Legacy of the Sustainable Forest Management Network

Outcomes of Research Collaborations Among J.D. Irving, Limited, University of New Brunswick, and Université de Moncton

David A. MacLean, Luke Amos-Binks, Greg Adams, Gaetan Pelletier, and Marc-Andre Villard

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 2009

GRANTING COUNCILS
- Networks of Centres of Excellence (NCE) Program
    - Natural Sciences and Engineering Research Council of Canada (NSERC)
    - Social Sciences and Humanities Research Council of Canada (SSHRC)

FUNDING PARTNERS

GOVERNMENTS
- Canadian Forest Service
- Environment Canada
- Parks Canada
- Government of Alberta
    Sustainable Resource Development
- Government of British Columbia
    Ministry of Forests and Range
- Government of Manitoba
    Department of Conservation
- Government of Newfoundland and Labrador
    Department of Natural Resources
- Government of Ontario
    Ministry of Natural Resources
- Gouvernement du Québec
    Ministère des Ressources naturelles, de la Faune et des Parcs
- Government of Yukon Territory
    Energy, Mines and Resources

INDUSTRIES
- AbitibiBowater Inc.
- Ainsworth Lumber Co. Ltd.
- Alberta-Pacific Forest Industries Inc.
- Canadian Forest Products Ltd.
- Daishowa-Marubeni International Ltd.
- J.D. Irving, Limited
- LP Canada Ltd.
- Manning Diversified Forest Products Ltd.
- Tembec Inc.
- Tolko Industries Ltd.
- Weyerhaeuser Company Ltd.

ABORIGINAL GROUPS
- Heart Lake First Nation
- Kamloops Indian Band
- Métis National Council
- Moose Cree First Nation
- Treaty 8 First Nations in Alberta

NON-GOVERNMENT ORGANIZATIONS (NGOs)
- Ducks Unlimited Canada

INSTITUTION PARTNERS
- University of Alberta
    (Host Institution; also a Funding Partner)
- Concordia University
- Dalhousie University
- Lakehead University
- McGill University
- Memorial University of Newfoundland
- Mount Royal College
- Royal Roads University
- Ryerson University
- Simon Fraser University
- Thompson Rivers University
- Trent University
- Université de Moncton
- Université de Montréal
- Université de Sherbrooke
- Université du Québec à Chicoutimi
- Université du Québec à Montréal
- Université du Québec à Rimouski
- Université du Québec à Trois-Rivières
- Université du Québec en Abitibi-Témiscamingue
- Université Laval
- University of British Columbia
- University of Calgary
- University of Guelph
- University of Lethbridge
- University of Manitoba
- University of New Brunswick
- University of Northern British Columbia
- University of Ottawa
- University of Regina
- University of Saskatchewan
- University of Toronto
- University of Victoria
- University of Waterloo
- University of Western Ontario
- University of Winnipeg
- Wilfrid Laurier University

AFFILIATES
- Canadian Institute of Forestry
- Forest Ecosystem Science Co-operative
- Forest Engineering Research Institute of Canada
- Lake Abitibi Model Forest
- Manitoba Model Forest
- National Aboriginal Forestry Association

Legacy of the Sustainable Forest Management Network

Outcomes of Research Collaborations Among J.D. Irving, Limited, University of New Brunswick, and Université de Moncton

By

David A. MacLean[1]*, Luke Amos-Binks[1], Greg Adams[2],
Gaetan Pelletier[2], and Marc-Andre Villard[3]

---

[1] University of New Brunswick, Faculty of Forestry and Environmental Management, PO Box 4400, Fredericton, N.B., E3B 5A3, Canada

[2] J.D. Irving, Limited, PO Box 5777, 300 Union Street, Saint John, NB E2L 4M3, Canada

[3] Université de Moncton, Chaire de recherche du Canada en conservation des paysages, Moncton, NB E1A 3E9, Canada

* Corresponding author: David A. MacLean – macleand@unb.ca

TABLE OF CONTENTS

1.0 Introduction

A 1997 evaluation of the J.D. Irving, Limited (JDI) Black Brook Forest District (210,000 ha) in northern New Brunswick resulted in Forest Stewardship Council (FSC) certification (subsequently relinquished), subject to several conditions. The certification evaluation team urged the company to establish a Forest Research Advisory Committee (FRAC) to address uncertainty with respect to management of timber and non-timber values for large forest areas over a long time horizon. The company formed the JDI FRAC in 1998, initially chaired by Dr. Gordon Baskerville, and charged the group with identifying, advocating, and conducting research that would address significant knowledge gaps defined by the certification team, and empower the manager to manage for a broad range of values (Pelletier *et al.* 2002). Only objective measures of non-timber values will permit the company to manage the temporally/spatially dynamic pattern of stand types and conditions to ensure that all values would be available somewhere in the forest at all times.

The JDI FRAC recommended and developed research projects that resulted in JDI becoming a Sustainable Forest Management Network (SFMN) partner in 2000, and conducting six SFMN- and JDI-funded projects over the next decade. In this report, we summarize and describe these various research projects, which encompassed 26 graduate student projects at University of New Brunswick (UNB) and Université de Moncton (UdeM) from 2002-2010. The focus of all research overseen by the FRAC is influencing on-the-ground management of the Acadian forest, and *empowering the forest manager*, which under Dr. Baskerville's leadership, became the mantra of the FRAC.

The FRAC membership evolved somewhat over the years, but has typically comprised about 10 company managers and researchers from different organizations. Current FRAC members include professors from three universities (UNB, UdeM, and University of Maine) and researchers from the Manomet Center for Conservation Sciences and the New Brunswick government. A key point is that the FRAC has been intimately involved in all research in this report, from inception (proposal stage) to completion. All graduate students present progress reports to the FRAC once or twice per year, and receive feedback from company managers, other researchers, and project participants.

This report describes the research questions, projects, and how results have been applied in JDI management. Research projects have addressed:

1) the natural disturbance history of the Black Brook District, as the cause of current temporal/spatial patterns of stand types and stages of development;

2) approaches to assess state of the forest quantitatively with respect to non-timber values, especially biodiversity;

J.D Irving Limited established a Forest Research Advisory Committee in 1998 to address scientific knowledge gaps.

3) TRIAD (zoning) management scenarios, including projecting indicators of timber production, habitat, and forest composition under alternative landbase allocations;

4) new harvesting methods inspired by natural disturbance regimes on 2600 ha of adaptive management areas;

5) indicators of biotic integrity of stands in reserves, adaptive management areas, and the working forest;

6) the effects of forest and insect management on carbon in forest and forest products; and

7) management implications of forest dynamics, succession, and habitat relationships under differing levels of silviculture.

The process has resulted in active partnership between researchers and forest managers, with regular two-way communication and two-way education. This partnership and approach is continuing post-SFMN, with JDI and researchers approved for a new 2010-2015 NSERC Collaborative Research and Development (CRD)-funded project (approx. $890,000) to evaluate experimental manipulation of habitat structures in intensively managed spruce plantations to increase conservation value.

1.1 Research to empower the forest manager

The 1997 evaluation of the JDI Black Brook District by a team from Scientific Certification Systems resulted in FSC certification of that forest subject to four conditions:

1) development of a policy for identification of reserve trees,

2) development of a policy for plantation design,

3) development of a pre-harvest biological survey of planting sites, and

4) establishment of benchmark reserves.

The evaluation team acknowledged that the quantitative science base for measuring non-timber values was weak, or non-existent, and urged JDI to establish its own Forest Research Advisory Committee to identify or advocate research directed at helping company managers to better manage for non-timber values.

The value of the research is that it provides managers a measurable basis for designing or building the future forest to support specified non-timber values. This management process is literally the design, and creation, of the future forest in the context of its dynamically evolving temporal/spatial pattern of stand types and stages of stand development. The design provides the forest manager with

FSC certification auditors noted that the science behind non-timber values needed to be improved and suggested the establishment of the FRAC.

the flexibility to choose appropriate management approaches from time to time, and from stand to stand, to create the target future forest. Effectiveness of management is assessed in the context of direct measures of what the forest is becoming over time.

The mandate of the JDI FRAC is to identify and advocate research to address knowledge gaps with respect to non-timber values identified by the certification team. The intent was for research results to directly help the manager to manage the forest for specified non-timber values. **The research focused on two primary issues: 1) establishing objective measures for each target non-timber value, and (2) establishing a functional cause-effect basis for management of the availability of conditions essential for each target non-timber value** (Pelletier *et al.* 2002). Objective measures of the non-timber values, in and of themselves, are essential to reasoned management of the temporally/spatially dynamic pattern of stand types, and stand conditions, to ensure that all values will be available somewhere in the forest all the time. The evaluation team, and JDI managers, recognized that the research must empower managers, not to supplant them as decision makers.

Although the particular FSC certification that lead to the FRAC subsequently ceased to be an issue, JDI continued the FRAC and subsequently achieved certification under the Sustainable Forest Initiative (SFI) and International Standards Organization (ISO). The FRAC meets several times a year, and has developed and recommended research aimed at helping manage the Black Brook forest with respect to a range of forest values. The research projects are substantial in scope, and involve funding from JDI as well as from traditional research agencies.

Research funded through the SFMN resulted in 26 graduate student projects and over $1.7 million in funding.

The seven major research projects (six completed and one on-going, post-SFMN) and 26 individual graduate student studies are listed in Appendix I, and described more fully, by project, in the following pages. The report concludes with description of how project results have altered JDI management and silviculture.

2.0 Spatial and Temporal Patterns of Natural and Human-Caused Forest Disturbance on the J.D. Irving, Limited Black Brook District: Past, Present and Future

The concept of using the natural disturbance regime as a guide for appropriate forest management has received much attention over the last decade. Disturbance is both a major source of temporal and spatial heterogeneity in the structure and dynamics of natural communities and an agent of natural selection in the evolution of life histories (Sousa 1984, Pickett and White 1985). Information on historic range of variability of natural disturbance can help forest managers to maintain structural and compositional patterns and regional mosaics of forests that are consistent with the natural disturbance regime (Mladenoff *et al.* 1993, Landres *et al.* 1999). Such information can also help select stand-level silvicultural

Understanding natural disturbances helps managers tailor management plans to develop forests that exhibit natural characteristics.

treatments that are appropriate, given the natural disturbance regime, silvics of species, and stand dynamics. Maintaining regional forest type diversity and applying appropriate stand-level treatments reflect the essence of the coarse-filter approach to maintaining biodiversity.

The distribution and location of forest types, species composition, age-class distribution and stand characteristics largely determine forest productivity, habitats, and diversity. Both natural and human-caused disturbances have significant effects on these factors. The degree to which human-caused disturbances vary from natural disturbances can alter forest structure and function. As such, it is important to understand how disturbances and forest management planning have altered forest structure over time and space.

The 210,000-hectare J.D. Irving, Limited Black Brook District in New Brunswick represents some of the most intensively managed forest lands in Canada, and also is JDI's primary location for research. The landbase was purchased by JDI in 1943, and soon after a full timber inventory was completed. The historical benchmark condition (~1946) of the Black Brook District was derived from a combination of interpretation of 1945 aerial photographs and timber inventory data from extensive ground cruises in 1945-1947. These historical aerial photographs were digitized and interpreted using modern techniques to produce a spatially explicit reference forest condition prior to intensive forest management (*Figure 1*). The inventory, in conjunction with the interpreted aerial photo set from 1945, provides a unique and important baseline from which to evaluate effects of intensive forest management on forest structure and biodiversity.

We conducted analyses to facilitate managing for biodiversity and timber management, based on a coarse-filter approach, using Black Brook as a case study (MacLean *et al.* 2002). Natural disturbance regimes, primarily spruce budworm (*Choristoneura fumiferana*), wind, and fire, were used to define guidelines for appropriate stand- and forest-level treatments. Scenario planning tools were used to quantitatively analyze forest landscape patterns under managed and natural disturbance conditions. A "pre-management" forest cover inventory was established using photointerpretation and digitizing of 1945 aerial photographs for the entire landbase. Historical harvest and silviculture maps were digitized to obtain pre-1982 harvest and silviculture locations.

We used modeling to project current and simulated potential forests under alternative scenarios; analyzed management and disturbance effects on species composition, patch size, and age class distributions; and compared temporal and size distributions of past harvesting and silviculture with those potentially created by natural disturbances. Actual and projected landscapes were then assessed for the risk of extirpation of each vertebrate species of interest, using a species sorting algorithm and spatially explicit landscape data.

JDI's Black Brook District is a hub of research activity.

The natural disturbance regime of Black Brook is dictated by periodic outbreaks of spruce budworm and secondary disturbances like fire and wind.

Objectives were to:

1) model development of the forest in the absence of human intervention and as influenced by spruce budworm outbreak scenarios and compare it to the managed landscape;

2) analyze management and disturbance effects on species composition, landscape metrics, age class distributions, and within-stand structures; and

3) assess past (1945), actual (2002) and projected (2027) landscapes for risk of extirpation of vertebrate species, using a species sorting algorithm and spatially explicit landscape data.
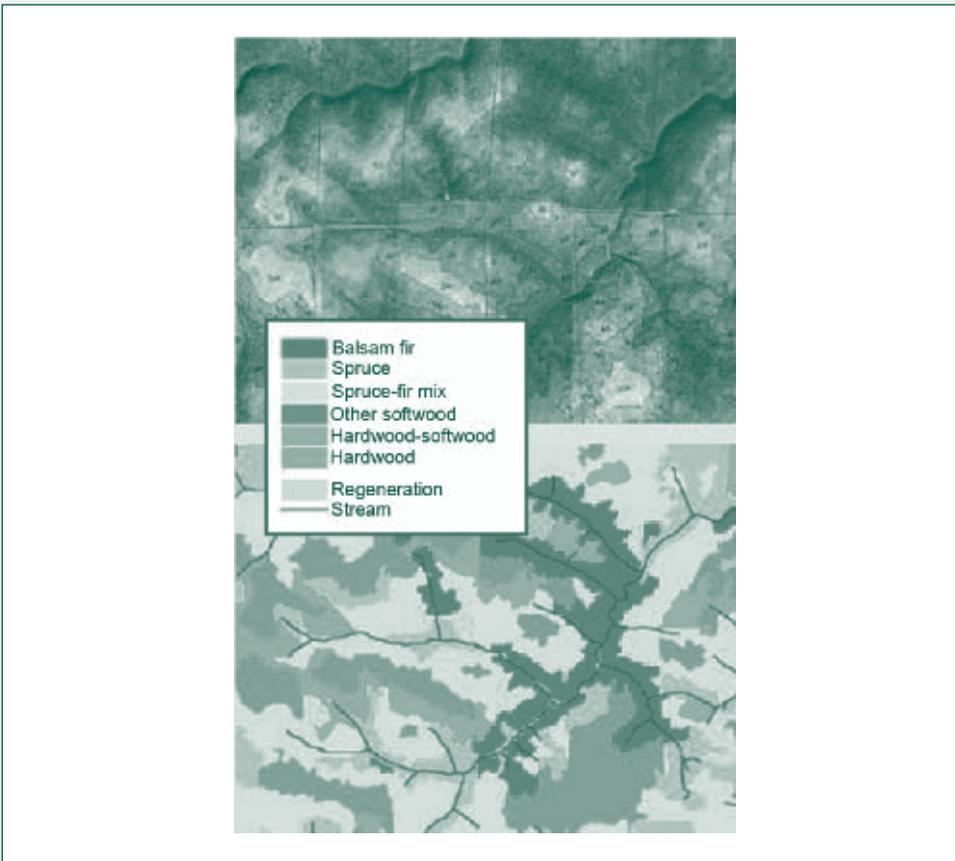

Figure 1.   Aerial photographs of the 210,000 ha Black Brook District in 1945 were digitized and interpreted using modern techniques to produce a spatially explicit reference forest condition prior to intensive forest management.

2.1 Using insect-caused patterns of disturbance in northern New Brunswick to inform forest management

The natural disturbance paradigm is based on the principle that organisms inhabiting a landscape have evolved to the structures and patterns present as a result of recurring natural disturbances. In order to maintain these structures and patterns, management practices should approximate those that occur under natural disturbance. The major natural disturbance agent of the Black Brook District is periodic outbreaks of eastern spruce budworm. Known outbreaks have occurred across the region at intervals of 30-40 years, around the 1870s, 1910s, 1950s, and most recently the 1970s-80s. As a result, spruce budworm outbreaks have an important influence on the adaptations of native species. Forestry practices including harvesting, silviculture, replacement of the most vulnerable balsam fir (*Abies balsamea*) with spruce (*Picea* sp.) plantations, and aerial protection against insects have altered the influence of spruce budworm across the landscape. However, use of modeling and access to historical inventory information allowed us to forecast forest development as influenced by budworm outbreaks and compare results to the managed landscape (Porter *et al.* 2004).

Spatial chronologies of spruce budworm defoliation were developed by digitizing annual aerial defoliation survey maps from 1945 to the cessation of budworm outbreaks around 1992. Aerial spray protection was used to reduce the impact of defoliation on host species during outbreaks, and observed defoliation data were adjusted based on annual spray efficacy records in order to create an accurate representation of defoliation levels in the absence of insecticidal protection (Porter *et al.* 2004). Stand tables representing the historical forest condition were forecast using growth loss and mortality versus defoliation functions, and adjusted (unprotected) defoliation values during the 1950s and 1970s-1980s outbreaks. This resulted in a projection of the 1945 benchmark condition of Black Brook District to 2002, incorporating influences of the 1950s and 1970s-1980s spruce budworm outbreaks.

Simulating the landscape without human intervention but with budworm outbreaks resulted in 47% of the landbase being made up of balsam fir-spruce mixedwoods.

The landscape simulated under spruce budworm outbreaks had fewer balsam fir and spruce dominated stands. Mortality of balsam fir and spruce led to 47% of the landbase being made up of spruce-balsam fir dominated mixedwoods, with the remainder hardwood-dominated mixedwoods and hardwood stands. The reduction in dominance of balsam fir appeared to only be temporary, as regenerating balsam fir over time regained position in the overstory. Simulations revealed that mortality in balsam fir stands was largely stand replacing, but that sufficient advanced regeneration existed to permit its persistence over the long term. This pattern may be well reflected by clearcutting with consideration for advanced regeneration. Mortality in spruce stands was often incomplete due to reduced susceptibility to defoliation (*Figure 2*), indicating that partial cutting may be more appropriate in those stands.

Results showed that spruce budworm disturbances would produce a clumped age distribution, reflecting mortality events. This creates several management issues, both for the landowner who desires stable income, and for society that depends on a stable flow of timber as produced from a more even distribution of age classes. Providing suitable amounts of older and multi-cohort stands that reflect what would exist following natural disturbance may be the best way of ensuring long term forest productivity and diversity.
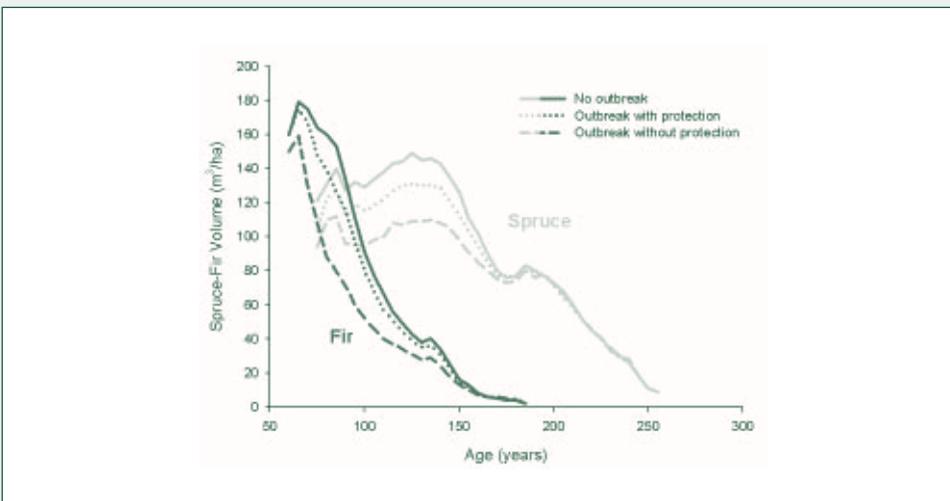
Figure 2.   *Spruce and balsam fir stand volume development in the Black Brook District, simulated under no spruce budworm outbreak, an outbreak with insecticide protection, and an outbreak without insecticide protection.*

Stand (patch) sizes that resulted from simulation of successive 1950s and 1970s-1980s spruce budworm outbreaks were similar to those that existed on the landbase in 1945, and were much larger than in the actual forest in 2002. Forest management has typically reduced harvest openings across the landbase, and harvesting has created progressively smaller patches, as compared to natural disturbance. Average patch size in 2001 was 11 ha, substantially less than the 63 ha size simulated under budworm outbreaks.

2.2   Effects of intensive forest management on forest structure from 1945-2027

The main objective of this study was to compare changes in forest structure (landscape and stand characteristics) of the Black Brook District from 1945 to 2002 and to the projected forest of 2027. Using the 1945 historical forest condition as a benchmark, impacts of the intensive forest management regime that began in the late 1950s was quantified (Etheridge *et al.* 2005 and 2006).

The area of softwood-dominated forest was relatively stable from 1945 (40%) to 2002 (42%) and was projected to increase by another 11% by 2027. However significant changes in mixedwood and hardwood dominated forest area occurred (Etheridge *et al.* 2006). Mixedwood forest area was reduced from 37% in 1945 to 18% in 2002, while hardwood-dominated forest increased from 10% to 25% over the same period. Mixedwood and hardwood dominated areas were projected to remain similar from 2002 and 2027. The increase in hardwood-dominated area was largely attributed to mortality of spruce-fir components of mixedwood stands during the 1950s and 1970s-1980s spruce budworm outbreaks. Etheridge *et al.* (2005) concluded that better understanding of successional dynamics and persistence of fir- and spruce-mixedwood stands was needed, which led to studies by Amos-Binks *et al.* (2010; summarized in Section 6.1).

In general, the 1945 forest was heavily concentrated in old balsam fir-dominated stands, but by 2002, balsam fir content was reduced by 34-57% in softwood stands and 16-18% in mixedwood stands. This shift was a direct effect of mortality induced by spruce budworm, but also from indirect budworm effects (via active JDI management strategies to reduce fir abundance across the landscape, in favour of less susceptible spruce plantations).

With only 4% of the landbase made up of natural softwoods, we needed to determine the value of plantation forests for habitat.

Significant reductions in the amount of old forest occurred between 1945 and 2002 (Etheridge *et al.* 2005). In 1945 about 85% of the forest was greater than 70 years old and much of it was thought to have its origin from a severe spruce budworm outbreak during the 1870s. By 2002 old forest made up only 44% of the landbase and was projected to decline a further 3% by 2027. More specifically, old softwood and mixedwood habitats with large trees declined from 112,600 and 55,200 ha, respectively, to 8200 and 7200 ha. The fact that only 4% of the landbase is made up of natural softwood due to significant investments in planted stands emphasized that further research into the value of plantations as a source of habitat is necessary.

The Black Brook District of 1945 was made up of large patches that originated from the 1870s spruce budworm outbreak. Over half of the landbase consisted of patches greater than 1000 ha (due to wide ranging natural disturbances) and only 13% were smaller than 100 ha (*Figure 3*; Etheridge *et al.* 2006). Average patch size of softwood, mixedwood and hardwood stands declined by 70%, 90% and 40%, respectively, from 1945 to 2002. In 2002, 58% of patches were less than 100 ha – due to harvest and silvicultural activities necessary to produce a consistent flow of wood products. This decline was expected to continue from 2002 to 2027 and was largely due to relatively small harvest block sizes. Overall, the decrease in patch sizes may have significant implications for species that rely on large patches and contiguous forest habitat for their sustenance. There is a need for planning for larger patches over the landscape.

2.3   Risk of extirpation of vertebrate species in the Black Brook District

The objective of this study was to test the effectiveness of categorical population risk rating and use it to identify vertebrate wildlife species of management concern. Higdon *et al.* (2005) developed a landscape-based ranking system for relative risk of extirpation of individual vertebrate species, and applied it to the Black Brook District. This ranking system was then applied to three spatially explicit forest inventories representing the forest in 1945, 2002, and 2027 (Higdon *et al.* 2006). A total of 157 vertebrate species were incorporated into the species-sorting algorithm (SSA) based on range maps and expert consultation. Four risk categories were identified and assigned to species based on variables that assessed species' potential abundance, proportion of landscape suitable for occupancy, habitat connectivity, and population growth potential (Higdon *et al.* 2005).

Of the 157 species studied, 26 (17%) were rated as Class I (potential high risk of management concern). Species identified for the high risk ranking (Class I risk) were:

1) wide-ranging species with large habitat requirements,

2) species associated with riparian forest,

3) high risk based on an outside organization's ratings, and

4) species with limited forest habitat.
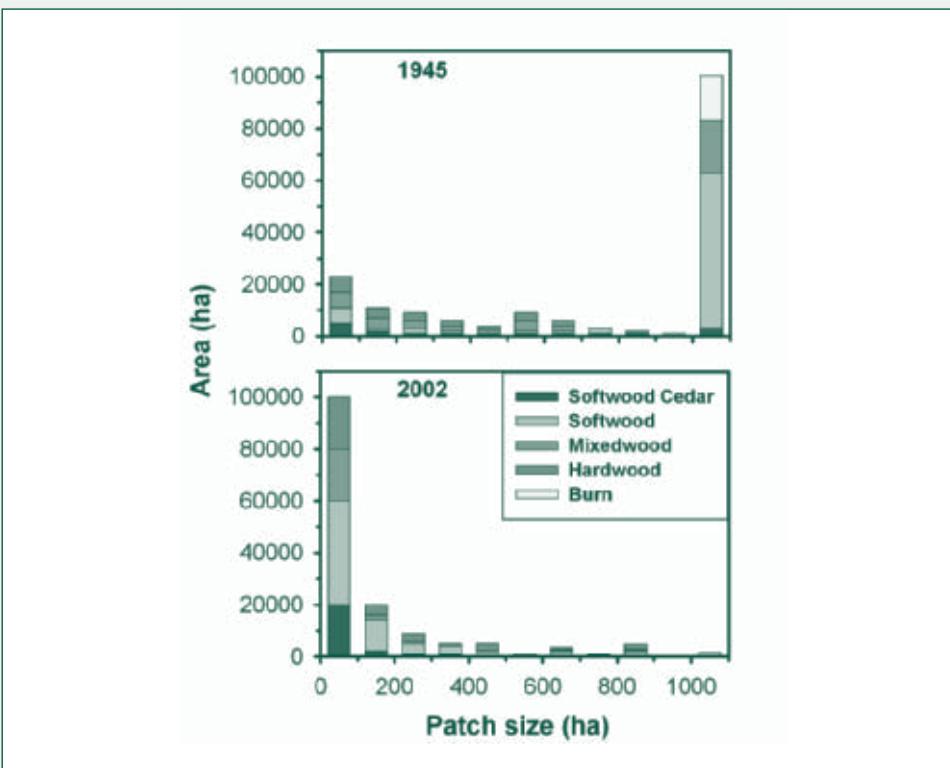
Figure 3.   *Patch size distribution of forest in the Black Brook District in 1945 and 2002. (Modified from Etheridge et al. 2006).*

The 5 wide-ranging species included those that tended to have large home ranges and low densities, and high risk was largely due to the study area being unable to support threshold population levels in isolation. Similarly, 9 species were associated with riparian forest and were limited by amount of habitat available simply due to the limited size of the landbase. Those species classified as high risk based on an outside organization's ratings may in fact be fairly secure across the landbase, but were included based on the fact that they were identified as being at risk at a provincial or national level. This highlights the point that specific landscapes must be dealt with within their own context, as a species may be of concern at a national or regional level and abundant in the study area or vice versa. The above mentioned species populations may cause little direct concern for forest management, as there is little a forester can do to increase the size of the management area or amount of riparian forest in order to attain sufficient area to maintain threshold population levels. Species rated as Class I due to limited forest habitat availability were of greatest concern, as these habitats are directly influenced by forest management activities. Habitat in the Black Brook District for two Class I species, Pileated Woodpecker and Sharpshinned Hawk, is shown in *Figure 4.*

Figure 4.   Habitat associations for two Class I species on the Black Brook District. The lighter shaded area is hardwood about 90 years of age, habitat for Pileated Woodpecker (Dryocopus pileatus). The dark shaded area is mid-aged (40-90 years, depending on tree species) pure spruce-fir forest in patches about 20 ha, habitat for Sharpshinned Hawk (Accipiter striatus). Habitat maps were generated using J.D. Irving, Limited's GIS database, with habitat use information provided by the Forest Habitat Program, New Brunswick Department of Natural Resources.

The SSA was used to assess the risk of extirpation of the same 157 vertebrate species (Higdon *et al.* 2006). The relative risk for vertebrate species was assessed based on landbase conditions in 1945, 2002 and projected to occur in 2027. SSA results were fairly similar for 1945, 2002 and 2027 in that 27, 20 and 26 species, respectively, were assessed as Class I risk. There were, however, some concerns about the availability of future habitat, particularly when most Class I species were assessed as such due to insufficient old softwood and mixedwood habitat. Mixedwood forest was plentiful in 1945. Since then it has been significantly reduced due to management and the influence of spruce budworm, and it was projected to decline further in future. Although lack of habitat was the main contributor to species risk, overall trends in reduction of patch size and fragmentation in all forest types contributed for certain species.

3.0 TRIAD Case Study: Harvesting Inspired by Natural Disturbance, Stand Structure Effects, and Scenario Planning

A second SFMN and JDI funded project began in 2002, to evaluate the relative effects of intensive forest management or zoning scenarios on a suite of indicators of timber and non-timber values. This project followed the TRIAD approach to forest management (Seymour and Hunter 1992, MacLean *et al.* 2009), which proposed reserves and plantations, embedded within a landscape managed by alternative silvicultural systems (Franklin 1989, Gillis 1990).

Silvicultural systems should be patterned after local natural disturbance regimes (Seymour and Hunter 1992). Therefore, intensively managed (e.g., plantations, thinned stands), extensively managed (e.g., naturally regenerated, perhaps over a longer rotation), and protected areas (unmanaged areas, meant to sustain values that could conceivably otherwise be lost) should co-exist on the landscape. The challenge is to determine how much of each management type, where, at what times, to produce what values. In principle, focusing intensively managed forest on a portion of the landbase would concentrate silvicultural investments, permit enhanced protection against insects and fire, and permit high yields while reducing 'pressure' on extensively managed forest. The precautionary principle mandates benchmark scientific reserve areas: since we cannot know all consequences of actions, unmanaged benchmarks should be retained for scientific study and 'to err on the side of caution'.

Mixedwood forest was defined as a habitat of primary concern due to management objectives, influence by spruce budworm, and its projected further decline.

The principle behind TRIAD management is that increased productivity provided by intensive management can ease pressure on the remaining forest, allowing it to better serve non-timber goals.
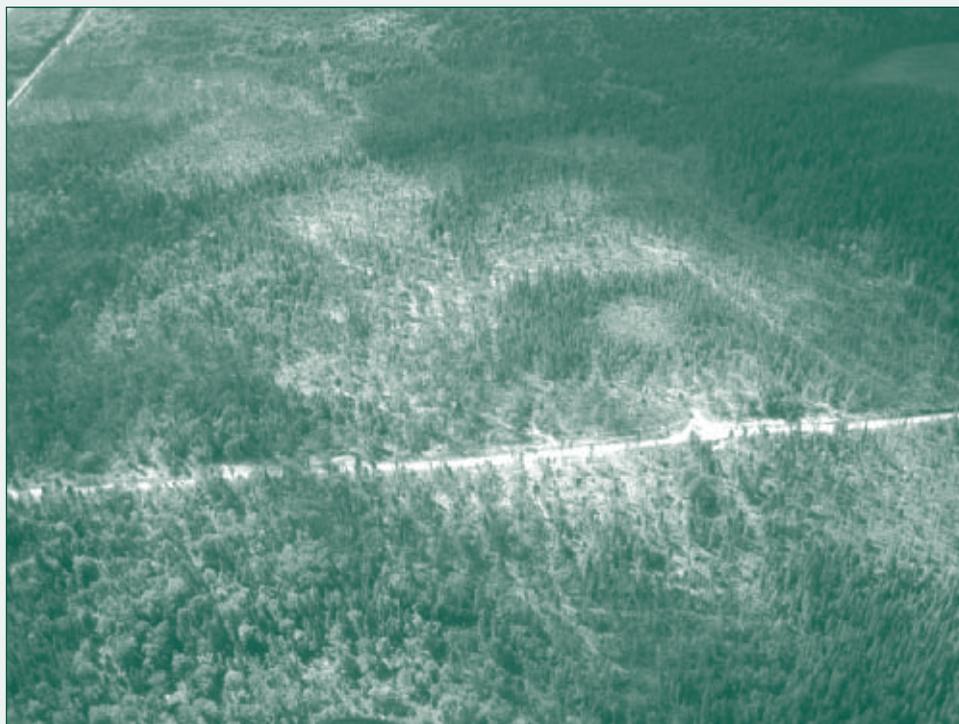
Figure 5.   Harvest inspired by natural disturbance was implemented across 2600 hectares of an adaptive management area in JDI's Black Brook District.

As part of this study, JDI committed to implement 2600 ha of adaptive management treatments inspired by natural disturbance (primarily spruce budworm and gap replacement). The company also agreed to assist in establishing a network of 240 permanent sample plots spanning reserves, adaptive management areas, and working forest. These formed the basis for TRIAD scenario planning analyses and for studies of pre- and post-treatment response and between-treatment comparisons of stand structure.

Objectives were to:

1)   conduct a case study of TRIAD management scenarios, including projecting indicators of timber production, habitat, and forest composition under alternate landbase allocations;

2)   develop and implement new harvesting methods inspired by natural disturbance regimes on 2600 ha of adaptive management areas; and

3)   assess and compare stand composition and vertical and horizontal structure of stands in reserves, adaptive management treatments, and the working forest.

This project was conducted in collaboration with the biodiversity assessment projects conducted by UdeM researchers, described in Section 4, which used the same network of plots.

3.1 TRIAD management scenarios in the Black Brook District

Triad forest management strategies were evaluated using the Black Brook District as a test landbase by Montigny and MacLean (2006). A total of 64 allocation scenarios (0-15% reserve area, 39-64% intensively managed softwood and 21-61% extensively managed area) were used to determine how varying land allocations within the TRIAD concept would influence a number of indicators.

Short-term harvest was insensitive to the amount of area in reserve and intensive management, but doubled over the long term as the intensive management zone increased from 39% to 64%, due to increased growth from the intensive zone. Hardwood harvest levels decreased as the area allocated to reserves increased, due to reduced management area. In general the area of old forest increased with area assigned to reserves. Old mixedwood forest was of particular concern because it was of low abundance and generally insensitive to increases in reserve area. The intensive management area is of particular value because it permits an increase in the amount of area available for reserve forest while maintaining a similar harvest level over the long term.

In 2005, the reserve area in JDI's Black Brook District was made up of 27 forest reserves totaling 9500 ha or 5% of the landbase. Identifying reserve areas that are of value to conservation efforts is an important process. A gap analysis was conducted to evaluate representation by ecosite of the reserve area and to test two approaches to identify additional reserves that would increase the total reserve forest to 6%, 7%, 10%, or 15% of the landbase (Montigny and MacLean 2005). The **heterogeneity method** was designed to incorporate the greatest amount of forest features in the smallest area, by selecting areas with maximum diversity. The **representation method** was designed to identify a target area of 10% the landbase, including with 10% coverage of each ecosite. The heterogeneity method identified fewer reserves that were larger, had 10% more core area, 30% larger patch sizes, and 30% less edge. Management simulations revealed that selection method resulted in similar softwood harvest levels of 2.3-2.5 million m³ per 5 year period, although the hardwood harvest level was 0.02-0.09 million m³ higher under the representation method. **We concluded that the heterogeneity method was preferable, as it had little influence on harvest levels but increased conservation value due to reserve area being concentrated in fewer, larger patches**.

3.2 Adaptive Management Areas – harvesting inspired by natural disturbance

In a second, related SFMN TRIAD/Intensive forest management study that began in 2002, JDI implemented 2600 ha of treatments inspired by natural disturbance (primarily spruce budworm and gap replacement), and assisted in establishing a network of 240 permanent sample plots (PSP) spanning reserves, adaptive management areas, and working forest. This has formed the basis for studies of pre- and post-treatment response and between-treatment comparisons of stand structure.

Increases in intensive management areas provided long-term increases in timber production while also permitting increases in reserve area.
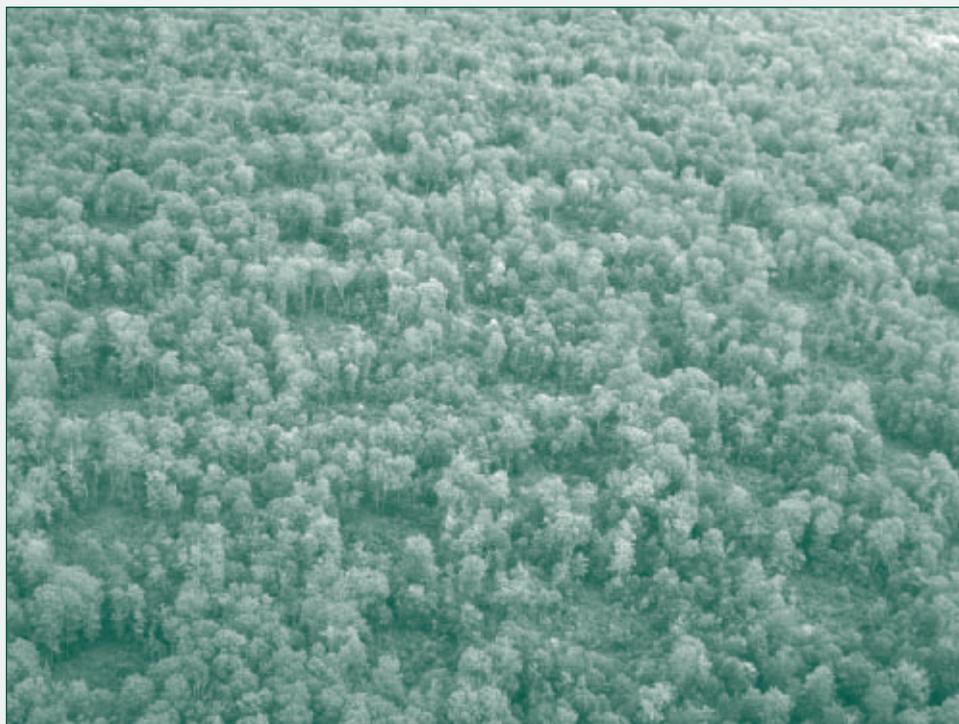
Figure 6.   Group selection harvests were applied to shade tolerant hardwood stands to approximate the creation of gaps caused by blowdown, root rot, insects and senescence.

Modified harvest treatments were conducted by JDI. Treatments were defined based on stand type, predominant natural disturbance agent, and stand structure resulting after disturbance. A previous classification of natural disturbances in the Maritimes (Clowater *et al.* 1999) differentiated 14 classes based on:

1)   four agents (fire, spruce budworm outbreaks, windstorm, or gap dynamics),

2)   four disturbance cycles (return intervals),

3)   four extents (regional, multi-stand, single stand, or tree), and

4)   four intensity classes based on post-disturbance stand condition: stand replacing (0-25% of stand remaining after disturbance), partial stand replacing (26-50% remaining), patch replacing (51-95% remaining), or single tree replacing (gap creating; 95-100% remaining).

Fire is not a major influence on this landbase, but it was examined based on the 1945 air photos and sampling of characteristics of unburned patches within previous fires, age structure, and succession dynamics (Oates 2003). Wind (major blowdown events) similarly is not a major influence, except at very long intervals.

The above classification scheme was used to assign stand-level treatment prescriptions (% of stand remaining) based on budworm and gap dynamics (*Table 1*). Since spruce budworm only influences host species (balsam fir and white (*Picea glauca*), red (*P. rubens*), or black (*P. mariana*) spruce), harvest removals under budworm-inspired treatments only applied to the spruce-fir component of the stand. The degree of tree mortality resulting from a budworm outbreak depends upon stand species composition (both host/non-host mix and which host species: balsam fir > white spruce > red spruce > black spruce) and stand age (mature/overmature > immature). Actual harvested proportion varied depending on species composition. Harvest prescriptions were based on average mortality levels by species, (e.g., removing 8-9 out of 10 mature balsam fir, 4 out of 10 mature white or red spruce, and 2 out of 10 black spruce). Disturbance regimes applied to shade tolerant hardwood stands were group selection and single tree selection treatments. These treatments approximate the creation of gaps by the death of small clumps or single trees, caused by blowdown, root rot, other insects, death resulting from longevity, etc. (*Figure 6*).

Table 1.   *Percentage of the stand remaining after the disturbance as a guide to target removal levels during harvesting (From MacLean 2004 as in Clowater* et al. *1999).*

Disturbance Category	Severity	Stand Remaining (%)		Target Removal Intensity (%)*	
		Range	Midpoint	Range	Midpoint
B1: Budworm – stand killing	Stand-replacing	0-25	12.5	75-100	87.5
B2: Budworm – partial mortality	Partial stand-replacing	26-50	37.5	51-75	62.5
B3: Budworm – minor effects	Patch-replacing	51-95	72.5	5-50	27.5
G1: Gap creation – patch creation	Patch-replacing	80-95	87.5	5-20	12.5
G2: Gap creation – natural stand dynamics	Gap replacement	96-100	97.5	0-5	2.5

* Target removal intensity only applies to host species of the spruce budworm (balsam fir, white spruce, red spruce and black spruce)

The above treatments were applied after the establishment of a PSP network, and have subsequently been used to assess regeneration (Griffin 2005), blowdown dynamics (Amos-Binks 2005), and to compare characteristics between actual budworm-killed forest and budworm-inspired treatments (Eiry Spence, MScF project at UNB, in progress). Griffin (2005) noted high regeneration density, ranging from 34,000-50,000 stems/ha, with the lowest densities occurring in the control plots. Stocking of balsam fir ranged from 73-83%. Blowdown occurred at greater levels (15%) in treated areas compared to control areas (1%) (Amos-Binks

Prevalent natural disturbances were used to develop harvest treatments that retained characteristics of disturbances of various stand types.

2005) but is a natural component of stand dynamics following spruce budworm-induced mortality (Taylor and MacLean 2009). Balsam fir was the most vulnerable species to blowdown, with 29% damaged. In general, smaller trees (in terms of diameter and height) were more susceptible to wind damage, likely owing to the fact that smaller trees were sheltered by larger trees prior to harvest and suffered from the sudden exposure following harvest. Current research is examining stand and landscape variables that influence blowdown (Amos-Binks and MacLean, unpublished).

There are clear roles for both even-aged and uneven-aged management in natural disturbance-based management. Clearcut treatments can approximate stand-replacing disturbance, while patch-replacing disturbances can be approximated by partial cut treatments. Thus, natural disturbance insight can provide useful input into harvest and silviculture planning and design. A key factor is the amount of mortality within stands that will result from disturbance. Mortality in typical spruce budworm outbreaks averages about 85% in mature balsam fir, 35-40% in immature fir and mature spruce, and 13% in immature spruce stands.

Forest structure and composition at both the stand and landscape level are influenced by insect outbreaks. Harvest prescriptions in stands can be based upon removing an equivalent amount of trees to what would be killed by insects. At the landscape level, data about insect effects can help to set targets for species composition, age class distribution, patch size distribution, and connectivity. Realistically, no jurisdiction or forest company will blindly "emulate" what insects do in killing forests over large regions. However, in some cases, stand-level harvest that approximates insect effects may well make ecological sense, (e.g., where it results in mixed-species stands or multi-age class stands that otherwise would be rendered homogeneous by clearcutting).

Additional research is ongoing by UNB MScF student Eiry Spence who is comparing long-term stand-level characteristics and landscape-level patterns of mortality of an uncontrolled spruce budworm outbreak in the Cape Breton Highlands in the 1970s-1980s with that of the adaptive management area harvest inspired by spruce budworm. This research is fundamental in developing stand-level prescriptions for frequency of harvest and selection of residual structures. Landscape-level patterns will be used to inform the design of harvest blocks in terms of size, shape, and spatial arrangement.

3.3 Stand structure before and after harvest inspired by natural disturbance: assessment by photo-based techniques

The residual forest that remained following harvest inspired by spruce budworm provided a wide variety of stand conditions because of the range of harvest removal levels. Long-term monitoring of permanent sample plots established within the residual forest will assess the effectiveness of the harvest as an alternative management option. Stem maps describing the spatial location of trees sampled in a

Both even-aged and uneven-aged management have their place in natural disturbance-based management.

forest inventory are increasingly used to model relationships between neighboring trees in distance-dependent growth and yield models, as well as used in stand visualization software. Current techniques and equipment available to acquire tree spatial locations prohibit widespread application because they are time consuming, costly, and prone to measurement error.

Dick *et al.* (2010) presented a technique to derive stem maps from a series of digital photographs processed to form a seamless 360º panorama plot image. The process described allowed for the calculation of distance from plot center and azimuth to each plot tree. The technique was tested on 46 permanent sample plots established within the adaptive management area. A total of 1398 sample trees were sampled within the varying conditions provided by the harvest treatment and compared to traditional stem mapping methods. Average absolute distance error was 0.38±0.44 m, and average absolute azimuth error was 2.3±2.5º. Computed average horizontal accuracy was 0.40±0.42 m, with 85% of measured trees within 0.5 m of the field measured tree location. The camera equipment and post-processing software used in this study were inexpensive compared to popular tools used, providing a cost-effective alternative when tree stem mapping is desired.

4.0 TRIAD Case Study: Assessing the Biotic Integrity of Forest Reserves and Working Forest of the Black Brook District

Because the Black Brook District features a broad range of harvesting intensities, it provides an excellent opportunity to examine the relative tolerance of different taxa to the treatments applied. This was the starting point of a research project aiming to identify ecological thresholds in species response to harvesting intensity. We reasoned that taxa requiring mature forest stands or associated features would exhibit species-specific thresholds in certain stand characteristics (e.g., density of large trees or snags, canopy closure) or landscape features (e.g., % mature woodland) beyond which they would have a high probability of being present or reproducing successfully. Knowledge of these thresholds (or threshold ranges) would then provide the manager with useful information to adjust treatment intensity at the stand level or to distribute harvest treatments across the landbase (Betts and Villard 2009).

Initially, we chose forest birds (passerines and woodpeckers) as indicators because they:

    1) have been shown to be sensitive to alterations of their habitat at local and landscape scales,

    2) can be censused efficiently over large scales,

Stem maps can be accurately derived using 360º panoramic images of sample plots.

Threshold ranges of stand and landscape characteristics can help harvest planning.

3) represent a substantial proportion of the terrestrial vertebrate species inhabiting forest ecosystems, and

4) collectively use a wide array of stand structures and compositions.

To investigate forest bird species' response to harvesting intensity, we conducted a survey at 390 sampling stations using the point count method. This work, led by Jean-Sébastien Guénette (M.Sc., UdeM), was complemented by systematic searches for signs of Pileated Woodpecker (*Dryocopus pileatus*) presence at a subset (126) of these point count stations (Jérôme Lemaître, MSc, UdeM).

The following questions were posed:

1) Are there thresholds in the probability of detecting a species (or indices of its reproduction) according to harvesting intensity at the stand level?

2) At the landscape scale (1 km radius around a station)?

3) If so, do thresholds differ whether we consider probability of presence versus probability of reproductive activity?

At the landscape level, we found that 13 of the 42 species examined were significantly less frequent as harvesting intensity increased.

We found that 13 of the 42 forest bird species common enough to be included in the analyses were significantly less frequent as harvesting intensity increased (Guénette and Villard 2005). These species generally exhibited thresholds in their response to **(a) a multivariate gradient in stand structure reflecting harvesting intensity, or to (b) individual variables reflecting stand structure (i.e. canopy closure, density of large-diameter trees)**. Statistical simulations also revealed that the threshold detection method we used (logistic regression models and ROC analysis) was robust enough to address the variations in sample size and extent of gradients sampled (Guénette and Villard 2004).

This work was consulted by the New Brunswick Department of Natural Resources when it revised guidelines for old forest management on Crown lands. However, we recently found that habitat requirements for nesting may be substantially greater than those linked to the probability of presence of a species at a station (Poulin *et al.* 2008). At the landscape level, we found that 14 of the 42 species examined responded to percent mature/old forest cover within a 1-km radius (Villard and Guénette 2005). When comparing landscape-level thresholds in habitat requirements between northwestern and southeastern New Brunswick, Betts and Villard (2009) found that they varied geographically for a given species, but showed remarkable consistency over time in a given region.

Another study focused on the Pileated Woodpecker, a crow-sized species requiring large-diameter trees and snags for nesting, foraging, and roosting. The trademark cavities left behind by this species make it possible to rapidly determine its distribution over large areas, and to analyze its selection of foraging substrates. We found that this woodpecker foraged preferentially on deciduous trees >35 cm dbh, and on conifer trees >30 cm dbh. It used American beech (*Fagus grandifolia*) as a foraging substrate to a much greater extent than expected based on its availability (Lemaître and Villard 2005). On this basis, JDI has established prescriptions to ensure that large beech trees and snags are maintained in managed hardwood stands.

A SFMN TRIAD/Intensive Forest Management research project undertaken in collaboration with Dr. MacLean made it possible to expand the scope of the 'threshold' projects above to encompass a much broader set of potential biodiversity indicators. Potential indicators sampled included carabid beetles, as well as songbirds and woodpeckers. In addition, Dr. MacLean's students collected data on stand structure (e.g., density of large trees and snags, coarse woody material, etc.) and the presence of two species of epiphytic lichens. Species/taxa showing sensitivity (or tolerance) to harvest treatments were screened for eventual inclusion into a multi-metric index. M.Sc. candidate Anne-Sophie Bertrand (UdeM) examined various scoring systems to assign numerical values to the observed status of indicators, compared these scores among JDI's reserves, adaptive management areas, and working landscape, and analyzed its variation along gradients in stand structure.

5.0 Forest Management Planning, Pest Management and Carbon Sequestration

Concerns about global climate change and increased levels of greenhouse gases are an important consideration in forest management. Carbon dioxide (CO_2) is the most abundant greenhouse gas and modern society's reliance on fossil fuels has increased the concentration of CO_2 in the atmosphere. Forest ecosystems are able to store considerable quantities of CO_2 through the process of photosynthesis and, as a result, much attention has been given to the world's forests as a means to slow the rise of CO_2 levels. Forest management strategies that increase capacity of forests to store CO_2 in solid form (i.e., as standing, living trees or as harvested forest products) are desired.

There is increased interest in forest management strategies that mitigate carbon dioxide emissions in light of climate change.

Natural disturbances (fire, insect outbreaks, etc.) further complicate matters because they cause significant tree mortality and initiate the release of CO_2 into the atmosphere from decaying trees. Given the regional extent of many insect outbreaks, large influxes of CO_2 may have significant effects on the global carbon cycle and, in turn, climate change. Strategies to mitigate large scale natural disturbances through improved forest and pest management are an important consideration for carbon sequestration strategies.

Objectives of this study were to:

1) integrate the Carbon Budget Model for the Canadian Forest Sector (CBM-CFS3) into a forest management planning framework using available forest inventory data, and quantify carbon dynamics;

2) account for end-use wood products and their associated retention of carbon in forest management planning;

3) incorporate the Spruce Budworm Decision Support System (SBW DSS) into a forest management planning framework;

4) assess impacts of potential spruce budworm outbreaks on forest and carbon management strategies;

A related SFMN-funded project on pest management and carbon (also reported in sections 5.5 and 5.6) had the following additional objectives, to:

5) assess the cost-effectiveness of investing in pest management activities for forest carbon sequestration; and

6) explore long-term costs and benefits of pest management activities.

Results relating to each of these objectives are summarized below. A SFMN Research Note (MacLean *et al.* 2010b) provides a succinct summary of results of our carbon research.

5.1 Carbon budget modeling and forest management planning

Carbon dynamics need to be quantified for a large number of stand types and over long periods of time.

Forest carbon resides in two main pools: live biomass and dead organic matter (*Figure 7*). CO_2 is sequestered through photosynthesis into solid form in the live biomass pool and transfers into the dead organic matter pool occur through mortality. The sizes of the live biomass and dead organic matter carbon pools are largely a function of growth, mortality, and decay rates. The decay of dead organic matter results in the gradual release of CO_2 back into the atmosphere. To incorporate carbon sequestration into a forest management planning framework, carbon dynamics need to be quantified for a large number of stand types over long periods of time.
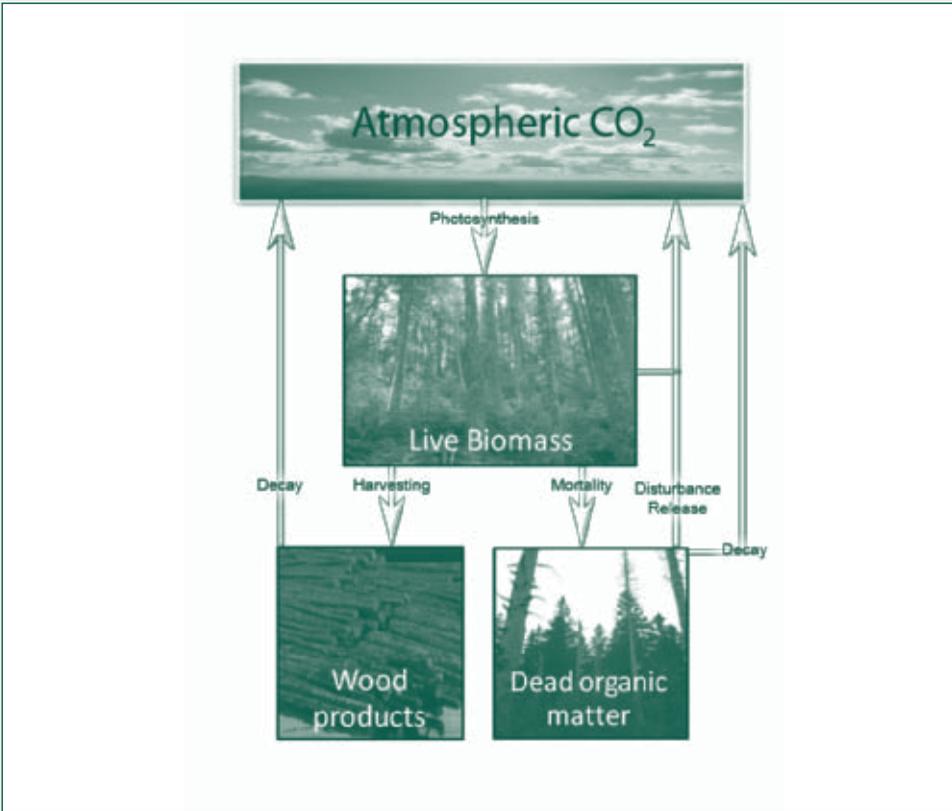
Figure 7. Transfer of carbon from the atmosphere to solid biomass to wood products and dead organic matter. Carbon is returned to the atmosphere through the decomposition of wood products and dead organic matter remaining on site (from MacLean et al. *2010b).*

Neilson *et al.* (2007) used data from sample plots on Crown License 1 in northern New Brunswick, in combination with the carbon budget model CBM-CFS3, to estimate carbon dynamics and yields for a variety of stand types. Carbon yields were then applied across the landbase to quantify total forest carbon which was then projected over time under varying management strategies. Differences in carbon yield among stand types occurred as a result of differences in species composition and age. Due to higher wood density of hardwood species, **hardwood stands contained 10-20% more carbon than softwood stands at ages 40 years and older. Stands tended to contain more carbon as they approached maturity (80 years or older) but, as expected, amount of carbon declined as stand breakup began to occur**.

The method of quantifying carbon yields and dynamics described in Neilson *et al.* (2007) is particularly useful for forest managers because it uses readily available existing inventory information. By tracking carbon based on residence time, managers can account for long term carbon dynamics in forest management plans and help develop strategies to mitigate CO_2 emissions.

Forest inventory data and the carbon budget model CBM-CFS3 were used to quantify carbon across a 400,000 ha landbase.

5.2 Accounting for end use wood products and associated carbon retention

The ability of a forest to sequester carbon comes both from pools that remain on site and from harvesting activities that remove wood and carbon from the forest. Current carbon accounting rules consider any harvest of wood as an immediate emission of carbon to the atmosphere. Logically this does not make sense; the emission of carbon occurs gradually and depends largely on the end product produced from harvested timber. Solid wood products like buildings and furniture retain carbon for decades or centuries. Once the carbon that is locked up in timber leaves a site it is often difficult to track but if it is not accounted for in carbon accounting frameworks, management strategies related to carbon sequestration may be implemented that won't meet the objectives.

Hennigar *et al.* (2008a) used the carbon accounting structure of the Canadian Forest Service Carbon Budget Model for the Forest Product Sector (CBM-FPS) to integrate long-term retention of carbon in end products into forest management planning models. Harvested timber (sawlogs and pulpwood) was tracked based on end use and variable decay rates. By integrating the retention of carbon in wood products into a forest management planning framework, the role of harvesting is better represented in carbon accounting. Results from a hypothetical forest showed that when maximizing total (forest + products) carbon, mean harvest projected for 200 years was 173% higher than when maximizing only forest carbon. Forest carbon was reduced by only 2%, indicating that **when retention of carbon in forest products is considered harvesting stands earlier outweighs the benefits of maintaining carbon in older declining stands**. In fact, total carbon storage increased by 5% when forest + products carbon was considered, compared to forest carbon only. These results reinforce the need to include forest product carbon when attempting to quantify the contribution of forests and integrate it into efforts to mitigate carbon emissions.

Differing management objectives can determine whether a forest acts as either a carbon sink or source. Neilson *et al.* (2008) examined the effects of five different management plans on carbon storage using the carbon accounting framework described in Neilson *et al.* (2007) and the wood products carbon model of Hennigar *et al.* (2008a). Scenarios were applied to the 428 000 ha Crown License 1 in northern New Brunswick and were based on achieving the base (current) timber supply of the landbase, as well as to assess management plans that maximized total carbon sequestration, increased and decreased the current harvest level by 10%, or doubled the base timber harvest level. Results showed that by accounting for carbon in both forest and products, and using a management objective focused on optimal total carbon storage, carbon storage could be increased by 3 tonnes/ha without adverse effects on other values. Alternatively, the inclusion of forest products as a source of carbon storage allowed for an increase in harvest level of 10% while maintaining the level of carbon storage. These results further reinforced that accounting for carbon in both forest and wood products can lead to different management strategies and allows managers to quantify impact of management on carbon sequestration.

Wood products must be included in carbon accounting frameworks as carbon is retained in wood products for long periods.

Excluding wood products when accounting for carbon storage in forest management models may result in management plans and policy that don't meet the objectives.

5.3 Incorporation of the Spruce Budworm Decision Support System (SBWDSS) into a forest management planning framework

Spruce budworm causes significant mortality and growth reductions by defoliating host species (balsam fir and spruce) during outbreaks that recur every 30-40 years. Hennigar *et al.* (2008b) quantified varying levels of defoliation among host species. White, red and black spruce on average experienced 72%, 41% and 28% (respectively) of the defoliation experienced by balsam fir. Differential mortality and growth reductions resulting from the differences in defoliation can have significant effects on a forest's ability to sequester carbon and on socioeconomic values.

Hennigar *et al.* (2007) integrated the SBWDSS, which quantifies the impacts of spruce budworm outbreaks on wood volume, into a timber supply model for the Black Brook District. By integrating the two management tools, the timing of harvest, salvage harvesting and the application of insecticide were planned so as to improve the outcomes from the forest. A total of 200 scenarios were modeled, based on combinations of outbreak severity and insecticide use. Projections of a severe spruce budworm outbreak with no use of insecticides for foliage protection or changes in management planning resulted in a 46% reduction in the harvest level. Using the SBWDSS to prioritize stands for harvest and using salvage operations within the wood supply model, reduced this impact by 34%.

Further benefits were obtained by using aerial insecticidal protection. A scenario that combined the protection of 20% of the susceptible area with re-planned timing of harvests reduced the projected impact on harvest levels more than another scenario that protected the entire susceptible forest (*Figure 8*). By integrating the SBWDSS into a timber supply model, managers can take advantage of improved scheduling of harvests and salvage harvesting, along with carefully prioritized protection activities, to reduce impacts of spruce budworm outbreaks on a variety of values. The approach can be applied to other natural disturbances and can improve forest management and policy development.
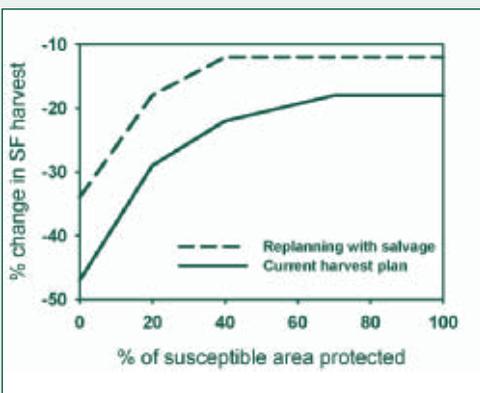
Figure 8. Percentage change in spruce-fir harvest level for the Black Brook District, 20 years following the initiation of a spruce budworm outbreak, for scenarios with differing levels of insecticide protection and the current harvest plan versus optimized re-planning as per Hennigar et al. (2007) .

By revising management plans and incorporating salvage harvesting and protection priorities, volume impacts from spruce budworm outbreaks can be reduced.

5.4 Impacts of potential spruce budworm outbreaks on forest and carbon management

The ability to alter harvest schedules, salvage harvest and protect susceptible stands when faced with a spruce budworm outbreak can have important impacts on carbon storage. Tree mortality that occurs to host species as a result of defoliation and decay of resulting dead organic matter can lead to region-wide release of CO_2 into the atmosphere. Using the Black Brook District, Hennigar and MacLean (2010) applied an integrated forest management model to assess the effects of various intensities of spruce budworm outbreaks on carbon storage (forest and wood products) and the benefits of alternative management plans.

Simulations revealed that moderate and severe spruce budworm outbreaks could cause reductions in carbon stored of 0.42 and 0.53 tonnes/ha, respectively. Aerial spray protection of 40% of the landbase during a severe outbreak, in conjunction with re-planning of harvesting activities, could reduce the impacts to forest carbon storage by 41% and to wood product carbon storage by 56%. It also reduced the impact on harvest level by 73%. Reduction of the impact on harvest level can help by avoiding future wood supply shortages that would result in increased use of energy intensive replacement materials.

Re-planning of harvest activities and salvage harvesting were particularly important to carbon storage, as they capitalized on wood volume that would likely decay in the forest and transferred it to wood products that decay at a slower rate. This research helps determine how alternative management plans could be considered as carbon offset projects. It allows for the quantification of the impacts of a natural disturbance and the potential benefits achieved by alternative planning.

Extrapolation of these results to all of New Brunswick suggested that a severe spruce budworm outbreak could effectively increase total provincial annual carbon emissions (all sources) by up to 40%, on average, over the next 20 years. Overall, research has indicated that incorporating tools such as optimized planning for salvage, alternative harvest scheduling and spatial allocation of foliage protection can reduce volume and carbon loss from spruce budworm and minimize the area of insecticide application. Our modeling reinforces the fundamental importance of spatiotemporal scales and need to examine all forest dependant carbon pools when developing sound forest policy that aims to reduce atmospheric CO_2 during budworm outbreaks. Differences between budworm impacts on timber and carbon and the examination of optimum management trade-offs for timber, carbon, and other values are important for effective forest planning to mitigate impacts from insects.

5.5 Cost-effectiveness of budworm control for sequestering carbon in forests

Moderate, unprotected, spruce budworm outbreak simulations on the Prince Albert Forest Management Area (PAFMA) in Saskatchewan and Crown License 1 in New Brunswick resulted in estimated losses of 13.3 and 13.7 million tonnes of carbon, respectively (Slaney *et al.* 2009). Budworm control program scenarios in the PAFMA resulted in a range of net CO_2 protected, from a low of 1.20 million tonnes under a 10,000 ha aggressive control program to a high of 16.75 million tonnes under a 150,000 ha very aggressive control program. Likewise, control program scenarios for License 1 resulted in a range of net CO_2 protected, from a low of 1.26 million tonnes under a 10,000 ha aggressive control program to 19.20 million tonnes under the 150,000 ha very aggressive control program.

Across the evaluated spruce budworm control program scenarios in the PAFMA, cost per tonne of CO_2 sequestered ranged from a low of $0.72 under a 10,000 ha aggressive control program to a high of $2.37 under a 150,000 ha very aggressive control program (Slaney *et al.* 2009). Similarly, across the evaluated scenarios for License 1, cost per tonne of CO_2 protected ranged from a low of $0.57 under a 10,000 ha semi-aggressive control program to a high of $1.40 under a 150,000 ha very aggressive control program. Variation in the above estimates between landbases resulted largely from the different tree species composition and age classes present in the forest at the time of analysis.

In general, our findings indicated that pest management could provide carbon credits at a much lower cost compared to other forest management activities such as forest conservation ($13–$71 per tonne CO_2) and afforestation/reforestation ($0.71–$150 per tonne CO_2). When compared to carbon credit prices at $5.75 per tonne CO_2 (CCX, April 2008), it would seem as though pest management-derived credits could offer an attractive investment opportunity for forest landowners.

Maintaining carbon in living trees through pest management is less costly than sequestering carbon via other management activities.

The final carbon sequestration cost estimates from pest management, however, would be marginally higher than those reported above since the cost of CO_2 credit verification would need to be included. Additionally, it may be necessary to more precisely evaluate the complete lifecycle of carbon within the protected forest. Finally, carbon sequestration cost estimates from pest management would depend significantly on the timing and severity of outbreaks, as well as the region-specific characteristics of the forest. If such institutional arrangements were established, it would be necessary to keep an up-to-date SBW DSS calibrated to each landbase under consideration.

5.6 Long term costs and benefits of investing in spruce budworm control programs

Chang *et al.* (2009) sent a public mail survey to a sample of New Brunswick and Saskatchewan residents to investigate attitudes about controlling two forest pests: spruce budworm and forest tent caterpillar (*Malacosoma disstria*). Participants were asked a series of questions related to their knowledge of these pests and preferences about control options and program extents. Spruce budworm was the most widely known forest pest in New Brunswick, and forest tent caterpillar was most widely known in Saskatchewan. Both groups of respondents largely supported (at over 80%) controlling future budworm and tent caterpillar outbreaks with the biological insecticide *Bacillus thuringiensis* (*Bt*). Ecologically sensitive areas and wildlife habitat were deemed the top priority that should be protected during the next outbreak of either pest (Chang *et al.* 2009).

Protection costs and timber product values were incorporated into the spruce budworm decision support system to evaluate economic aspects of budworm control (Slaney *et al.* 2010). The analysis was designed to allow pest managers to evaluate how the traditional priority of reducing impacts to timber volume production corresponds to economic criteria. Twelve budworm protection strategies were simulated on two different landbases (New Brunswick and Saskatchewan) using alternative program extents and intensities. The largest most intensive protection program predictably provided the highest amount of volume saved and the highest net present value on both landbases (3.94 million m^3 and $39.98 million for the Saskatchewan landbase and 4.04 million m^3 and $41.49 million for the New Brunswick landbase).

However, large protection programs may not be viable for managers with limited budgets who may be inclined to pursue more cost effective spray programs. Smaller less intensive programs provided greater benefit-cost ratios and volume protected per dollar of protection cost (8.22 and 0.52 m^3/$ for Saskatchewan and 10.26 and 0.65 m^3/$ for New Brunswick). Sensitivity analyses of product values and protection costs revealed that smaller, less intensive programs could improve net present values when costs are higher and product values are lower. Results highlight that consideration of market conditions and costs dictates whether managers should deviate from the traditional approach of maximizing volume protected to a more economic-based approach.

In an analysis of Crown land in New Brunswick, spruce budworm outbreak and control program scenarios resulted in a wide array of market and non-market benefits and costs. Present value market benefits (discounted at 5%) ranged from a low of $54.31 million under a moderate budworm outbreak with a 10% forest area protection program scenario, to a high of $268.23 million for a severe budworm outbreak with a 100% forest area protection program scenario. Similarly, present value market costs ranged from a low of $28.91 million under a moderate outbreak with a 10% area protection program scenario, to a high of $386.39 million under a severe outbreak with a 100% area protection program.

Over 80% of random survey respondents in New Brunswick and Saskatchewan were in favour of biological control of forest pests.

With accurate prioritization of stand-level losses, the highest benefit-cost ratios were attained by protecting 10-20% of the landbase.

The largest most intensive protection programs provided the highest volume saved and highest net present value.

For non-market benefits, based on a 29% survey response rate, we estimated an annual average household willingness to pay (WTP), for a 5-year period to control the next budworm outbreak (over 100% of the affected area) of $76.20 (Chang *et al.* 2010). Aggregating this to the provincial level (after adjusting for the proportion of the population who prefer control, relative size of the Crown landbase within the province, and percentage of area protected), resulted in the present value of non-market benefits ranging from a low of $7.93 million under a 10% area protection scenario to a high of $79.34 million under a 100% area protection scenario. Using a similar method for non-market costs, we estimated an annual average household WTP (for a 5-year period) to compensate those negatively impacted by an uncontrolled outbreak of $59.80. Aggregating this to the provincial level resulted in present value non-market costs ranging from a low of $0.55 million under a 10% forest area protection program to $5.51 million under a 100% forest area protection program.

When combining costs and benefits for a moderate outbreak scenario, protecting 10% of the New Brunswick Crown landbase (i.e., ~330,000 ha) produced the highest market and total (market and non-market) net present values at $25.40 million and $28.82 million, respectively, compared to larger protection scenarios. The market and non-market value benefit-cost ratios were also highest under this scenario at 1.88 and 1.98, respectively. Net present values became negative and benefit-cost ratios became less than one when moving from the 20% to the 40% of the area protection programs.

Under a severe outbreak, the 20% area protection program size produced the highest market and total net present values at $116.47 million and $123.30 million, respectively. Slightly different results emerged for the benefit-cost ratio analysis, where the highest values occurred under the 10% protection program scenario, at 3.72 and 3.77, respectively. Net present values became negative and benefit-cost ratios became less than one when moving from 40% to 100% of the area protection programs.

Sensitivity analysis revealed that lower discount rates, lower unit pesticide costs, and higher timber product prices generally tended to: **(i) increase net present value and benefit-cost ratio for each protection program and outbreak scenario; and (ii) cause the highest market and total net present value estimates to occur when protecting larger percentages of the Crown land base than previously determined**. Higher discount rates, higher unit pesticide costs, and lower timber product prices tended to have the opposite effects.

Overall, it is clear that under the base-case prices and discount rates, protecting 10%-20% of the Crown land in New Brunswick with insecticides under both moderate and severe spruce budworm outbreak scenarios was justified on economic grounds. The larger protection programs may save more volume and product value, however the greater overall protection expenditures significantly diminished any net benefit from doing so. These results were consistent when non-market values were included in the analysis. However, if discount rates or pesticide costs become significantly higher, or timber product prices become

Protecting 10-20% of Crown land in New Brunswick from spruce budworm using insecticides is economically justified but is sensitive to forest product prices and protection costs.

significantly lower than those used in the base-case analysis, protection programs may not produce an economic benefit. On the other hand, if timber product prices increase or discount rates or pesticide costs decrease, and/or if carbon credit values are included in the cost-benefit framework, there would be an economic justification for protecting a larger proportion of the landbase.

6.0 Forest Dynamics, Succession, and Habitat Relationships under Differing Levels of Silviculture

This project was initiated by the JDI FRAC in cooperation with the Fundy Model Forest, to address the research needs of these organizations in the Acadian forest. It was also supported by the Alberta Department of Sustainable Resource Development, and was funded by the SFMN, Fundy Model Forest, and NSERC. Collaborators included JDI, Fundy Model Forest, UNB – Fredericton and Saint John campuses, UdeM – Moncton and Edmundston campuses, University of Maine, and Oregon State University.

Previous SFMN and other 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 effects of alternative 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 here build upon those efforts by addressing important outstanding questions and issues raised by previous research, and expanding study and analysis into new questions.

Research questions pertained to 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. Overall goals were to:

(a) better understand succession dynamics of the Acadian mixedwood forest, its value as habitat, and 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 diversity and habitat values of the forest while supplying an economic supply of industrial raw material.

Figure 9. Mixedwood forest made up 37% of the Black Brook District in 1945 but only 19% by 2002, necessitating further research into the forest dynamics and habitat value of this forest type.

A total of 12 graduate students conducted studies under the following four objectives:

1) **Determine successional dynamics of mixedwood stands** using historical analysis, stand reconstruction, regeneration surveys, and stand growth modeling;

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

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

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

A summary of results of each study is provided in the following sections. More details on the studies and results were presented in MacLean *et al.* (2010a).

6.1 Succession dynamics of mixedwood stands

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

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 project was to identify patterns of change in the 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 the complex interactions between various disturbances that allowed new tree cohorts to establish (Amos-Binks *et al.* 2010). In particular, a significant period of change in species composition occurred between 1946 and 1982, induced by outbreaks of spruce budworm 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 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 is longer lived and 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.

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

The presence of multiple species in mixedwood stands results in differential growth, in-growth and mortality patterns and is further complicated by periodic outbreaks of the spruce budworm. This study aimed to determine the influence of disturbance and stand structure on development of balsam fir and spruce mixedwood stands in New Brunswick. A total of 154 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 the PSPs was significantly related to balsam fir basal area (BA), % hardwood BA, maximum cumulative spruce budworm defoliation from 1983-1987, and location (in three spruce budworm outbreak zones, northern, middle, southern New Brunswick). Balsam fir mortality was more than double that of spruce but there was little difference in survivor growth between species.

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

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

Regression analysis revealed that the presence of hardwood in the stand was most influential on the growth of surviving host species. Specifically, higher hardwood and balsam fir contents at the time of plot establishment were related to greater survivor growth. These findings provide evidence for the promotion of mixedwood stands as a means to mitigate wood supply losses in the event of spruce budworm outbreaks.

6.1.3 Shade tolerant hardwood natural regeneration – Bruno Chicoine (MScF, UdeM) and Martin Béland

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. A total of 1065 (1 m²) 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 the environmental conditions resulting from the silvicultural 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.

6.2   Effects of pre-commercial thinning on biodiversity indicators

6.2.1 The effects of pre-commercial thinning on bryophyte communities – Amy Witkowski (MSc, UNB) and Kate Frego

Bryophytes are an important component in forest ecosystems. They are particularly sensitive to physical disruption and microclimatic changes that often occur following forest management actions. 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 all bryophyte species was estimated using 1 m² sample plots established in naturally regenerated pre-commercially thinned stands and naturally regenerated unthinned stands.

Comparisons of pre-commercially thinned stands and unthinned stands showed similar compositions and suggested that the resulting conditions could sustain these communities. Some bryophyte species shown 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 to plantations, tbryophytes in pre-commercially thinned stands showed greater similarity to those in stands that were left untreated following harvest. This suggested that pre-commercial thinning had a reduced impact on bryophytes than plantations. Pre-commercial thinning appeared to have negligible effects on bryophytes beyond the initial harvest and conserved more bryophyte species than do plantations.

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

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

6.2.2 The effects of pre-commercial thinning on the abundance of herbaceous species – Kerienne La France (MScF, UNB) 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 project was to a) identify changes in stand structure and microsites between thinned and unthinned stands, b) to 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 unthinned stands in southern New Brunswick. The stands ranged in age from 16-42 years.

Results showed that thinned sites had lower softwood stem density and fewer snags per hectare, while slash height of thinned stands was comparable to unthinned 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 unthinned 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.

6.2.3 The effects of pre-commercial thinning on the abundance of small mammals – Julie Henderson (MScF, UNB) and Graham J. Forbes

Pre-commercial thinning accelerates the 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.

The purpose of this project was to determine if pre-commercial thinning influences abundance of small mammals 5, 10, or 20 years after treatment and to examine the 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 the abundance 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 microdebris resulting from thinning activity would

benefit small mammals by providing protective cover in thinned stands. However, neither higher abundance in thinned stands nor associations with microdebris were found. It may be possible that the reduction of canopy cover caused by pre-commercial thinning offsets the benefits of increased woody debris.

6.3 Key stand structures and abundance of biodiversity indicators of plantations and mixedwood stands

6.3.1 Abundance, age, body mass and spatial distribution of American marten in northwestern New Brunswick – Pascale Forget (MSc, UdeM) and Claude Samson

The American marten (*Martes americana*) is typically associated with old coniferous forest and could be particularly vulnerable to intensive forest management. Previous studies indicated 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 to complete their lifecycle. Using four different sites characterized by age and proportions of plantations present in the landscape, we tested this hypothesis.

Results showed that marten appear to look for a combination of plantations > 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, when compared to an area where plantations > 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 the American marten by providing tall, dense coniferous cover as long as they are interspersed with mature natural stands.

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

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

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 placed into 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 (180-4000 m) and monitored their movements following release.

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.

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.

6.3.3 Demographic response of two songbird species to selection harvesting – Samuel Haché (MSc, UdeM) 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 songbird responses remain poorly understood. We assessed two of these mechanisms (change in stand structure and abundance of nest predators) and measured their effects on the 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 recruitment and return rates in Ovenbird populations.

Results indicate that alterations to stand structure and abundance of nest predators influenced the 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 habitat alteration process that is expected to last for up to 10 years post-harvest. The negative response of the Black-throated Blue Warbler could be compensated for 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, possibly through an increase in territory size of returning individuals.

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

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

Results showed that the density of large trees and snags, presence of potential nesting sites, and area of mature forest were important variables discriminating used and unused nesting sites at the neighbourhood scale. Local-scale variables explained more variation in nest site selection than neighbourhood-scale

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

Brown Creeper nest density was two times lower in treated plots than in controls, emphasizing the critical role of foraging habitat.

variables. Threshold values for nesting were determined to be large diameter tree densities of 127 large trees/ha and 56 snags/ha, or when >53% of the neighbourhood area consisted of mature forest. Single tree harvesting did not reduce the density of snags, but nest density and number of territories were two times lower in treated plots than in controls. This suggests that partial harvests reduce 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 that nutritional requirements will be met following harvest treatments.

6.4   Effects of alternative zoning allocations

6.4.1 Triad Scenarios on Crown License 1 in New Brunswick – Chris Ward (MScF, UNB), Tom M. Beckley, Thom A. Erdle and David A. MacLean

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 evaluate the outcomes of various Triad management scenarios based on social, economic and ecological indicators.

Results showed that by varying levels of intensive, extensive and reserve forest, the 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 area resulted in reduced short term harvest levels. However, over the long term increased harvest levels obtained through the availability of plantations compensated for those short term reductions. More details are provided in an SFMN Research Note (Ward *et al.* 2010).

6.4.2 Bioenergy production: a case study for Crown lands of New Brunswick – Jean-Francois Carle (MScF, UNB), David A. MacLean, Thom A. Erdle and Roger Roy

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 only 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 would offset 26-46% of fossil fuel energy consumption in New Brunswick. By focusing management on energy production and 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%.

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.

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

7.0 Future Directions: Experimental Manipulation of Habitat Structures in Intensively Managed Plantations to Increase Conservation Value

The SFMN ends in 2010, but the research collaboration between the JDI FRAC and researchers at UNB, UdeM, and University of Maine continues. Specifically, the next issue to be addressed is how habitat structures, especially deadwood, can be manipulated using commercial thinning in spruce plantations. This project is continuing with approved NSERC CRD and JDI funding from 2010-2015.

Figure 10. Plantation forestry and commercial thinning in varying development stages make up over 40% of JDI's Black Brook District.

Habitat suitability of plantations is an important concern as they make up over 40% of the landbase in the Black Brook District.

Management of at least part of Canada's forest will likely intensify over the next decades. There is increased interest in forest zoning or TRIAD (three zones – intensive, protected, and multiple use) forest management (Messier *et al.* 2003, Montigny and MacLean 2006, MacLean *et al.* 2009, Ward *et al.* 2010). A criticism of intensive forest management zones is that planted stands are 'sanitized', with less structural diversity, fewer species, and removal of downed and standing deadwood (snags). Concerns are typically focused on the paucity of deadwood and reduced species diversity in the resulting overstory.

The objective of this next generation of research is to determine the degree of influence that key habitat structures, early in the rotation of planted stands, have on animal and plant taxa and thereby on key ecosystem processes, and how these

can be incorporated into management strategies. We will experimentally manipulate habitat structure elements in spruce plantations, and determine influence and effects of the landscape context around sample plantations on the selected taxa. We will focus on taxa that have a clear connection to deadwood and thinning response – namely saproxylic invertebrates, bryophytes, and bird species directly dependent upon deadwood, ground vegetation species sensitive to disturbance, and small mammal species that have been observed to have low density in planted stands. We will test the hypotheses that:

1) lack of plantation recruitment is due to dispersal limitation – *propagules do not arrive (short distance dispersal) or are not available from surrounding stands*;

2) lack of plantation recruitment is due to poor site conditions – *propagules arrive but cannot establish (germinate or germinate and survive to adulthood or die once they arrive)*; and

3) lack of adult survival (plants) or habitat use (animals) in plantations is due to poor site conditions – *propagules arrive, establish, but are not locally self-sustaining populations, habitat conditions lacking.*

This project was developed by the JDI FRAC, and will support nine Masters and PhD students at UNB and UdeM. Given direct involvement of company managers in all phases of the study, results will be readily incorporated into management practices.

Specific research objectives are to:

1) determine the rate of response of saproxylic (wood inhabiting) invertebrates to management;

2) test the effects of three potentially limiting factors on the distribution of understory plants – dead wood availability, microclimate conditions, and propagule availability and/or early establishment;

3) evaluate the causes of low abundance of red-backed voles, whether it be due to changes in food supply or ground and below-ground microclimatic conditions; and

4) test predictions that bird assemblages will respond to post-treatment increases in woody debris and to the landscape context, and that use of girdled trees by birds will be higher in landscapes with a greater proportion of naturally regenerated forest.

The ecological contribution of managed, including planted, forests to biodiversity objectives at the landscape scale is not well understood. This contribution is important to understand in the context of sustainable forest

management for the wide range of values expected by the public and customers of the forest industry. The research results will be applicable to many areas in Canada.

The nature and amount of some habitat structures present in planted stands at a given point in time depend on attributes of the original forest as well as the management regime of the plantation. Important structural elements can be grouped into a few broad categories such as dead wood, vertical structure, and species diversity. We will examine the consequences of changing selected structural elements on different taxa during regularly scheduled management entries (i.e. commercial thinnings following an earlier plantation cleaning). The study design will include manipulations of the amount of deadwood and other structures in six large (>20 ha) white spruce plantation blocks. The experimental plantations will be located in three landscape contexts: low, moderate, and high surrounding plantation cover.

8.0 J.D. Irving, Limited Use of SFMN Research Results in Management

Many examples of adaptive management have been developed as a result of the FRAC process and interaction of JDI management foresters and scientists on 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) clearer understanding of forest dynamics at the forest and stand scales over time, for a broader range of values than primary forest products; and

3) a long-term legacy of study sites including the working forest, reserve areas, and 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.

With respect to direct changes to forest management, there are clear indications in the most recently developed management plan for the Black Brook District for 2008-2033. Of major influence were the FRAC studies related to forest change from 1945 to 2002 and projections through to 2027, along with the use of the Species Sorting Algorithm to translate these changes into a potential wildlife habitat context. Specific management objectives and targets have been established for the next 80 year planning horizon, with respect to maintaining areas of each

cover type including shade tolerant hardwood, eastern cedar, natural softwood, and mixedwood stands, such that they will remain stable relative to current levels. Objectives have also been established for areas of old shade tolerant hardwood, old spruce-fir, old cedar, and old mixedwood forest. Targets have been set such that there will be a minimum of 10% of the old forest in each of the stand types relative to current conditions.

Based on FRAC and other research, the structural definition of the "old" development stage has also been changed. The number of large live trees (>30cm) to retain has increased from 10 live >30 cm (and 15 dead >30 cm) to 60 for shade tolerant and old hardwood stand types as well as old mixedwood stands. FRAC research has also been used in revising the New Brunswick Crown land standards. Assessments of dead stems and coarse woody debris have been included in Forest Development Surveys in the district to quantify these characteristics.

Other findings from FRAC research have been integrated into best management practices. Based on studies of Pileated Woodpecker, harvesting work orders for selective and shelterwood harvesting in shade tolerant hardwood stands specify practical guidelines for retaining a component of large beech trees (usually 5-8 per hectare) for nest or den sites for a number of birds and mammals. JDI also now retains poplar in planted stands during commercial thinning as long term potential snags.

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

FRAC projects have led to the development of operational analysis tools to allow JDI to assess unpredictable or new aspects of forest management (such as future spruce budworm infestations). The company is now able to evaluate various combinations of harvesting and protection in a planning context to a much greater degree. Similarly, as carbon accounting becomes an important consideration in forest management activities, FRAC projects that assess management plans from both the forest carbon and forest products standpoints allow carbon to be integrated as a forest value.

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

All the research projects have contributed to the understanding of forest dynamics over time for a broad range of values. These range from understanding regeneration response of shade tolerant hardwoods to various stand management options through to the response of bryophytes, vascular plants, and small mammals to pre-commercial thinning of natural regeneration. Individual studies have covered a range of stand types and development stages, studying a range of stand attributes including habitat quality for different taxa. Recognition that, over time, some planted stands will be required to serve as old softwood habitat has resulted in the new 2010-2015 research project related to varying levels of structural diversity and coarse woody debris at the commercial thinning stage of planted stand development. Vascular plants, bryophytes, beetles, song birds and small mammals will be monitored across replicated study sites.

The regular presentation and review of individual project results by FRAC members and graduate students with JDI managers has provided excellent opportunities for learning. JDI has been committed to communicating results to JDI employees across the company as well as to the general public. The company believes that this helps convey the complexity of forest management, as well as emphasizes JDI's long-term commitment to forest stewardship.

A critical benefit of the FRAC is the long term legacy of permanent sample plots across the range of protected areas, adaptive management research areas, and the working forest. JDI maintains 6720 hectares of core protected reserves that were established in the late 1990s. An additional 1387 hectares of adaptive management reserves are maintained, where harvesting was conducted according to a natural disturbance inspired regime. 242 permanent sample plots have been established in the protected reserves, adaptive management, and working forest to provide baseline ecological information and to provide sites for re-evaluation over time. While these will be important for providing data and trends related to forest succession, they will also provide study sites to observe changes in response to factors such as insect infestation or long term climate change.

9.0   Conclusions

A unique aspect of the studies described in this report is that they were developed from the outset by a structured group of company forest managers and researchers. From its inception, the FRAC pursued several research questions related to managing for biodiversity and using natural disturbance information as input into stand- and forest-level management decisions. Thus, there has been company 'buy-in' regarding the value of the research, much intangible assistance rendered in addition to direct JDI and SFMN funding, and on-going redirection and mutual learning on the part of both managers and researchers. The value of this cannot be overemphasized, and it is clear that regular and continued communication is a key component of effective applied research projects.

The goals of ecosystem management are: 1) to guide practices by natural variability in stand structures and forest landscape patterns, and 2) to maintain viable populations of all native species. Natural disturbance is an important factor guiding ecosystem management. Understanding natural disturbance processes and their effects on forest structure can provide useful input into forest management design and selection of ecologically-appropriate harvest and silviculture treatments. As a result of the SFMN and FRAC research, these factors are now better incorporated into JDI management planning.

Insect outbreaks are the major natural disturbance factor in much of eastern Canada. Analysis and scenario planning analysis of natural disturbances can provide useful input into forest management planning, both in terms of forest composition objectives (species, age, patch size) and silviculture and harvest treatments that are consistent with natural disturbance. Carbon in forests and forest products has emerged as a new value that has been incorporated into planning in the last several years, and we have developed operational tools to deal with these emerging issues.

The FRAC and JDI-SFMN research generated over the last decade are good examples of adaptive management, a long term repeated process of gradually modifying management techniques based upon the results of modeling and research. Management decisions can be improved over time by identifying key questions and uncertainties, conducting research and monitoring, and learning from experience. The JDI FRAC is a proven process for effective company-researcher interaction, to *empower the forest manager.*

Literature Cited

Amos-Binks, L. 2005. Relating tree and stand level characteristics to blowdown following an emulated eastern spruce budworm, *Choristoneura fumiferana*, outbreak. BScF Thesis, Faculty of Forestry and Environmental Management, University of New Brunswick, Fredericton, NB.

Amos-Binks, L.J., D.A. MacLean, J.S. Wilson, and R.G. Wagner. 2010. Temporal changes in species composition of mixedwood stands in northwest New Brunswick: 1946-2008. Can. J. For. Res. 40: 1-12.

Betts, M.G., and M.-A. Villard. 2009. Landscape thresholds in species occurrence as quantitative targets in forest management: generality in space and time? Chapter 9. In: Setting Conservation Targets for Managed Forest Landscapes. Edited by M-A. Villard and B-G. Jonsson. Cambridge University Press, Cambridge, UK. Pp. 185-206.

Chang, W-Y., V.A. Lantz, and D.A. MacLean. 2009. Public attitudes about forest pest outbreaks and control options: case studies in two Canadian provinces. For. Ecol. Manage. 257: 1333-1343.

Chang, W-Y., V.A. Lantz, and D.A. MacLean. 2010. Non-market benefits and costs of controlling forest pest outbreaks: a contingent valuation analysis in two Canadian provinces. Can. J. Agric. Econ. (submitted Nov. 2009).

Chicago Climate Exchange (CCX). 2008. Chicago Climate Exchange CCX Market Report Vol.5, No. 4.

Clowater, R., T. Erdle, J. Loo, D. MacLean, P. Neily, and V. Zelazny. 1999. Categorization of major natural disturbances in the Maritime Provinces. Unpublished.

Dick, A., J.A. Kershaw Jr., and D.A. MacLean. 2010. Spatial tree mapping using photography. North. J. Appl. For. In press

Etheridge, D.A., MacLean, D.A., Wagner, R.G., and Wilson, J.S. 2005. Changes in landscape composition and stand structure from 1945-2002 on an industrial forest in New Brunswick, Canada. Can. J. For. Res. 35: 1965-1977.

Etheridge, D.A., MacLean, D.A., Wagner, R.G., and Wilson, J.S. 2006. Effects of intensive forest management on stand and landscape characteristics in northern New Brunswick, Canada (1945-2027). Landsc. Ecol. 21: 509-524.

Franklin, J.F. 1989. Toward a New Forestry. Amer. Forests (Nov.-Dec.): 37-44.

Gillis, A.M. 1990. The new forestry: an ecosystem approach to land management. BioScience 40: 558-562.

Griffin, C. 2005. Evaluating regeneration response following an emulated spruce budworm outbreak. BScF Thesis, Faculty of Forestry and Environmental Management, University of New Brunswick, Fredericton, NB.

Guénette, J.-S., and M.-A. Villard 2004. Do empirical thresholds truly reflect species tolerance to habitat alteration? Ecol. Bull. 51: 163-171.

Guénette, J.-S., and M.-A. Villard. 2005. Thresholds in forest bird response to habitat alteration as quantitative targets for conservation. Conserv. Biol. 19 : 1168-1180.

Higdon, J.W., D.A. MacLean, J.M. Hagan and J.M. Reed. 2005. Evaluating vertebrate species risk on an industrial forest landscape. For. Ecol. Manage. 204: 279-296.

Higdon, J.W., D.A. MacLean, J.M. Hagan and J.M. Reed. 2006. Risk of extirpation for vertebrate species on an industrial forest in New Brunswick, Canada: 1945, 2002, and 2027. Can. J. For. Res. 36: 467-481.

Hennigar, C.R., D.A. MacLean, K.B. Porter, and D.T. Quiring. 2007. Optimized harvest planning under alternative foliage protection scenarios to reduce volume losses to spruce budworm. Can. J. For. Res. 37: 1755-1769.

Hennigar, C.R., D.A. MacLean, and L.J. Amos Binks. 2008a. A novel approach to optimize management strategies for carbon stored in both forests and wood products. For. Ecol. Manage. 256: 786-797.

Hennigar, C.R., D.A. MacLean, D.T. Quiring, and J.A. Kershaw Jr. 2008b. Differences in spruce budworm defoliation among balsam fir and white, red, and black spruce. For. Sci. 54: 158-166.

Hennigar, C.R and D.A MacLean. 2010. Spruce budworm and management effects on forest and wood product carbon for an intensively managed forest, Canada. Can. J. For. Res. (submitted April 2009)

Keppie, D.M. 2004. Animals in managed forest, Black Brook 2004. Report submitted to J.D. Irving, Limited, Saint John, NB. 20p.

Landres, P.B., P. Morgan, and F.J. Swanson. 1999. Overview of the use of natural variability concepts in managed ecological systems. Ecol. Applic. 9: 1179-1188.

Lemaître, J. and Villard, M.-A. 2005. Foraging patterns of Pileated woodpeckers in a managed Acadian forest: a resource selection function. Can. J. For. Res. 35: 2387-2393.

MacLean, D.A. 2004. Predicting forest insect disturbance regimes for use in emulating natural disturbances. In Emulating natural forest landscape disturbances: Concepts and applications. Edited by A.H. Perera, L.J. Buse and M.G. Weber. Columbia University Press, New York. Pp 69-82.

MacLean, D.A., G. Adams, G. Pelletier, L. Amos-Binks, J-F. Carle, B. Chicoine, A. Colford-Gilks, P. Forget, S. Haché, J. Henderson, K. La France, J-F. Poulin, M. Smith, C. Ward, A. Witkowski, T.M. Beckley, M. Béland, M.G. Betts, T.A. Erdle, G.J. Forbes, K. Frego, J.A. Kershaw Jr., M.R. Roberts, R. Roy, C. Samson, M-A. Villard, R.G. Wagner, and J.S. Wilson. 2010a. Management implications of forest dynamics, succession, and habitat relationships under differing levels of silviculture. Sustainable Forest Management Network Center of Excellence, University of Alberta. Synthesis Report. 75p.

MacLean, D.A., L.J. Amos-Binks, C.R. Hennigar, E.T. Neilson, G.L. Slaney, P. A. Arp, V.A. Lantz and F-R. Meng. 2010b. Forest and pest management strategies for carbon sequestration in forests and forest products. Sustainable Forest Management Network Center of Excellence, University of Alberta. Research Note.

MacLean, D.A., B. Hemens, J. Higdon, D. Etheridge, R.G. Wagner, K.B. Porter, J.M. Hagan, and J.M. Reed. 2002. Using analyses of natural and human-caused forest disturbance on the J.D. Irving Ltd. Black Brook District to inform forest and biodiversity management. Pp. 99-104. In: Advances in Forest Management: From Knowledge to Practice. Edited by T.S. Veeman *et al.* Proceedings 2002 Sustainable Forest Management Network Conference, Edmonton, AB.

MacLean, D.A., R.S. Seymour, M.K. Montigny and C. Messier. 2009. Allocation of conservation efforts over the landscape: the TRIAD approach. Chapter 14. In: Setting Conservation Targets for Managed Forest Landscapes. Edited by M-A. Villard and B-G. Jonsson. Cambridge University Press, Cambridge, UK. Pp.283-303.

Messier, C., C. Bigué, and L.Bernier. 2003. Using fast-growing plantations to promote forest ecosystem protection in Canada. Unasylva 54: 59-63.

Mladenoff, D.J., M.A. White, J. Pastor, and T.R. Crow. 1993. Comparing spatial pattern in unaltered old-growth and disturbed forest landscapes for biodiversity design and management. Ecol. Applic. 3: 293-305.

Montigny, M.K., and D.A. MacLean. 2005. Using heterogeneity and representation of ecosite criteria to select forest reserves in an intensively managed industrial forest. Biol. Conserv. 125: 237-248.

Montigny, M.K., and D.A. MacLean. 2006. Triad forest management: scenario analysis of effects of forest zoning on timber and non timber values in northwestern New Brunswick, Canada. For. Chron. 82: 496-511.

Neilson, E.T., D.A. MacLean, F. R. Meng, and P.A. Arp. 2007. Spatial distribution of carbon in natural and managed stands in anindustrial forest in New Brunswick, Canada. For. Ecol. Manage. 253: 148-160.

Neilson, E.T., D.A. MacLean, F. R. Meng, C.R. Hennigar and P.A. Arp. 2008. Optimal on and off site forest carbon sequestration under existing timber supply constraints in northern New Brunswick. Can. J. For. Res. 38: 2784-2796.

Oates, M.N. 2003. The role of fire as a natural disturbance in the northwestern Acadian forest of New Brunswick. BScF thesis, University of New Brunswick, Fredericton, NB.

Pelletier, A-M. 2005. Préférences d'habitat estival, structure d'âge et reproduction d'une population de martres d'Amérique (*Martes americana*) dans un secteur forestier aménagé de manière intensive au Nord-Ouest du Nouveau-Brunswick. Thèse de Maîtrise inédite. Faculté de sciences forestières, Université de Moncton, Campus d'Edmundston. Nouveau-Brunswick.

Pelletier, G., D.A. MacLean, M-A. Villard, and G.L. Baskerville. 2002. Application of biodiversity and natural disturbance research to forest management on J.D. Irving Ltd. Private lands in New Brunswick. Pp. 51-56. In: Advances in Forest Management: From Knowledge to Practice. Edited by T.S. Veeman *et al.* Proceedings 2002 Sustainable Forest Management Network Conference. Edmonton, AB.

Pickett, S.T.A., and P.S. White, editors. 1985. Ecology of Natural Disturbance and Patch Dynamics. Academic Press, San Diego, CA.

Porter K.B., B. Hemens, and D.A. MacLean. 2004. Using insect caused patterns of disturbance in northern New Brunswick to inform forest management. *In* Emulating natural forest landscape disturbances: Concepts and applications. Edited by A.H. Perera, L.J. Buse and M.G. Weber. Columbia University Press, New York. Pp 135-145.

Ross-Davis, A.L. and K.A.Frego. 2002. Comparison of plantations and naturally regenerated clearcuts in the Acadian Forest: forest floor bryophyte community and habitat features. Can. J. Bot. 80: 21-33.

Samson, C. 2004. Impact de l'aménagement forestier intensif sur l'habitat et la dynamique de population de la martre d'Amérique. Rapport d'étape présenté à J.D. Irving Ltd. Faculté de foresterie, Université de Moncton, Campus d'Edmundston.

Seymour, R.S., and M.L. Hunter, Jr. 1992. New forestry in eastern spruce-fir forests: principles and applications to Maine. Maine Agric. Exp. Sta., Univ. of Maine, Misc. Publ. 716.

Slaney, G.L., V.A. Lantz, and D.A. MacLean. 2009. The economics of carbon sequestration through pest management: application to forested landbases in New Brunswick and Saskatchewan, Canada. For. Pol. Econ. 11: 525-534.

Slaney, G.L., V.A. Lantz, and D.A. MacLean. 2010. Assessing costs and benefits of pest management on forested landbases in eastern and western Canada. J. For. Econ. 16: 19-34.

Sousa, W.P. 1984. The role of disturbance in natural communities. Ann. Rev. Ecol. Syst. 15: 353-391.

Taylor, S.L. and D.A. MacLean. 2009. Legacy of insect defoliators: increased wind-related mortality two decades after a spruce budworm outbreak. For. Sci. 55: 256-267.

Villard, M.-A., and J.-S. Guénette. 2005. Les oiseaux forestiers montrent-ils la même sensibilité à l'exploitation forestière aux échelles du peuplement et du paysage? Vertigo 6(2) [online] http://vertigo.revues.org/index4243.html

Ward, C., T. Beckley, D.A. MacLean, and T.A. Erdle. 2010. Forecasts of Triad zoning scenarios on New Brunswick Crown License 1. Sustainable Forest Management Network Center of Excellence, University of Alberta. Research Note.

APPENDIX 1

Summary of J.D. Irving, Limited, UNB, and UdeM research projects and graduate theses

This included 26 graduate students supported (18 at UNB, 7 at UdeM), total funding $1,768,000. Graduate student supervisors are listed in parentheses; students supported via NSERC Industrial Post-graduate Scholarship, levering an additional $15K/yr for 2 years (MSc) or 3 yrs (PhD) are indicated by *.

I.   **2001-04. MacLean, D., I. Methven, R.G. Wagner, and K.B. Porter. Spatial and temporal patterns of natural and human-caused forest disturbance on the J.D. Irving Limited Black Brook District: past, present, and future.** $136K SFMN + $200K JDI to the project.

    1.   Jeff Higdon. 2004. A spatially explicit assessment of vertebrate species risk on an industrial forest landbase in New Brunswick, Canada. MScF UNB (MacLean) 2000-2004.

    2*.   David Etheridge. 2005. Influence of forest management on the spatial and temporal patterns of forest structure in northwestern New Brunswick. MScF UNB (MacLean) 2002-2005.

    3.   Brendan Hemens. Spatial and temporal patterns of natural forest disturbance at Black Brook, northern New Brunswick. MScF UNB (MacLean) 2001-2008 part-time, incomplete.

II.   **2002-05. MacLean, D. Triad case study: harvesting inspired by natural disturbance, stand structure effects, and scenario planning.** $157K SFMN

    4*.   Mike Montigny. 2005. TRIAD forest management: scenario planning analysis on an industrial forest in New Brunswick. MScF UNB (MacLean) 2002-2005.

    5.   Adam Dick. 2010. Stand structure before and after harvest inspired by natural disturbance: assessment by photo-based techniques. MScF UNB (MacLean and Kershaw) part-time 2003-2010.

III.   **2002-05. Villard, M-A. Triad case study: assessing the biotic integrity of forest reserves and working forest of the Black Brook District.**

    6.   Jean-Sébastien Guénette. 2003. Thresholds in the tolerance of forest birds to habitat alteration. UdeM (Villard). 2001-2003.

    7.   Jérôme Lemaître. 2004. Pileated Woodpecker (*Dryocopus pileatus*) distribution and foraging in a managed forest landscape. MSc UdeM (Villard) 2001-2004.

    8.   Anne-Sophie Bertrand. 2006. Selection of indicators of biological integrity applicable to managed forest landscapes. MSc UdeM (Villard) 2002-2006.

IV. **2003-06. MacLean, D., F-R. Meng, P.A. Arp, J. Bhatti, and D. Quiring. Influence of forest management, silviculture, and pest management on carbon sequestration.** $276K SFMN

   9*. Eric Neilson. 2007. Integration of carbon sequestration objectives into forest management planning. MScF UNB (MacLean) 2003-2007.

   10*. Chris Hennigar. 2009. Modeling the influence of forest management and spruce budworm epidemics on timber supply and carbon sequestration. PhD UNB (MacLean and Quiring) 2004-2009.

   11*. Jonathan Leggo. Black spruce growth allocation in response to insect defoliation. PhD part-time UNB (Quiring and MacLean) 2004-2010.(+ partial support of 2 grad students, 1 post-doctoral assistant and 5 undergrad research assistants)

V. **2003-06 Lantz, V., B. Cooke, W. Kurz, D. MacLean, and K. Porter. Role of pest management in sequestering carbon in the 2008-12 Kyoto commitment period: integration with CBM-CFS3 and economic analyses.** $164K SFMN

   12. Greg Slaney. 2008. Benefits and costs of pest management investments: application to forested landbases in New Brunswick and Saskatchewan. MScF UNB (Lantz and MacLean) 2004-2008.

   13. Chang, Wei-Yew. Socio-economic impact analysis of forest pest outbreaks and control options. PhD UNB (Lantz) 2006-2010. (+ partial support of Chris Hennigar)

VI. **2005-08 MacLean, D., M. Béland, T. Erdle, G. Forbes, K. Frego, K. Greenway, G. Pelletier M. Roberts, C. Samson, M-A. Villard, B Wagner, J. Wilson. Management implications of forest dynamics, succession, and habitat relationships under differing levels of silviculture.** $433K SFMN + $150K Fundy Model Forest + $180K NSERC= $835K

   A) Successional dynamics of mixedwood stands

   14*. Luke Amos-Binks. 2010. Dynamics of mixedwood stands in northwestern New Brunswick. MScF UNB (MacLean) 2006-2010.

   15*. Amanda Colford. 2010. Effects of spruce budworm on balsam fir and red spruce mixedwood stand dynamics MScF UNB (MacLean) 2005-2010.

   16. Bruno Chicoine. 2009. Natural regeneration response in stands of tolerant and mixed hardwood after various partial cuttings. MSc UdeM (Béland) 2006-2009.

B)   Pre-commercial thinning effects on biodiversity indicators

17.   Amy Witkowski. 2010. Effects of pre-commercial thinning on forest bryophyte diversity. MSc UNB (Frego) 2005-2010.

18.   Keri La France. 2010. Effects of pre-commercial thinning and plantation management on ground vegetation. MScF UNB (Roberts) 2005-2010.

19.   Julie Henderson. 2010. Vertebrate response to pre-commercial thinning in New Brunswick. MScF UNB (Forbes) 2005-2010.

C)   Key stand structures and effects of intensive silviculture

20*.   Pascale Forget. 2008. Influence of stand and landscape structure on occurrence and population dynamics of pine marten. MSc UdeM (Samson) 2005-2008.

21.   Matt Smith. Population viability of a mixed-wood indicator in managed landscapes. PhD UNB (Forbes) 2006-2010.

22.   Aurore Pérot. 2008. Density versus productivity as indicators of habitat quality. MSc UdeM (Villard) 2005-2007.

23*.   Samuel Haché. 2009. Effects of experimental selection harvesting on productivity and recruitment of two warbler species. MSc UdeM (Villard) 2006-2008.

24*.   Jean-Francois Poulin. 2008. Investigating mechanisms underlying thresholds in the response of an indicator species (Brown Creeper) to forest structure. MSc UdeM (Villard) 2006-2007.

D)   Effects of zoning landscapes

25.   Chris Ward. 2009. Forecasts of Triad Zoning Scenarios on New Brunswick Crown License 1. MScF UNB (Beckley, Erdle, MacLean) 2005-2009.

26.   Jean-Francois Carle. 2010. Design and implementation of bio-energy strategies in forest management scenarios. MScF UNB (MacLean) 2006-2010.

Sustainable Forest Management Network
3-03 Civil Electrical Engineering Building
University of Alberta
Edmonton, Alberta T6G 2G7
CANADA
Phone: (780) 492-6659
Fax: (780) 492-8160
Email: info@sfmnetwork.ca

www.sfmnetwork.ca