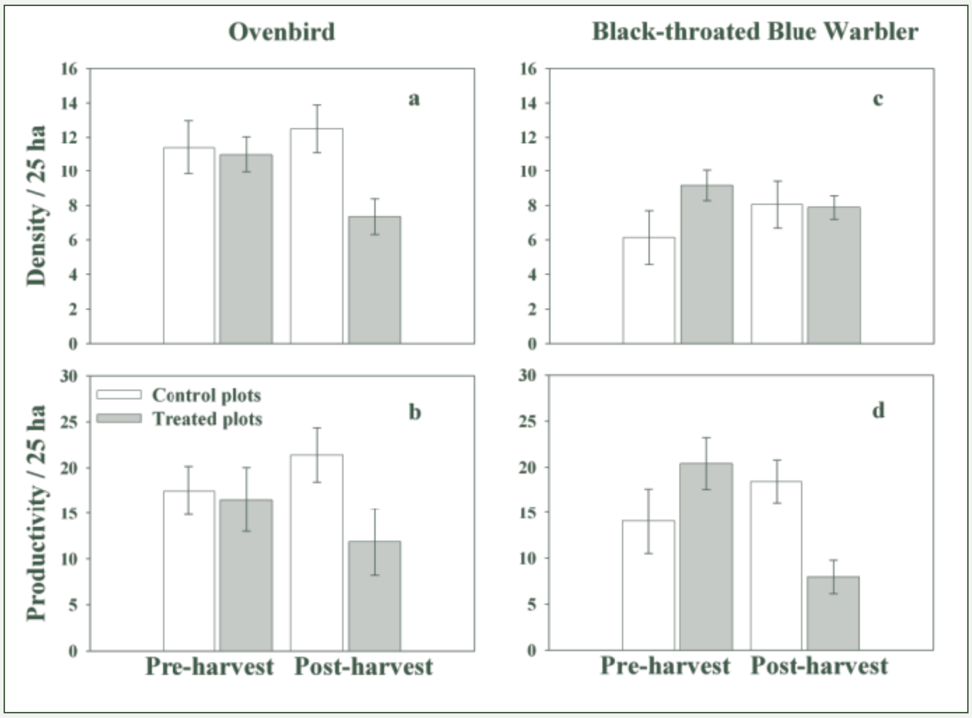


Figure 19. Mean (± SE, n = 5) density and productivity of Ovenbird (a, b) and Black-throated Blue Warbler (c, d) in control and treated plots during pre- and post-harvest years.

Mechanisms of response to harvesting

Changes in stand structure and abundance of predators affected habitat selection and thus productivity.

Results suggest that shortly after harvesting, alterations to both stand structure and the abundance of a nest predator influenced habitat selection by Ovenbirds and, indirectly, their productivity. Those same processes seemed to influence habitat selection in the Black-throated Blue Warbler, but treatment also seemed to have a direct influence on productivity, possibly through a reduction in nest concealment. Lower density of Ovenbirds appears to reflect the post-harvest increase in territory size of returning individuals and differences in habitat selection strategies between experienced and inexperienced recruits. To tease apart those processes, experimental removals could be performed to determine whether inexperienced recruits tolerate a broader range of habitat structures or are forced to settle in recently treated sites. However, this short-term response (insufficient immigration to compensate for natal dispersal and adult mortality/dispersal) highlights the potential influence of recruitment on population dynamics in forest songbird species.

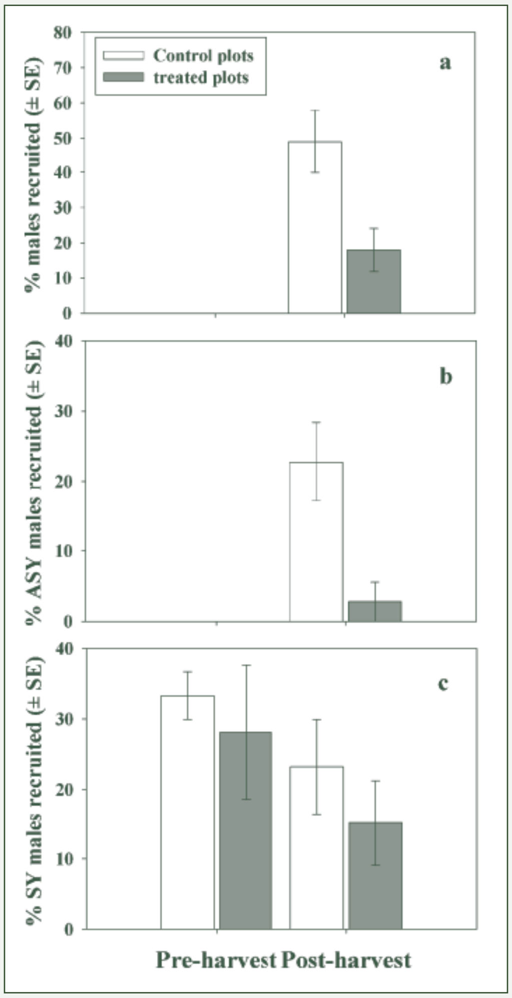


Figure 20. Mean (± SE, n = 4) proportion of total male (a), ASY (b), and SY (c) recruits for Ovenbird in control and treated plots during the post-harvest year (SY recruits were also identified during the pre-harvest year).

Based on results of Bourque and Villard (2001), Ovenbird response to treatment was expected to be more drastic. However, we only measured the beginning of a habitat alteration process that is expected to affect this species over the first 10 years post-harvest, or even longer (Jobes *et al.* 2004). The negative short-term response of Black-throated Blue Warbler to the treatment should be compensated with higher habitat quality as the shrub layer recovers, providing more foraging substrates and better nest concealment. However, when sapling regeneration reaches a certain height, habitat quality should decrease again (Jobes *et al.* 2004).

The main treatment effect for both songbird species seems to be creation of skid trails in which litter depth was very low and shrubs almost completely removed (Haché 2008). Thus, a lower density of skid trails produced by machinery able to reach further into the forest, or timing of harvest treatments following sufficient snow accumulation, would represent strategies to reduce impact of selection harvesting on populations of these songbird species.

Skid trails have negative impacts on songbirds by reducing litter depth and shrub cover.

Conclusions

This study quantified demographic responses of two songbird species to partial harvesting, identified mechanisms responsible for observed responses, and highlighted the influence of recruitment on population trends of forest birds. These results provide critical empirical data to parameterize demographic models predicting population status under different harvesting scenarios over large spatial and temporal scales. Such models provide useful information to forest managers.

Further studies would be needed to experimentally separate and quantify the importance of effects of food availability and predation rate on the reduction of productivity in Black-throated Blue Warbler following harvesting. Our results suggest that recruitment is an important process in Ovenbird population dynamics and was negatively influenced by the treatment, at least indirectly. In the four treated plots, density decreased after harvesting, suggesting that reliable model predictions will also require accurate estimates of the “catchment area” (Mazerolle *et al.* 2005) over which local populations recruit individuals, to determine relevant spatial scale (Tittler *et al.* 2006).

3.4 Response of an old forest associate, the Brown Creeper, to forest harvesting at stand and landscape scales – Jean-François Poulin and Marc-André Villard

Forest management creates complex landscape mosaics composed of stands varying in composition, age, and disturbance history (Lindenmayer and Franklin 2002). Although low-intensity harvesting may maintain habitat for some species, others are sensitive to reductions in specific forest stand structures (Vance and Nol 2003; Fisher and Wilkinson 2005; Guénette and Villard 2005) or to overall loss and fragmentation of their habitat at the landscape scale (Villard *et al.* 1999; Lichstein *et al.* 2002; Cushman 2006). However, few studies have investigated the range of habitat alteration over which sensitive species exhibit a negative response, and the processes underlying this response.

In New Brunswick, coniferous stands are mainly managed through even-aged systems such as clearcutting and variable retention harvesting. Shade tolerant hardwood stands are maintained under uneven-aged conditions using different types of partial harvesting (e.g., patch cutting, single-tree selection harvesting). While even-aged harvesting procedures offer few options to maintain populations of old-forest specialists other than set-aside reserves, partial harvesting can potentially be adjusted to meet requirements of such species. To do so, it is important to understand mechanisms underlying response of species sensitive to partial harvesting.

The Brown Creeper is strongly associated with large diameter trees and snags.

We selected the Brown Creeper (*Certhia americana*) as a focal species because it is strongly associated with large-diameter trees (foraging substrates), and snags with peeling bark (nesting substrates) (Hejl *et al.* 2002; Poulin *et al.* 2008). Furthermore, Guénette and Villard (2005) indicated that it is sensitive to harvesting, even at moderate intensities, and a recent meta-analysis revealed that it is one of the two vertebrate species most sensitive to partial harvesting (Vanderwel *et al.* 2009). The main objectives of this study were to identify stand/landscape structures associated with presence of Brown Creeper nests and successful reproduction, and to examine the effect of single-tree selection harvesting on demographic parameters (nest density, productivity, etc.).

Threshold response to nesting habitat characteristics

An **ecological threshold** can be defined as a sharp change in a biological response corresponding to a small alteration in ecosystem conditions (Guénette and Villard 2004; Huggett 2005). A threshold may be breached when ecosystem conditions change over time at a given location, or threshold responses may be observed when measuring an ecological response variable (e.g., probability of species presence) along a gradient in ecosystem conditions (Bütler *et al.* 2004; Homan *et al.* 2004; Guénette and Villard 2005).

Threshold values can be important guides for conservation of species of interest.

Thresholds are of high interest for conservation and management because they may guide the development of conservation targets (Villard and Jonsson 2009). For example, Guénette and Villard (2005) sampled forest birds in stands varying in structure and floristic composition, and related stand characteristics to probability of species presence. In northern hardwood stands, they found a threshold of 66 large trees (≥30 cm diameter at breast height) per hectare above which the Brown Creeper was significantly more likely to be detected at point count stations. Although this number represents a useful reference point for conservation and management, it was questioned whether meeting this threshold would ensure reproduction and, ultimately, persistence of this and ecologically-similar species.

For this study, we compared habitat characteristics around nests, and at randomly-located sites where no Brown Creeper was detected in apparently suitable habitat. Habitat variables were quantified at local (radius = 80 m) and neighbourhood (radius = 250 m) scales. The main variables discriminating nesting and unused sites were density of large diameter trees, density of snags, presence of potential nesting substrates, and area of mature untreated forest within a radius of 250 m. Local-scale variables (density of large trees, snag density, presence of potential nesting substrates) explained more variation in nest site selection than neighbourhood-scale variables.

Large trees are essential to recruitment of new snags (Vanderwel *et al.* 2006) and high densities of snags should increase the creeper's probability of finding suitable nesting substrates. Large diameter trees also support higher densities of bark-dwelling invertebrates (Jackson 1979; Mariani and Manuwal 1990), and larger bark surface allows individuals to reduce number of flights required per unit of energy intake (Franzreb 1985; Mariani and Manuwal 1990). The nests monitored were mostly located >100 m from the nearest edge (forest/clearcut, forest/conifer plantation, and forest/road). Similar results were found in Finland for the Eurasian Treecreeper (Kuitunen and Mäkinen 1993). This apparent avoidance of forest edges by creepers may explain their relatively high area requirements (Davis 1978; this study). For example, territories located along edges would likely have to be elongated to include enough trees to meet energetic requirements of a breeding pair (Kuitunen and Mäkinen 1993). We also found Brown Creeper nesting success to be significantly lower near edges, which may reflect higher predation rates.

Large trees provide a source of snag recruitment essential for the persistence of Brown Creeper.

We examined univariate relationships to determine whether responses to habitat parameters showed evidence of thresholds. Significant threshold values were found for three variables. The probability of presence of a nest was significantly higher above 127 large live trees/ha (*Figure 21*) and 56 snags/ha, or when area of mature/old untreated forest was ≥10.4 ha (53% of the area considered). The threshold in large-tree density was nearly twice as high as that reported by Guénette and Villard (2005) for Brown Creeper's probability of presence in shade tolerant hardwood stands of the same study region (66 stems/ha). Thus, thresholds in species occurrence may be misleading from a conservation perspective and species such as the creeper apparently select patches of untreated forest for nesting.

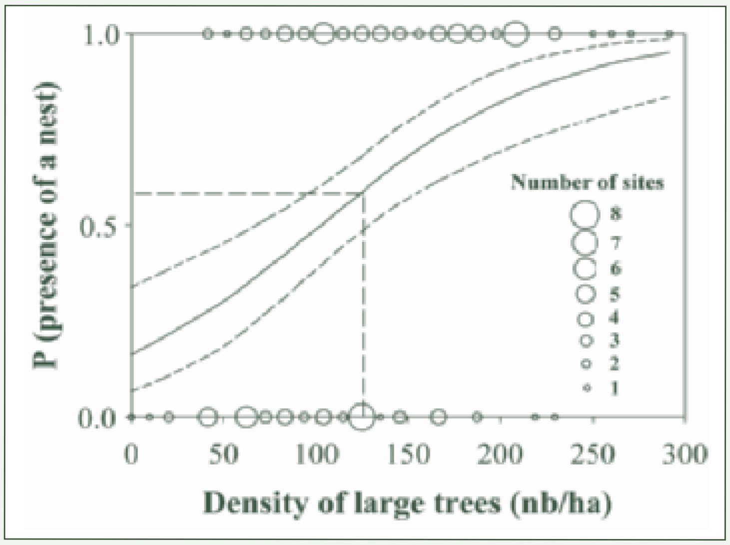


Figure 21. Probability of presence of a nest as a function of the density of large trees (≥30 cm dbh) (from Poulin et al., *2008).*

Current uneven-aged harvest systems are unlikely to maintain Brown Creeper populations over the long-term.

Current uneven-aged harvest systems are unlikely to maintain Brown Creeper populations over the long-term. Conservation targets must be established at the landscape scale and they should include maintenance of patches that are left unmanaged, or managed under extended harvest rotations, to provide a sufficient amount of foraging substrates and a continuous renewal of snags. Patches could be left untreated and managed as a network of shifting reserves. Such patches should also provide suitable habitat for a wide variety of forest taxa with requirements for large-diameter trees, dead wood, and associated features.

Effects of single-tree selection harvesting

High densities of large-diameter trees and snags are important predictors of the presence of Brown Creeper nests (*Figure 22*), but their relative importance has not been examined. We tried to tease apart these factors using experimental single-tree selection harvesting. This treatment removes approximately one-third of trees in each diameter class every 15-25 years. We compared nest density, number of territories and nesting success between 5 pairs of sites (1 control, 1 treatment) of 25 ha each.

Figure 22. Brown Creepers utilize a variety of stand structures including large trees for foraging and snags with peeling bark for nest sites.

Partial harvests caused Brown Creepers to increase their territory size.

Single-tree selection harvesting did not significantly reduce density of snags relative to pre-harvest, because operators were asked to maintain as many as possible. Indeed, only density of large trees differed significantly between control and treated plots. One might hypothesize that creeper response would be proportional to loss of foraging substrates. However, nest density and number of territories were two times lower in treated than in control plots, despite the treatment only removing 30-40% of tree basal area. These results suggest that quality of remaining foraging habitat was reduced. Brown Creeper pairs appeared to increase size of territory to compensate for losses in habitat quality.

Conservation strategies for bark-gleaning birds have mainly focussed on abundance of potential nesting substrates (but see Mannan *et al.* 1980; Giese and Cuthbert 2003; Lemaître and Villard 2005). These strategies do not necessarily guarantee that appropriate levels of food will be maintained after a given habitat alteration (Weikel and Hayes 1999). Partial opening of the canopy through harvesting is known to change microclimatic conditions on tree trunks. Selection harvesting negatively affects abundance and fertility of epiphytic lichens (Edman *et al.* 2008), which could potentially alter invertebrate communities on tree trunks and thus, food abundance for creepers.

The Brown Creeper response to partial harvesting seems to be driven by energetic requirements. Little is known about effects of canopy opening on bark-dwelling arthropods, which could affect food abundance for Brown Creepers and other bark gleaners. This species may require patches of untreated, mature to old forest to nest successfully (Poulin *et al.* 2008).

Due to Brown Creeper's sensitivity to harvesting it may be an indicator of late successional stands.

Conclusion

Long-term monitoring (Johnson 1999) or dynamic-landscape metapopulation models (Wintle *et al.* 2005) would be required to assess probability of persistence of Brown Creepers in managed landscapes under alternative harvest scenarios, including maintenance of untreated patches within selection cutblocks. Due to its high sensitivity to harvesting, the Brown Creeper may represent a good indicator of ecological integrity in late-seral stands (Wintle *et al.* 2005; Venier *et al.* 2007; Poulin *et al.* 2008) and it may act as an umbrella for other species requiring old forest conditions.

Objective 4. Effect of alternative zoning allocations

4.1 Triad scenarios on Crown License 1 – Chris Ward, Tom M. Beckley, Thom A. Erdle and David A. MacLean

Triad forest management aims to provide specific values from parts of the forest but all values across the whole forest.

Triad forest management refers to the allocation of a forest into reserves and intensive management, within a matrix of extensive management. Many authors have suggested the approach as a potential solution to the difficulty of maintaining both timber and non-timber values at the forest level (*Figure 23*). Most often cited is the potential benefit of intensifying production of timber in a smaller portion of forest, which would allow greater consideration of non-timber values in other portions. Success under a Triad approach would result in specific values being provided in certain parts of the forest, but all values being provided through the collective outcomes across the whole forest.

Despite interest in the Triad or zoning approach, there have been few quantitative analyses of forest-level impacts on a broad range of social, economic and environmental values under alternative allocation scenarios. The objective of this study was to forecast various Triad forest management scenarios, and to evaluate their outcomes using indicators representing a range of social, economic and ecological forest values.

Methods

The Upsalquitch Crown License 1 in northern New Brunswick was used as the study area. Remsoft Woodstock forest estate modeling software was used to forecast 36 scenarios where reserves and intensively managed area varied in 5% increments from 10-35%, and the rest of the forest was allocated to extensive management. With intensive management, natural stands were clearcut and planted to spruce species. Plantations received herbicide treatment, were commercially thinned at age 35, and clearcut at age 50. Under extensive management, all stands deemed eligible for non-clearcut harvesting were so treated (shelterwood, even-aged strip/ patch, or uneven-aged selection). Both clearcut and non-clearcut treatments in the extensive zone had between 10% and 20% permanent retention, in an effort to maintain mature forest characteristics. No treatments were implemented in the reserve zone.

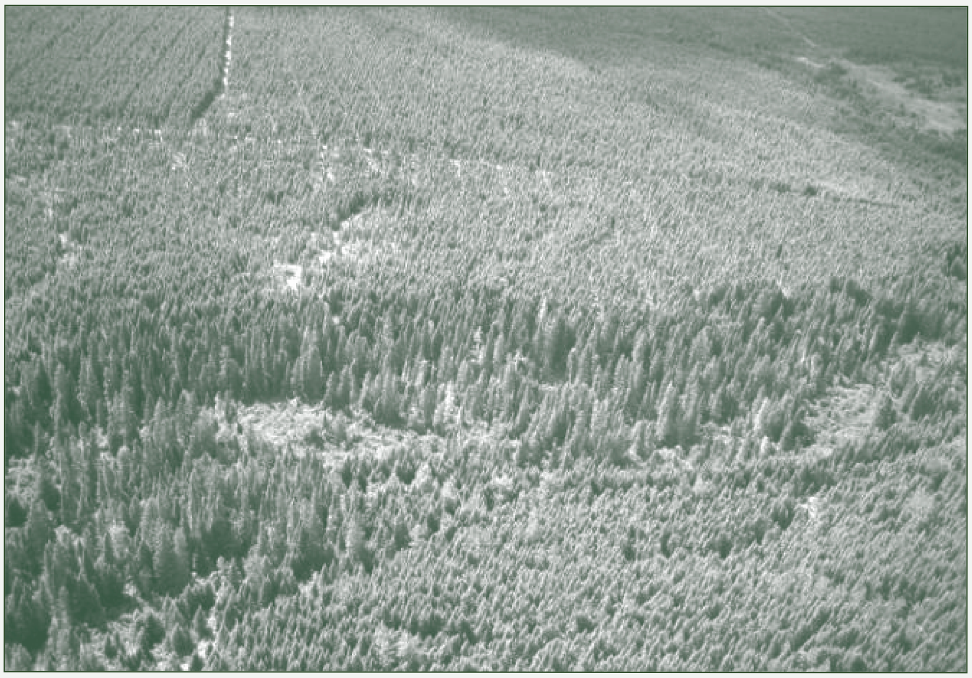


Figure 23. Contrasting values such as timber production and ecological health make forest management planning difficult, but can be addressed by allocating varying management intensities in predetermined zones across the landscape.

Results

Harvest levels

Average annual spruce-fir jack pine (SFjP) harvest volume ranged from 408,000 m^3/yr to 668,000 m^3/yr across the 36 scenarios (*Figure 24*). When reserve area was held constant, average annual harvest volume increased by 21% as the intensively managed area increased from 10% to 35%. When the area under intensive management was held constant, average annual harvest volume decreased by 20% as reserve area increased from 10% to 35%.

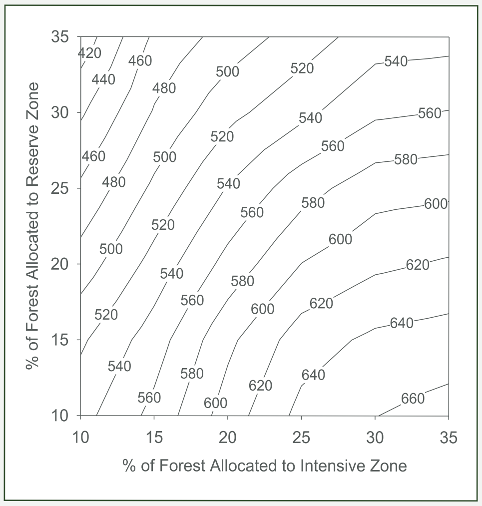


Figure 24. 100-year annual average spruce-fir-jack pine harvest, expressed in thousands of m^3, for New Brunswick Crown License 1 under Triad scenarios with 10-35% of the area in reserves, 10-35% under intensive management and the remainder managed extensively.

Increased productivity from intensively managed stands allowed for increased proportions of area allocated to reserves.

In most cases, an average annual harvest level was maintained across scenarios that simultaneously increased reserves and intensively managed area. As an example, if 540,000 m^3/yr was an annual average harvest target, it could be achieved using various reserve/intensive allocation combinations (see *Figure 24*). In these cases, the harvest volume lost by allocating an extensively managed hectare to reserve was offset by an equal volume gained by allocating an extensively managed hectare to intensive management. This results from the harvest rate in the intensively managed area on this landbase (4.3 m^3/ha/yr) being approximately double that in the extensively managed area (2.1 m^3/ha/yr).

Three alternative scenarios that each resulted in average SFjP annual harvests of 600,000 m^3/yr (*Figure 25a*) or 488,000 m^3/yr (*Figure 25b*) demonstrated the multiple ways of achieving the same average harvest level. Although alternative scenarios produced similar average harvest levels, timing of when the volume was available for harvest differed. For example, under the 600,000 m^3/yr scenarios, increasing area in reserves from 10% to 25% reduced short-term harvest by 12%, and increasing intensively managed area from 20% to 35% increased long-term harvest by a similar amount (*Figure 25a*).

Future forest conditions

Strategies that produced similar average harvest levels resulted in distinctly different forest conditions. The effect of allocation choices on the range of resulting forest conditions was evaluated using the same six scenarios as in *Figure 25* with the results shown in *Figure 26*. In all cases, after 50 years:

1) area of unmanipulated forest increased to the approximate reserve area;
2) area in plantations increased to the intensively managed area; and
3) combined uneven-aged management and even-aged untreated area declined by an area equal to that of the increase in plantations and unmanipulated forest. For example, with an average harvest of 488,000 m^3/yr, the unmanipulated area in year 50 varied by 14% (from 17% under the 20% reserve scenario to 31% under the 35% reserve scenario). This was accompanied by a doubling of plantation area from 10% to 20%, which reduced the combined uneven-aged management and even-aged untreated area by 24% (73% to 49%) (*Figure 26b*).

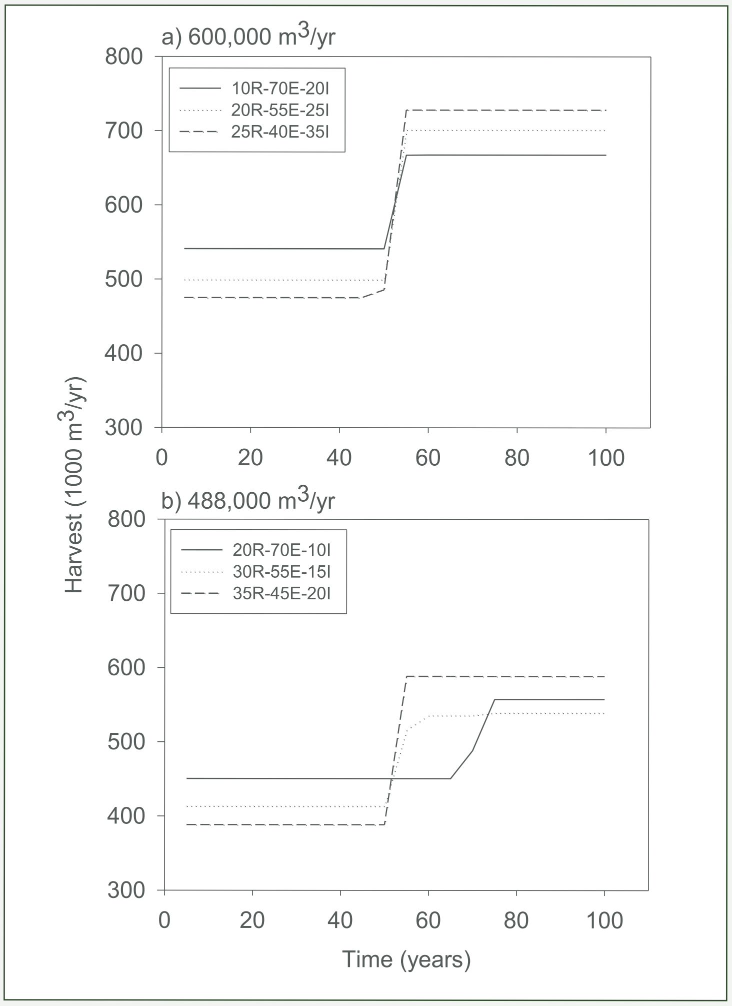


Figure 25. Spruce-fir-jack pine harvest projected over a 100-year planning horizon for New Brunswick Crown License 1 under three zoning allocation scenarios with forecast annual average harvests of 600,000 m^3/yr (a), and 488,000 m^3/yr (b). Legend refers to percent of forest area allocated to reserve (R), extensive (E) and intensive zones (I).

Forest value indicator outcomes

Nomograms (e.g., *Figure 24*) were examined for each value in the analysis, and each revealed one of four general patterns: vertical contours, horizontal contours, contours placed at 135°-315°, or contours placed at 45°-225°. Indicators with patterns of vertical, horizontal or 135°-315° contours were, respectively, most sensitive to changes in area allocated to intensive management, reserves, or extensive management. Contours at 45°-225° were equally sensitive to changes in reserve and intensive management.

Two examples of these included average harvest levels (*Figure 25*) and mature and late-succession forest. These indicators could be “averaged” at the forest level because their provision from the extensive zone was approximately half that from

reserves or intensively managed area. For example, mature and late-succession forest was nearly always present in reserves, rarely in intensively managed area, but was partially maintained in the extensive zone. Likewise, on this landbase, harvest rates in the extensive zone (2.1 m^3/ha/yr) were half that in the intensive zone (4.3 m^3/ha/yr), but greater than those in the reserves (0 m^3/ha/yr). When area from the extensive zone was re-allocated in equal amount to both reserves and intensive management, the indicator could be maintained (or "averaged") at the forest level, but where that indicator was provided became limited to the location of reserves or intensively managed areas. In the case of mature and late-succession forest, the same total amount could be maintained across a range of allocations to intensive management, so long as area allocated to reserves was near equal. However, as intensive management increased, old forest increasingly became present only within reserves.

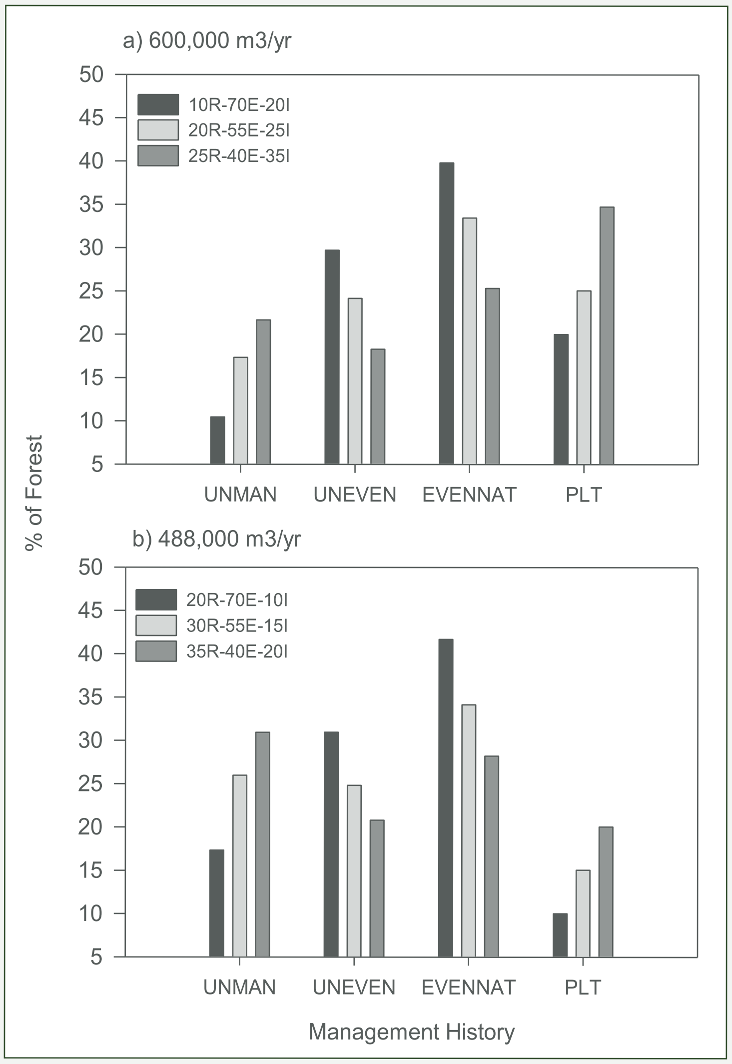


Figure 26. Total area of New Brunswick Crown License 1 by unmanipulated (UNMAN), uneven-aged management (UNEVEN), natural regeneration having been harvested by even-aged treatments (EVENNAT) and plantations (PLT) in year 50 under three Triad scenarios that produced annual average harvests of 600,000 m^3/yr (a), and 488,000 m^3/yr (b). Legend labels describe percent of forest area in reserve (R), extensive (E) and intensive (I) zones.

Conclusion and Management Implications

Reserves are normally considered areas free from timber harvesting, while the definition of extensive and intensive varies considerably. The effort in this study was to have a zone where silvicultural practices could be implemented to create significantly higher timber yields than on other portions of the landbase (intensive management zone), and another zone where treatments were conducted that explicitly considered both timber and non-timber values (extensive management zone). The extensive zone is often described as the matrix within which the reserves and intensively managed area are placed. To be effective this zone must be a source of timber, but be sufficiently different from the intensive zone such that it provides conditions that might not exist when the main objective is timber production.

An oft-cited claim about the Triad approach is that increased intensity of management for timber in a portion of the forest will allow increased reserve area, without reductions in harvest levels. In this analysis, increasing the intensively managed area required less area to meet a given harvest level and therefore allowed for increases in reserve area while maintaining the average timber production over 100 years. Reserves created in the short-term reduced operable inventory in the short-term and intensive management (as defined here) implemented in the short-term increased operable inventory in the long-term. As a result, increasing reserve area reduced short-term (year 1-25) harvest levels, even with simultaneous increases in intensively managed area. When plantations became available after 40-50 years, the short-term reduction in harvest volume was usually recouped, depending on area in plantations and area removed for reserves. This suggests that the ability to implement the Triad approach without reductions in harvest levels depends on what time frame is considered; no reduction in the cumulative harvest over 100 years is quite different than an immediate reduction in harvest and a similar increase after 40-50 years. The short-term wood supply impact of creating reserves will depend on the forest age class structure and other forest conditions.

Increasing the intensively managed area allowed for increased reserve area but reduced short-term harvest levels.

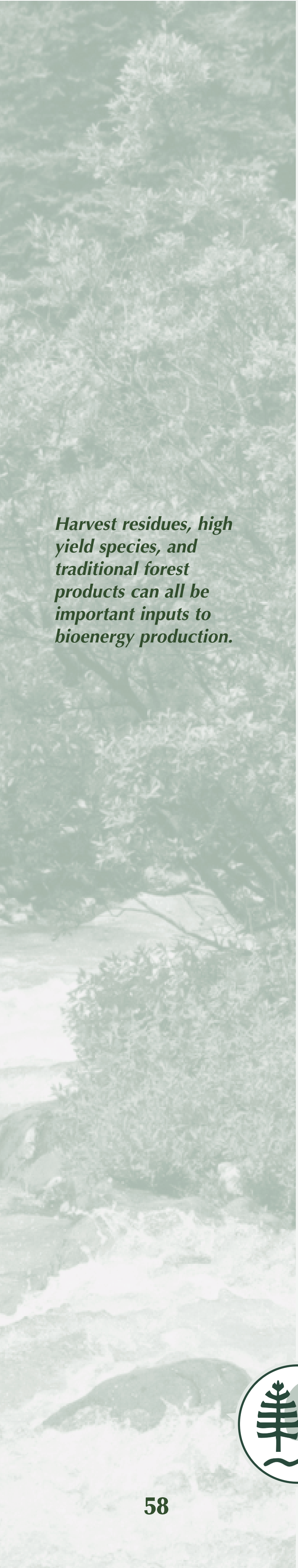
Scenarios with very different distributions of area in reserve, extensive, and intensive management zones resulted in similar performance of some indicators. This revealed that different Triad strategies could lead to the same end in some respects (e.g., harvest volume). However, in most cases those similarities were accompanied by very different outcomes in other respects (e.g., area of plantations versus uneven-aged management). Therefore, the desirability of any one scenario will depend on the importance placed on each value.

Very different forest allocations can result in similar outcomes over the long-term for some indicators, but differed in other respects.

4.2 Bioenergy production – a case study for Crown lands of New Brunswick – Jean-François Carle, David A. MacLean, Thom A. Erdle and Roger Roy

There is renewed interest in utilizing forest biomass to produce energy due to growing concerns about energy security, global increases in CO_2 emissions, sustainability of natural resources, and the need to revitalize rural economies (Richardson *et al.* 2002; NBDNR 2008). Bioenergy can use existing forest sector infrastructure to create opportunities for an industry facing many challenges. However, there is a need to evaluate several aspects of bioenergy production:

- joint production possibilities for timber supply and bioenergy,
- proportion of fossil fuel-based energy requirements that can be supplied from forest-sourced biomass,
- possibility of using low-grade timber given declines in pulp consumption (Perlack *et al.* 2005),
- the role of intensive management for energy production in meeting energy requirements,
- CO_2 equivalent (CO_2e) emissions from fossil fuel combustion used in bioenergy production, and
- costs.



Harvest residues, high yield species, and traditional forest products can all be important inputs to bioenergy production.

In this study, biomass and bioenergy production levels were projected from: harvest residues (i.e., branches and tops) of various tree species, alternative scenarios of harvest residue utilization, pulpwood biomass, and willow plantations. These supply sources were evaluated for all Crown land in New Brunswick using a forest-level optimization model. Projections of biomass and bioenergy production levels were then combined with stand-level biomass recovery efficiencies, delivered cost, and diesel fuel consumption data, to calculate net biomass and energy production, CO_2e emissions from fossil fuel combustion, and costs for biomass harvest, production and supply. Objectives were to:

1) evaluate effects of alternative management strategies on bioenergy and timber production from 3.3 million ha of Crown land in New Brunswick;
2) calculate stand-level forest biomass recovery efficiency, delivered cost, and fuel consumption indicators for combinations of harvest scenarios, stand types, and harvesting systems; and
3) evaluate biomass, energy production, CO_2e emissions, and costs for various proportions of area of Crown land available for biomass harvest in New Brunswick.

Forest level biomass and energy production

We developed an integrated modeling framework to forecast timber, biomass, and bioenergy production using forest inventory data, the STAMAN stand growth model (Erdle and MacLean 1999), allometric equations to estimate biomass, and the Spatial Woodstock forest estate model (Remsoft 2006). We used this to forecast forest-level potential biomass, energy, and timber volume harvest over a 100-year time horizon. Scenarios tested for all Crown land in New Brunswick included:

1) objective functions that maximized timber supply or energy production,

2) use of biomass from combinations of harvest residues (i.e., branches and tops) only, pulpwood, and/or willow (*Salix* sp.) plantations, and

3) evaluation of alternative biomass utilization rates and discount rates. Scenarios including willow plantations set a maximum area of 40 000 ha (1.2% of Crown land) at any given time.

By increasing the use of plantations and PCT a 40% increase in energy and volume production was forecast by 2070.

Maximizing timber production with a discount rate of 8% (i.e., status quo) and using a realistic, 66% utilization rate of residues (Stokes 1992; Wall 2008), but no pulpwood biomass or willow plantations, provided delivered gross energy and timber volumes of 17 PJ/yr* and 6.1 Mm^3 in the first 20 years. These numbers then increased to 24 PJ/yr and 8.7 Mm^3 after 2070 (*Figure 27a,c*). The forecast 40% increase in energy and volume production forecast from 2007 to 2070 was directly related to the use of softwood plantations and pre-commercial thinning (PCT) forecast in the model. Managed stands increased operable growing stock, harvest level, and energy production. Scenarios that maximized discounted (8%) energy production with the same utilization rate resulted in a 4-5% increase in energy production and a maximum 5% decrease in timber harvested (*Figure 27a,c*). When 30% of pulpwood biomass was allocated to energy production, energy generated increased by 44-59% and timber harvested decreased by 15-19% (*Figure 27b,d*), compared to scenarios with residues only. Scenarios which included willow plantations increased potential energy production by 39-56% after 2030, when compared to scenarios that maximized timber supply (*Figure 27a,b*). Establishing willow plantations had a greater effect than objective function for comparable scenarios in which energy was maximized.

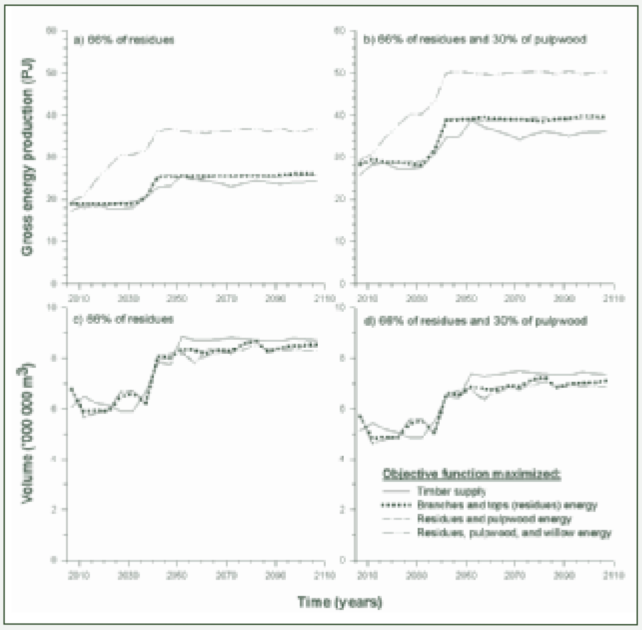


Figure 27. Discounted (8%) energy and timber volume production from 3.3M ha of Crown Land in New Brunswick, for four objective functions and two alternative utilization rates over a 100 year planning horizon.

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*PJ refers to petajoule, a measure of energy where 1 PJ = 1.0E15 joule.

Bioenergy could be used to offset fossil fuel energy, which in 2007 was about 110 PJ or 70% of total primary and secondary energy consumption in New Brunswick (Statistics Canada 2007). Gross energy production under scenarios using 66% of residues, or a combination of residues and 30% of pulpwood biomass, could offset 15-33% or 17-35% of total fossil fuel energy consumption (objectives to maximize discounted timber supply or energy production, respectively), and 26-46% if willow plantations were included.

Biomass recovery efficiency, delivered cost, and diesel fuel consumption

Cormier and Ryans (2006) developed the Bios model to assess the economic feasibility of forest biomass use. This forest biomass feedstock model was used to estimate delivered biomass costs, diesel fuel consumption, recovery efficiency as a function of forest type and residue source, harvesting system, and transport distance. Analyses were conducted for four typical stand type categories (softwood, mixedwood, hardwood, and plantation), five harvest scenarios with varying site conditions, and two harvesting systems (full-tree and cut-to-length) representing the range of operational conditions.

The base case harvest scenario was characterized by a mixedwood forest growing on well-drained soil, uneven texture and relief, average slope up to 20%, 200 m average block depth, and 100 km transportation distance. Depending on harvesting system and stand type, costs varied from $22-$30/oven dry ton (ODT) (cut-to-length system). Roadside costs for the full-tree system were lower than cut-to-length, with values varying from $15-16/ODT. Diesel fuel consumption for the cut-to-length system was higher than full-tree, with values varying from 12-14 L/ODT. Recovery efficiency was 40% for the cut-to-length system (constant due to limitations in the Bios model), versus a maximum of 57% for the full-tree system in hardwood stand types. Results showed that cut-to-length harvesting was more expensive in terms of cost and diesel consumption than full-tree systems, due to handling and lower recovery efficiencies. Total cost and diesel consumption of cut-to-length harvesting were 66-78% and 23-32% higher, respectively, compared to full-tree systems.

Indicators of forest biomass energy production

Forest biomass production requires the use of fossil fuels, resulting in direct carbon emissions. Emissions are a function of ecological retention on site (i.e., biomass retained as snags or dead wood, hard coded in the Bios model), site and stand conditions, harvesting system, and transportation distance to the conversion facility. We evaluated effects of these factors on delivered biomass and bioenergy production, diesel energy consumption and CO_2e emission, net energy ratio, emissions, and cost of delivered biomass energy. Under the status quo scenario (maximizing 8% discounted timber supply), total biomass and energy production increased due to high yield plantations, resulting in potential biomass and energy production of 1.15-1.28 M ODT/yr and 6.46-7.18 billion kWh/yr for years 2010 to 2070, respectively. Production of biomass and energy in 2070 increased by 11% compared to 2010.

Delivered biomass and energy production, and CO_2e emissions (*Figure 28*) were calculated using results of potential biomass and energy production at the forest level, stand level biomass recovery efficiencies, diesel fuel consumption, proportion of area available for biomass harvest (10, 30, 50, 80, or 100% of Crown land), and emission factors of the International Panel on Climate Change (IPCC 2006). Full-tree harvesting systems resulted in the highest biomass and energy production, varying from 3.5-56 billion kWh/yr (*Figure 28*) as clearcut area available for biomass removal increased from 10% to 100%. Using full-tree harvesting increased biomass and energy production by over 23%, compared to a cut-to-length system. Emissions of CO_2e were higher for a cut-to-length system, varying from 6,000-70,000 T/yr as area available for biomass removal increased from 10% to 100%. CO_2e emissions were over 10% higher for cut-to-length than full-tree harvest systems. However, biomass harvested in 2070 under a full-tree harvesting system produced approximately the same CO_2e emission as biomass harvested in 2010 under the cut-to-length harvesting system.

Full tree harvesting is more efficient for biomass removal.

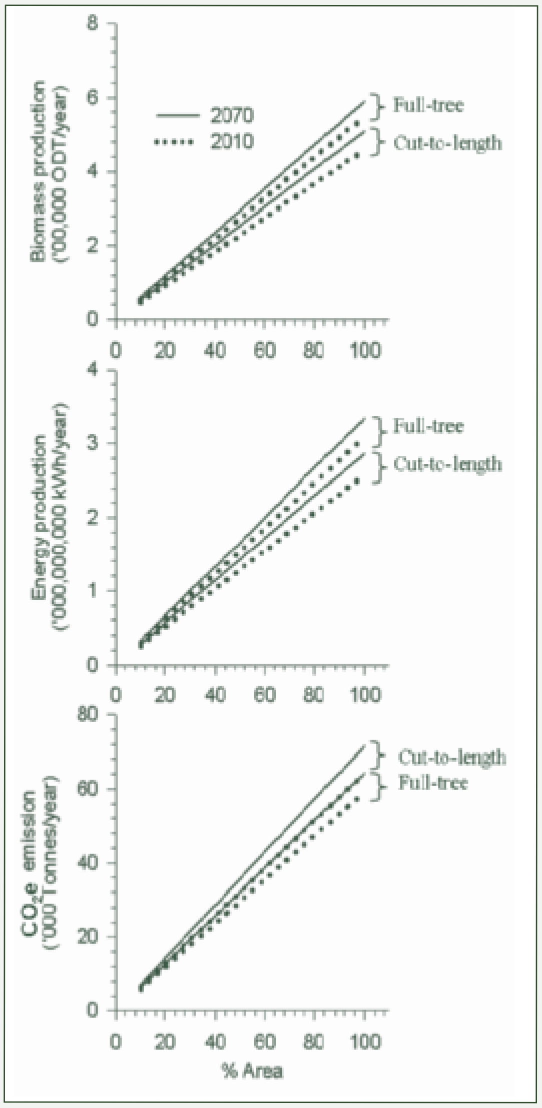

Figure 28. Delivered biomass and energy production and related CO_2e emissions for the status quo scenario (i.e., maximizing discounted (8%) timber supply) using base case harvest scenario.

Indicators of net energy, emissions, and cost of biomass energy were calculated including:

1) net energy ratio, indicating the ability to leverage existing fuel resources for generation of energy with an emphasis on the use of renewable fuels;
2) CO_2e emitted in the atmosphere per unit of energy produced; and
3) ratio of cost for biomass harvest and supply to total energy production.

Indicators that measured the benefits of energy production showed that full tree harvesting should be favored over cut-to-length systems.

Results showed that net energy, emissions, and cost indicators were better for the full-tree than cut-to-length harvesting system. More specifically, net energy ratio, emissions, and cost of biomass energy for the full-tree harvesting system varied from 29.7-31.4, 7.9-8.4 g CO_2e/kWh and \$0.85-\$0.95/kWh, respectively (*Table 8*). Values for the full-tree system were 23-32% higher, 19-24% lower, and 42% lower than for the cut-to-length system, respectively. The mixedwood stand type appeared to be the best option for harvest, in terms of all indicators, followed by hardwood, plantation, and softwood (respectively).

Table 8. Net energy ratio (ratio of renewable energy production divided by non-renewable energy consumption used in producing the biomass), CO_2e emissions per unit energy production, and cost of delivered biomass energy for the base case harvest scenario, four stand types, and two harvesting systems (full-tree and cut-to-length).

Stand type categories	Net energy ratio		Emissions (g CO_2e/kWh)		Cost of biomass energy (\$/kWh)	
	Full-tree	Cut-to-length	Full-tree	Cut-to-length	Full-tree	Cut-to-length
Softwood	29.7	22.5	8.4	11.0	0.93	1.66
Mixedwood	31.4	24.9	7.9	10.0	0.86	1.48
Hardwood	30.6	24.8	8.1	10.0	0.85	1.42
Plantations	30.3	23.4	8.2	10.6	0.95	1.66

Several studies have considered life cycle assessment of various energy production systems and their specific impacts on net energy production, emissions, and costs over the life time of a given plant. Spitzley and Keoleian (2004) reviewed the literature and found that willow energy production systems had net energy, emissions, and costs as high as 13.3, 52.3 g CO_2e/kWh and \$1.42/kWh, respectively. These net energy ratios, emissions, and costs were approximately 50% lower, and 550% and 57% higher, respectively, compared to the full-tree harvesting system in our study. However, our analyses did not use the same plant efficiency factors and include upstream non-feedstock energy uses, CO_2e emissions, and cost for plant construction. This would likely decrease the net energy ratio, and increase emissions and costs.

Conclusion

We created a modeling framework for timber, biomass, and bioenergy production at the forest level, which demonstrated a high potential for bioenergy production from residues, pulpwood biomass and willow energy plantations on Crown land in New Brunswick. Results showed that scenarios to maximize energy production using 66% of residues and 30% of pulpwood biomass produced 44-59% more energy but decreased timber production by 15-19%, compared to scenarios using residues only. Scenarios incorporating up to 40 000 ha of willow plantations were projected to increase energy production by 39-56% after 2030, compared to scenarios that maximized timber supply with the same levels of residues and pulpwood only. This would be enough energy to offset over 26-46% of total fossil fuel energy consumption in New Brunswick. Several indicators were evaluated to determine realistic biomass and energy production. Net energy ratio (renewable energy produced divided by non-renewable energy consumption used), emissions, and cost of biomass energy for the full-tree harvesting system were about 30, 8 g CO_2e/kWh and $0.85-$0.95/kWh, respectively. Values for the full-tree system were 23-32% higher, 19-24% lower, and 42% lower than for the cut-to-length system.

By utilizing a portion of branches and tops and/or diverting some low-grade timber, forests could provide a significant alternative to fossil fuels.

Use of Study Results by J.D. Irving, Limited

This is one of several projects conducted under the SFMN in partnership with J.D. Irving, Limited (JDI). As described in an upcoming SFMN Synthesis Report entitled *"Legacy of the Sustainable Forest Management Network: outcomes of research collaborations among J.D. Irving, Limited, University of New Brunswick, and Université de Moncton",* these projects have been developed and overseen by the JDI Forest Research Advisory Committee (FRAC). The focus has been on research aimed at helping to manage the Black Brook forest for a range of forest values. The research projects were substantial in scope, and involved funding from JDI as well as from traditional research agencies. Six completed major research projects have included 26 individual graduate student studies. One on-going, post-SFMN, project is just beginning, funded by the NSERC Collaborative Research and Development program from 2010-2015.

Many examples of adaptive management have been developed as a result of the FRAC process and interaction of JDI management foresters and scientists over the broad range of research projects that were enabled by SFMN funding. Benefits can be divided into three categories:

1) direct changes in on-the-ground practices and setting of management plan objectives;

2) a long-term legacy of study sites including the working forest and reserve areas; and

3) natural-disturbance inspired adaptive management reserve areas.

The FRAC and research partners have brought knowledge and expertise to the process and, in turn, the learning has been disseminated broadly through a variety

of methods including publications, conferences, numerous tours, and JDI public and internal science communication efforts.

Some specific examples of outcomes and changes to management include:

1) JDI has altered its management plan objectives to maintain minimum areas of four forest types and of old forest of each type,

2) JDI has implemented best management practices to retain large beech trees and poplar for habitat reasons,

3) Operational tools now permit the company to assess effects of spruce budworm outbreaks on the landbase, and assess management plans for carbon in both forest and forest products, and

4) Interaction of scientists and graduate students with the FRAC has provided excellent opportunities for learning for all parties.

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Appendix 1

Summary of individual graduate student projects and advisors organized by report section.

Objective	Graduate Student Project	Student	Advisors
1. Succession dynamics of mixedwood stands	1.1. Dynamics of mixedwood stands, as influenced by natural disturbance and succession	Luke Amos-Binks[1]	Dr. D. MacLean[1] Dr. J. Wilson[2] Dr. B. Wagner[2]
	1.2. Effects of spruce budworm on stand dynamics of balsam fir and red spruce mixedwoods	Amanda Colford-Gilks[1]	Dr. D. MacLean[1] Dr. J. Kershaw[1] Dr. M. Béland[3]
	1.3. Shade tolerant hardwood natural regeneration 15 years after silviculture treatments on an industrial freehold in northwestern New Brunswick	Bruno Chicoine[3]	Dr. M. Béland[3]
2. Effects of pre-commercial thinning on biodiversity indicators	2.1. The effect of pre-commercial thinning on bryophyte communities	Amy Witkowski[4]	Dr. K. Frego[4], Dr. M. Roberts[1]
	2.2. The effect of pre-commercial thinning on the abundance of herbaceous species	Kerienne La France[1]	Dr. M. Roberts[1] Dr. K. Frego[4]
	2.3. The effect of pre-commercial thinning on the abundance of small mammals	Julie Henderson[1]	Dr. G. Forbes[1]
3. Key stand structures and abundance of biodiversity indicators of plantations and mixedwood stands	3.1. Abundance, age, body mass and spatial repartition of American marten in an industrial forest of Northwestern New Brunswick	Pascale Forget[3]	Dr. C. Samson[5]
	3.2. Viability of northern flying squirrel in relation to landscape-scale forest management	Matthew Smith[1]	Dr. G. Forbes[1] Dr. M. Betts[6]
	3.3. Demographic response of songbird species to selection harvesting	Samuel Hache[7]	Dr. M.A. Villard[7]
	3.4. Response of an old forest associate, the Brown Creeper, to forest harvesting at stand and landscape scales	Jean-François Poulin[7]	Dr. M.A. Villard[7]
4. Effects of alternative zoning allocations	4.1. Triad Scenarios on Crown License 1 in New Brunswick	Chris Ward[1]	Dr. T. Beckley[1] Dr. T. Erdle[1] Dr. D. MacLean[1]
	4.2. Bioenergy production - a case study for Crown lands of New Brunswick	Jean-François Carle[1]	Dr. D. MacLean[1] Dr. T. Erdle[1] Dr. R. Roy[3]

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