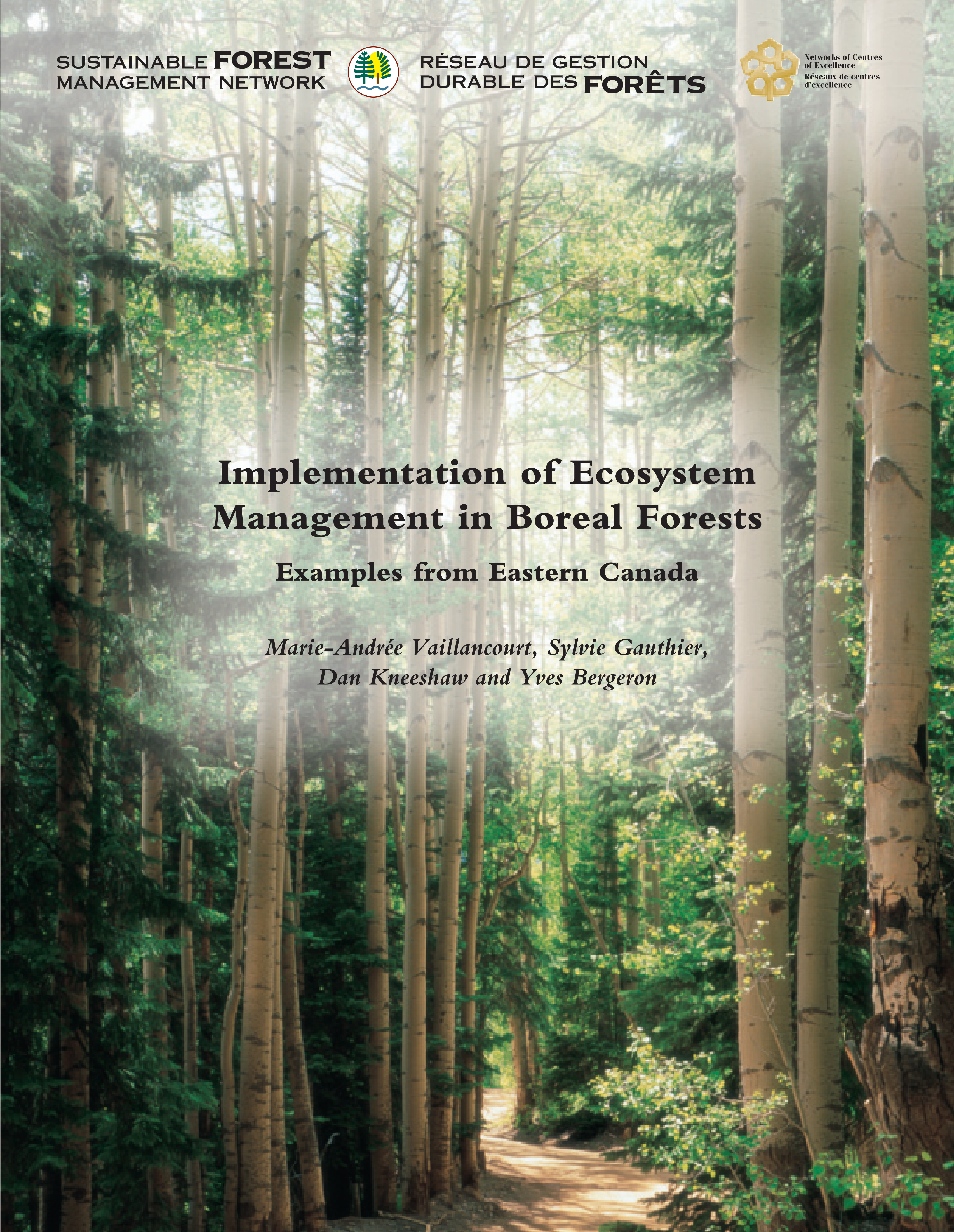

SUSTAINABLE FOREST MANAGEMENT NETWORK
RÉSEAU DE GESTION DURABLE DES FORÊTS

Networks of Centres of Excellence
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Implementation of Ecosystem Management in Boreal Forests

Examples from Eastern Canada

Marie-Andrée Vaillancourt, Sylvie Gauthier, Dan Kneeshaw and Yves Bergeron

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.

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

Implementation of Ecosystem Management in Boreal Forests

Examples from Eastern Canada

By

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Citation: Vaillancourt, M.A., Gauthier, S., Kneeshaw, D. and Bergeron, Y. 2009. Implementation of ecosystem management in boreal forests: examples from eastern Canada. Sustainable Forest Management Network, Edmonton, Alberta 40 pp.

ISBN# 978-55261-211-8
Printed in Canada
Cette publication est aussi disponible en français
Published June 2009

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Abstract

Over the last decade, the concept of ecosystem management has been frequently discussed by forest ecologists and forest managers throughout Canada. Forest ecosystem management (FEM) arose from a long period of reflection and knowledge acquisition on forest ecosystem functions that led to the idea that in order to preserve biological diversity and ecosystem integrity, forests must be managed using a more holistic approach. Current forest management based on extensive even-aged practices is modifying forest landscapes attributes (age structure, species composition, etc.) and raises concerns about the ability of these practices to maintain biodiversity and forest ecosystem viability. Natural disturbances play a major role in modifying forest landscapes attributes. Using natural disturbances as a template to develop an ecosystem management framework is the approach that has been widely adopted to maintain biodiversity in forest ecosystems while ensuring that forest productivity and associated economic activities are maintained over the long term.

In this synthesis, a hypothetical management unit representative of the eastern boreal forest is used to illustrate how a forest ecosystem management strategy can be developed using knowledge about natural disturbances such as fire, insect outbreaks and windthrow. The frequency of stand-replacing fires can help determine the proportion of an area to be managed using even-aged management practices. Spatial configuration attributes of fires can guide the planning of size and distance between regenerating areas whereas variable severity of fires can guide the retention of residual structures within regenerating areas. Other disturbances such as insect outbreaks, windthrow and single-tree mortality can guide the development of even-aged and uneven-aged management practices for the proportion of the management unit not affected by fire. Just as with fire, spatial configuration and severity attributes of these disturbance agents can guide harvest planning and selection of appropriate silvicultural methods. This hypothetical situation is followed with examples from research recently conducted in eastern boreal forests.

1.0 Introduction

An increase in the willingness to adopt forest ecosystem management (FEM) practices in public forests has recently been observed throughout Canada. Concerns have been raised about the ability of prevailing management strategies to maintain biodiversity and ecological processes which are important for maintaining ecosystem resilience and forest productivity over the long-term. There is also a social recognition that biodiversity, integral conservation of natural areas, and recreational and aesthetical importance of specific landscapes are values that should be integrated into forest management planning. Ecosystem management is a concept that has been developed after many years of reflection and knowledge acquisition on ecosystem functioning. It suggests that in order to maintain ecological functions and processes over the long-term, forests must be managed in a more comprehensive way aimed at maintaining significant ecological patterns and processes at their related scales of expression.

FEM has emerged from concerns about the ability of current forest practices to sustain biodiversity and ecosystem integrity

Scientific knowledge about forest dynamics in many regions of Canada's boreal forest has increased remarkably over the last thirty years. Many experimental projects have been undertaken to integrate the FEM concept into operational management strategies. These projects have contributed to the development of guidelines that are extremely useful to managers across the country who want to adopt FEM practices. There is, however, a great need to better inform the public and forest managers about the underlying concepts of FEM and to demonstrate how they can be achieved operationally.

This synthesis will:

1) briefly define the principal components of FEM;

2) explain the ecological basis of FEM;

3) explain how natural disturbances can be used as guides to FEM; and

4) illustrate how FEM can be implemented using case studies coming from different boreal regions of eastern Canada.

2.0 What is forest ecosystem management?

The conceptual framework for forest ecosystem management aims to accommodate harvesting activities and the preservation of ecosystem structure and functioning by managing forest ecosystems as integrated systems (Kimmins 2004). Many scientists and agencies have presented different definitions and interpretations of FEM (Grumbine 1994; Galindo-Leal and Bunnell 1995; Christensen *et al*. 1996; Kimmins 2004; D'Eon 2006a). Although it is difficult to present an absolute definition of FEM, common characteristics can be found among the different definitions:

1) **Sustainability of all ecosystem components and maintenance of ecological integrity.** The impact of forest management on living organisms and ecological processes must be considered at different spatial and temporal scales, not only at the stand scale but also at the landscape and regional scales.

2) **Multiple spatial and temporal scales.** Since forest ecosystems are larger than forest stands and conventional management unit boundaries, FEM planning must consider interdependence of the different spatial scales. Furthermore, ecosystems change over long time periods – FEM planning must therefore use longer time frames than those used traditionally.

3) **Establishment of ecological targets based on available scientific knowledge.** Ecological targets must be based on scientific knowledge acquired at both the regional and local scales for both natural and managed ecosystems. These targets must be easy to measure in order to assess the success or failure of FEM operations.

4) **Establishment of a unique management plan integrating all components of forest ecosystems.** In order to integrate all components of forest ecosystems in a unique operational planning process, all agencies acting within an area must work together (harvesting companies, trappers, mines, communities, tourism organisations, etc.) in the development of a management plan. This will assist in the development of ecological targets that attempt to accommodate the requirements of all interested parties.

5) **Monitoring of ecological targets and organisms' response.** Monitoring programs must be established in order to quantitatively verify whether the actions that have been taken achieve the desired results. If targets are not met, then the FEM plan must be adjusted. When developing a monitoring program the response of organisms to managment systems must be considered in order to verify whether ecological targets have been attained.

6) **Adaptive management.** FEM must be implemented within a flexible framework that permits changes to be incorporated. Scientific knowledge is constantly in development and new results obtained or new models developed must be easily integrated. The FEM framework must also be able to rapidly consider adaptations needed based on the results from the monitoring programs.

Most FEM definitions agree that human values – economic, recreational, or cultural, have to be integrated into planning. ***However, the main goal of FEM, to preserve biological diversity and ecosystem integrity, requires that ecological targets be defined first to ensure that ecosystem health is not compromised*** *and that other values be integrated subsequently*. Social, cultural and economic considerations must be integrated when establishing management strategies and operational plans. Ecological targets can then be modified as a result of trade-off exercises considering all stakeholder requirements within an area, with the knowledge that it may affect the ecological integrity of the system, and therefore its sustainability.

To achieve FEM goals, ecological targets must be determined prior to considering other values

2.1 Ecosystem management versus other forest management strategies

Many theories and notions of forest management have been developed during recent years and it is important to understand where FEM figures among them. The concept of FEM is embodied in the sustainable forest management notion defined by the Canadian Council of Forest Ministers (CCFM) as a management strategy designed to maintain and increase forest ecosystem health over the long-term while ensuring environmental, social, economical and cultural values for current and future generations. FEM is therefore a means to conserve ecological values and sustain forest productivity while considering social and economical values. It should be noted that in FEM, the maintenance of ecological integrity is considered a requirement to sustain socio-economic values.

FEM is a means to achieve sustainable forest management

FEM is distinguished from integrated resource management (IRM) in that instead of managing for each of the resources and values to manage individually, FEM is based on the management of the forest ecosystem as a whole. FEM focuses on the maintenance of the integrity of the entire system and facilitates the development of ecological targets in managed ecosystems. This approach relies on the hypothesis that maintaining ecological processes will sustain ecosystem

Integrated resource management focuses on multiple values and resources by considering each of them individually, FEM is focused on the forest ecosystem as a whole

resistance and resilience. In doing so it is assumed that ecosystem goods and services will continue to be provided, even those that are not known or not currently developed.

FEM can also include zoning strategies where different parts of a management unit are allocated to different management regimes. For example, a zoning strategy can include different management options such as intensive forest management, conservation (no forest management) and extensive management (where FEM strategies are utilized to meet economic, social and cultural needs). The strategy would describe the various management approaches that would be followed and the proportion of the landbase that would be allocated to each management zone. An example of a zoning strategy is the TRIAD approach (MacLean *et al.* 2009).

3.0 Ecological rationale for forest ecosystem management

3.1 Why is preserving ecological integrity and biodiversity in managed forests important?

Ecological integrity has been defined by Angermeier and Karr (1994) as *"a system's wholeness, including presence of all appropriate elements and all processes at appropriate rates"*. In other words, conserving biological diversity (at the level of genes, species, populations, and landscapes) as well as the associated processes (competition, predation, mortality, disturbance, etc.) are necessary to maintain ecosystem integrity.

Protected areas must be complemented by measures that ensure biodiversity maintenance in managed landscapes

Protected areas have been established in many ecosystems as a way to conserve representative landscapes and their associated biodiversity. Protected areas refer to areas that have been removed through regulatory means from the managed forest landbase. However, reserves are often too small and unconnected with large forest tracts and offer little redundancy to ensure long-term ecological integrity in a dynamic environment. Therefore we can't rely on protected areas alone to conserve biodiversity or maintain ecological processes. Forest harvesting occurs over large areas within Canadian boreal forests. Of the more than 1.5 million km^2 of productive forest in Canada, 60% has been logged at least once (Burton *et al.* 2003). Conserving biodiversity within these large tracts of managed forest areas is therefore a prerequisite to maintaining ecosystem integrity (Harris 1985; Lindenmayer and Franklin 2002) across the boreal.

Biodiversity plays an important role in the resilience and resistance of forest ecosystems following natural and human disturbances

Another reason to conserve biological diversity in managed areas is to help maintain ecosystem **resilience** and **resistance** of forests following anthropogenic and natural disturbances (see text box 1). In forest management there is a need to maintain the capacity of forest ecosystems to recover after environmental change in order to ensure a continued supply of goods and services provided by the ecosystem in the future. In implementing FEM, the goal is to maintain forest ecosystems that are both resistant and resilient to environmental variations such as climatic variations (early thaw, late frost, etc.). This can become very important within a climate change context.

Biodiversity and biological legacies are components that play a role in the maintenance of ecosystem resilience and resistance. Following disturbance events, the remaining or residual forests still possess characteristics that are inherited from the previous stand (e.g., living trees, standing dead trees, down woody debris, seeds, organic matter). These are referred to as the “biological legacies” (*sensu* Franklin *et al.* 2000) of disturbed stands. Biological legacies play an important role in forest stand recovery and the provision of suitable habitat. For example, in a large burned area, biological legacies consist of unburned or partially burned forest patches. These residual patches serve as refuges for forest-dwelling wildlife species as well as for tree species that are not adapted to fire (e.g., balsam fir, white spruce, cedar). Residual forest habitats enable species to re-colonize the disturbed area when favourable conditions occur (Galipeau *et al.* 1997; Johnson *et al.* 2003).

Biological legacies play an important role in forest stand recovery following disturbances

Research indicates that the capacity of an ecosystem to recover after disturbances and environmental stress is linked to the variety of responses of organisms in the ecosystem. Several ecological functions may be accomplished by more than one species within an ecosystem. This redundancy provides flexibility to an ecosystem relative to the organisms’ ability to respond to disturbances and environmental fluctuations. If environmental conditions change, certain species might respond more positively than others to these new conditions but overall the ecological functions may still be accomplished.

In addition to ecosystem resilience and resistance, biological diversity in forest ecosystems has a positive influence on primary production, nutrient retention and resistance to diseases (Perry and Amaranthus 1997). For example, in the boreal forest, mixedwood stands are more productive in terms of biomass (Paré and Bergeron 1995; Bergeron and Harvey 1997) and experience less mortality during spruce budworm outbreaks (Bergeron *et al.* 1995). In the same manner, landscapes dominated by various stand types (deciduous, mixed and coniferous stands) can be more resistant to insect outbreaks because of the diversity of natural enemies and predators which may stop or limit the growth of insect populations (Cappuccino *et al.* 1998).

Figure 1. Illustration of biological legacies. Top left: large snag occupied by a Barrow's Goldeneye nest. Top right: stump with growing balsam fir seedlings. Bottom left: burned standing dead trees and regenerating poplar one year following fire. Bottom center: standing dead tree occupied by Boreal owl nest. Bottom right: very large white spruce snag. (Photo credits: Christian Marcotte, Martin Simard, Danielle Charron, Antoine Nappi, and Marie-Andrée Vaillancourt)

Box 1. Resistance and resilience of an ecosystem

Resistance is the capacity of a system to absorb disturbance and prevent its amplification (Perry and Amaranthus 1997). When mechanisms for resistance are weak, then the capacity of an ecosystem to maintain a given state is also weak. A good example of ecosystem resistance is the presence of natural enemies preventing pest insect proliferation. This provides resistance to forest stands subjected to spruce budworm outbreak (SBW). A study conducted by Cappuccino *et al.* (1998) observed that the occurrence of spruce budworm's natural enemies in landscapes dominated by coniferous stands was smaller than in mixed stands which reduced conifer stand resistance to this disturbance. These forest stands sustained outbreaks that were more severe than in landscapes composed of a variety of forest stands (mixedwood, coniferous and hardwoods stands) (Su *et al.* 1996).

Resilience is defined as the capacity of an ecosystem to undergo a disturbance while maintaining its functions and control mechanisms (Holling 1973). Resilience also refers to the rate at which an ecosystem recovers to its original state after disturbance (Begon *et al.* 1987; Perry and Amaranthus 1997). The return of a forest stand to a similar state following a fire is an example of forest resilience. A hundred years following a severe fire event, a spruce stand showing similar structure, habitat features, and species composition as the pre-disturbance stand has demonstrated resilience. In this case, the rate of recovery was 100 years.

3.2 Identifying key attributes that maintain ecosystem integrity

Important attributes of forest ecosystems for conserving their capacity to function following environmental stress or disturbances can be divided into four categories (Gauthier *et al.* 2009a):

a) forest composition,
b) forest structure,
c) coarse woody debris, and
d) soil organic layer.

These key attributes are strongly affected by disturbance regimes and are manipulated by forest management operations. Therefore, they are the basis for defining ecological targets at both landscape and stand scales.

a) forest composition

Many habitat characteristics of forest stands are influenced by tree species composition. Forest productivity (Légaré *et al.* 2005), shrub and herbaceous layer diversity (De Grandpré *et al.* 2003), and wildlife habitat diversity (Drapeau *et al.* 2000; Work *et al.* 2004) are good examples of characteristics that vary with forest composition. At the stand scale, physical environment conditions (e.g., soil texture, drainage, climate, etc.) and time since last disturbance influence stand composition (Bergeron 2000; Le Goff and Sirois 2004). At the landscape scale, the relative importance of each forest stand type will also vary with physical characteristics and with the average frequency of major disturbances. When planning harvesting activities, it's important to determine forest composition targets based on the major disturbance regime (e.g., fire patterns and processes) of the region (Gauthier *et al.* 2009b).

b) forest structure

Forest structure attributes provide habitat for many organisms (Hobson and Schieck 1999; Drapeau *et al.* 2000; Work *et al.* 2004; Hannon 2005). At the stand scale, key structural attributes such as tree size, multi-storey (vertical) structure, snags, and downed woody debris should be maintained (Franklin 1993; Spies 1998). At a landscape scale, structural patterns such as the amount and distribution of old-growth forest, and the size and spatial distribution of regenerating stands should be integrated into the landscape design to provide forest structure and patterns more closely resembling those resulting from natural disturbances. These structural components vary in importance from region to region based on environmental conditions and disturbance regimes.

c) coarse woody debris

Standing dead trees and downed woody debris are key forest structure attributes identified as critical for the maintenance of biodiversity in intensively managed areas. Standing dead wood of various size and decomposition provide shelter, feeding and reproductive habitats for a large number of bird, insect and mammal

species (e.g., Martin *et al.* 1999, 2004; Imbeau et Desrochers 2002; Nappi *et al.* 2003; Saint-Germain *et al.* 2004). Downed woody debris plays an important role in the establishment and initial survival of many plant and tree species (nurse logs) (Lee and Sturgess 2001) as well as in the nutrient cycling of carbon (Harmon *et al.* 1986). (For more details on coarse woody debris, see Kopra and Fyles 2006; Kopra and Fyles 2005a; Kopra and Fyles 2005b).

d) soil organic layer

The quantity and distribution of the organic soil layer is an important attribute at the stand scale. Organic matter affects nutrient and water availability. It also affects micro-climate which plays a role in forest regeneration. Post-fire organic layers may have an increase in pH and nutrient availability in peatland spruce stands. (For more information on organic matter, see Welke and Fyles 2006).

In addition to these broad categories, there are several key attributes that often play a critical role in the maintenance of ecological integrity at the stand scale. **Local ecotonal features** such as vernal pools and stream banks provide important habitats to species dependant on both aquatic and forest habitat during their life cycle (deMaynadier and Hunter 1995; Newcomb Homan and Windmiller 2004). **Microtopographic features** such as pits and mounds resulting from treefalls create heterogeneity in forest stand understory and good germinating substrate for some plant and tree species (Peterson *et al.* 1990; Ruel *et al.* 1988).

3.3 The ecological role of natural disturbances in forest ecosystems

Within a single region, various biotic (insect outbreaks, diseases, browsing) and abiotic (wind, fire, ice storm) disturbances occur and interact at different spatial and temporal scales. These disturbances are influenced by a variety of factors such as climate, physical environment (topography, surface deposit, etc.) and biotic factors (e.g., stand characteristics). Natural disturbances can change forest composition and re-initiate stand succession at different temporal and spatial scales over landscapes, which results in a diversified mosaic of forest stands.

Forest management based on natural disturbance has been widely adopted to maintain biodiversity and ecosystem integrity

Natural disturbances are the main drivers of a variety of ecological processes and forest dynamics from which forest management can be inspired. By studying the effects of natural disturbance on key forest attributes and the underlying processes involved, strategies to maintain the natural character of managed landscapes can be developed re-creating conditions observed under natural disturbance regimes. Using natural disturbances as a template to develop an FEM framework has been widely adopted to maintain ecological integrity in forest ecosystems while ensuring that forest productivity and associated economic activities are maintained over the long-term (e.g., Bergeron and Harvey 1997; Alberta Research Council 1999; Spence and Volney 1999; OMNR 2001).

4.0 Natural disturbances as a guide for forest ecosystem management

Transforming FEM concepts from theory to operational implementation is one of the largest challenges currently facing forest managers. Forest management strategies based on natural disturbance dynamics are a useful way to meet biodiversity and ecosystem integrity objectives. By establishing guidelines based on natural disturbances, FEM aims to minimize differences between natural forest conditions and those generated by management operations, thus minimizing the adverse impacts on biodiversity and forest productivity (Bergeron *et al.* 1999). However, implementation of this approach requires a good understanding of the principal effects of natural disturbances on forest ecosystems at various spatial and temporal scales.

Implementation of FEM requires a good understanding of natural disturbance effects on forest ecosystems at various spatial and temporal scales

Return interval, size, and severity of disturbance are the three characteristics of disturbance regimes of concern to forest managers due to their effects on key forest attributes. These characteristics determine the natural range of variability (NRV) generated by the disturbance regime (Figure 2). There is a growing consensus that current forest management approaches reduce natural variability resulting in a homogenization, or loss of variability in forest conditions (McCrae *et al.* 2001; Hauessler and Kneeshaw 2003). This homogenization is caused by the regular (in terms of rate and intensity) and systematic (targeting mature and old-growth stands) harvesting strategies largely employed in Canada today.

Knowledge of the natural range of variability of disturbance regimes allows comparisons between naturally disturbed and managed forests. This helps set FEM targets aimed at minimizing the differences observed

Using information about natural variability and the range of associated forest patterns and structure, it is possible to compare forest conditions following natural disturbance and forest management. FEM targets can then be defined based on these differences observed at the landscape and stand scales. To help visualize the objective of reducing discrepancies between management and natural disturbance-based approaches, a simplified model illustrating the main characteristics of a disturbance regime is presented below (Figure 2).

As noted above, natural disturbance regimes can be described using three characteristics: return interval, size, and severity of disturbance. Using fire as an example, the natural variability of a fire regime can be described along three axes (Figure 2a). Within the boreal forest, there is a wide range of conditions along each of the axis from one region to another. For example, because fires occur randomly, a site can burn successively within a few years while another site can remain unburned for hundreds of years. In the same way, burned areas can vary from less than a hectare to thousands of square kilometres in size. While surface fire only affects the lower vegetation layers, crown fires kill every tree and can consume the organic layer to the bedrock. Combinations of all these characteristics – fire severity, fire size, fire interval – as well as others (e.g., specificity, seasonality, etc.) constitute the fire regime which is unique to a specific region (Figure 2a, soft gray area).

FEM strategies must create forest conditions within the natural range of variability and also maintain variability throughout the managed landscape

In contrast with natural variability, conditions created by conventional forest management practices tend to be homogenized (Figure 2a,b). Current practices have resulted in the standardization of the harvest interval or rotation period, the cutblock size and harvest intensity leading to reduced forest variability compared to the natural disturbance regime. Furthermore, this variability and the resulting forest patterns and structure they create, could be located outside of the historical range of natural variability, thus creating a situation in which both biodiversity and forest productivity could be compromised. For example, conventional management practices with short harvest rotations greatly reduce the amount of dead wood and can negatively affect species dependent on these structures. In an FEM framework, management strategies must create conditions within the natural range of variability and also ensure the maintenance of variability in managed landscapes (Figure 2c,d). Forest management must be based on a compromise that is socially and economically acceptable and meets ecological objectives by maintaining forest conditions within the historical range of variability based on the natural disturbance regime.

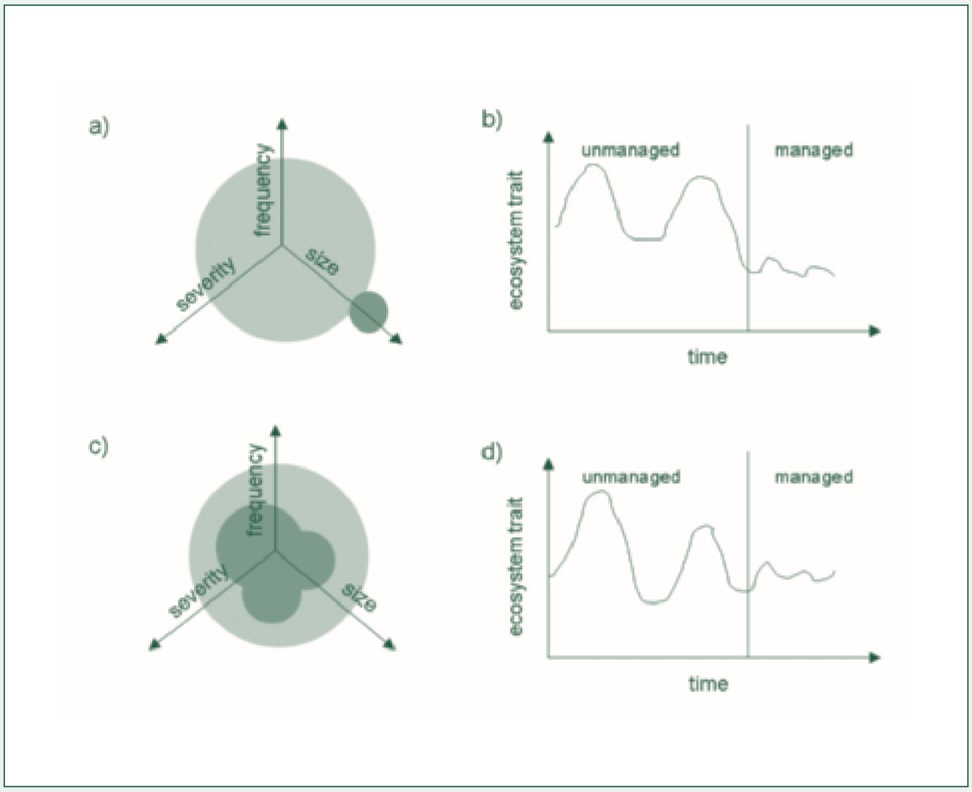

Figure 2. Range of variability in disturbance events and ecosystem traits in unmanaged and managed ecosystems (from Haeussler and Kneeshaw 2003) a) and c) illustrate the range of disturbance size, frequency and severity under unmanaged (light gray sphere) and managed (dark gray sphere) conditions (adapted from Swanson *et al.* 1994). b) and d) represent temporal fluctuations in an ecosystem trait or indicator before and after management intervention. In a) and b), management interventions have caused the system to move outside the natural range of variability. In c) and d), the system remains inside the range of natural variability, but management has constrained the amplitude of oscillations.

Knowledge about disturbance regimes, their effects on forest patterns and structure and their variability through time can guide the development of management strategies that are similar to natural forest conditions. Integrating this knowledge does not suggest that one can integrally mimic nature. Instead, understanding natural ecosystem functioning and disturbance dynamics and their concomitant effects on the forest mosaic in terms of forest patterns and structure can be used to develop management strategies and silvicultural techniques that reduce the gap between current forest management methods and natural variability.

5.0 Implementation of ecosystem management: an example from eastern Canada's boreal forests

Implementing FEM throughout the boreal forest is not a simple task. Complexity and variations within boreal forest ecosystems at regional and landscape scales do not enable development of a simple FEM plan that could be implemented everywhere. However, a general framework can be developed to facilitate the application of the FEM concept based on knowledge of forest dynamics and natural disturbance regimes acquired at regional or management unit scales.

Over the last decade, many experimental projects to develop FEM frameworks and increase knowledge on disturbance dynamics were initiated in different boreal regions across Canada. In this section, the first steps of FEM implementation are illustrated using a hypothetical case study that is representative of the eastern boreal forests. Examples from ongoing research are also used to illustrate various problems and challenges related to regional specificities. Socio-economic considerations and monitoring will be briefly addressed at the end of the synthesis.

Steps for development of an ecosystem management approach

- **Reconstruct the natural disturbance regime and long term evolution of forest stands following disturbance;**
- **Compare the forest patterns and structure of natural and managed landscapes and identify the main differences;**
- **Develop management objectives and silvicultural practices to minimize differences between forest management and natural forest dynamics;**
- **Implement silvicultural practices in the context of a working plan that takes into account social and economic values; and**
- **Monitor results to evaluate management objectives and modify silvicultural practices if needed.**

The starting point for the development of an FEM approach is the reconstruction of the natural disturbance regime. This task includes gathering reliable information on all major disturbances affecting the area, including the development of relationships to describe the natural range of variability of disturbance events and

The reconstruction of natural disturbance regimes includes gathering reliable information on all major disturbances affecting an area

associated ecosystem traits based on both historic and geographic variability. This information will serve as a blue print for the development and implementation of an FEM working plan and silvicultural systems that re-create environmental conditions found following natural disturbances. In this way, managed forest ecosystems will maintain variability and forest conditions beyond the natural range of variability will not develop.

Natural disturbances that affect forest ecosystems result in different impacts and ecosystem responses depending on the magnitude and type of disturbance event As such, various disturbance regimes can serve as "models" upon which to develop or adapt silvicultural systems. To describe the natural disturbance regime, the manager should look primarily at: **disturbance agents, return intervals (or frequency), severity and spatial distribution**.

Fire return intervals vary greatly between and within regions depending on biotic and abiotic factors such as climate, physiographic features, and forest structure and composition. Fires can severely affect very large forested areas.

Fires, insect outbreaks and windthrow are important disturbance agents that can vary in their severity and impacts on forest ecosystems

Forest insects such as the spruce budworm are important disturbance agents in the eastern boreal forest of Canada. Forest insect outbreaks can have a wide range of effects in terms of mortality and spatial distribution depending on forest age and composition both at the stand and landscape scales. Return interval of insect outbreaks often show a cyclic pattern. In the case of SBW, outbreaks have started every 30-40 years during the two last centuries (Morin *et al.* 2009). Although SBW can be a stand-replacing disturbance by causing total mortality at the stand level, it rarely results in a high percent of mortality at the landscape scale and it does not directly affect soil.

Windthrow is a widespread disturbance agent in the boreal forest. Its impact can vary widely from a single tree fall to thousands of hectares of blowdown. Within eastern boreal forest landscapes, small severity windthrows prevail. Impacts on soil can vary depending on the severity of windthrow and on the type of soil. Mineral soil can be exposed following windthrow but soil resources are not transformed, merely displaced.

Based on these main disturbance agents, three categories of natural disturbance severity can be outlined (Kneeshaw *et al.* 2009): **stand-replacing, intermediate (or patch) and gap disturbances**. Each category can be associated with management practices (e.g., clearcuts, partial cuts, selection cuts respectively) (see Figure 3). Comparisons at the stand and landscape levels between natural and managed systems can then be made to identify major differences and find silvicultural solutions to mitigate these differences.

Depending on factors such as climate and physiographic features, the proportion of the land base affected by fire will vary and influence the proportion of the area where dynamics are governed by other disturbance agents. **Determining the proportion of the area that is driven by the various natural disturbances and severity levels will help forest managers designate proportions of the land base to be managed under even-aged (clearcut harvest systems) and uneven-aged management systems (partial harvest systems). This is the baseline for defining management strategies**.

The amount of area historically affected by disturbance type, as well as severity level, determines what percent of the land base should be under even-aged and uneven-aged management

Box 2. Tembec's Natural Disturbance Based Management (NDBM) pilot project in Abitibi-Témiscamingue, Québec.

Context

Based on a research project of the NSERC-UQAT-UQAM Industrial Chair in Sustainable Forest Management started in 1999, Tembec, Norbord and the Ministère des Ressources naturelles et de la Faune du Québec (MRNF) decided to explore the potential application of NDBM concept on the Forest Management Unit (FMU) 085-51, for the black spruce – feather moss forest located north of La Sarre (Abitibi-Témiscamingue). In 2002, these organizations created a technical committee responsible for producing a general forest management plan based on the NDBM concept. In 2006, the project, lead by Tembec, was adopted by the MRNF as a pilot project.

Main issues

Tembec was interested in testing the NDBM strategy as a way to address several requirements related to FSC certification. This included a comparison of pre-industrial and current forest conditions with regard to:

- Spatial distribution of harvest areas;
- Maintenance of suitable woodland caribou habitat;
- Maintenance of mature and older seral stage forests;
- Maintenance of productivity despite the paludification process (bog expansion and productivity loss) (Simard *et al.* 2007); and
- Retention of residual forest and structural elements in harvest areas.

These issues became the main objectives for the general forest management plan.

Box 2. Continued

Steps for the development of the forest management plan

At the landscape level, the first step was to strategically locate future harvest areas to return to forest conditions that more closely resemble a natural disturbance driven landscape over the long term. There was an attempt to implement spatial guidelines provided by Belleau *et al.* (2007) (e.g., increased spacing between large harvested areas). Areas most frequented by forest dwelling woodland caribou were deferred from the 2008-2013 plan. Retention targets for mature and older stage forest were set at between 28 and 38% by area. This corresponds to the area of irregular and uneven-aged stands found under a 200 year fire cycle. Partial cut experiments were conducted in the northern part of the plan area to develop expertise in maintaining old growth forest attributes. In the southern part of the FMU, irregular and uneven-aged stands were below the targets because of past logging activities. In this area partial cuts were planned to increase vertical structure of even-aged stands and accelerate natural succession.

Tembec maintained 30% of residual forest between harvest areas (in well distributed patches greater than 50 ha). In-block retention (snags, wildlife trees, clumps of trees) targets of 20% by area were set to provide structural elements within harvested areas. In harvest areas where the potential of blow down was high, the width of riparian zones was increased.

Future steps

In 2006-2007, a monitoring system was developed and will be implemented as part of the 2008-2013 forest management plan. A great challenge will be to ensure the monitoring system allows for adaptive management and feedback into management practices. Another important step will be to develop and implement silvicultural treatments to more closely resemble natural disturbance processes at the stand level to maintain productivity or to increase the efficiency of forestry interventions.

5.1 Using the natural disturbance regime to guide management strategies: a case study

For the purpose of this case study, fire was considered separately as the main stand-replacing disturbance even though fire is not always severe and can join other disturbances (SBW and windthrow) in the intermediate and gap disturbance categories. This makes it easier to compare conventional large scale even-aged management systems with fire and define smaller scale even-aged practices and uneven-aged system based on other disturbances.

To determine the amount of a management unit affected by fire, information on the fire return interval is needed. **Fire cycle** has often been used to characterize the fire return interval. However, since this parameter varies greatly in time and space, it is recommended that **mean time since fire** may be a more reliable parameter for determining the proportion of forest that would burn during a defined rotation period (Lauzon *et al.* 2006). Table 1 recommends the amount of area to be managed under an even-aged management regime according to mean time since fire and economic rotation age.

Information on fire frequency is useful to determine the proportion of an area to be managed under an even-aged management regime

The area used in this case study covers 600,000 ha with a mean time since fire (mean stand age) of 150 years. Using an economic harvest rotation cycle of 80 years, the proportion of the area affected by fire would be 41% (Tables 2-3). Note that because of the variation in fire frequency, this amount was between 25-60% over the last 300 hundred years and represents the NRV for fire frequency. An even-aged management approach which targets 41% of the stands for harvest using clearcut systems during this rotation period will be within the NRV. Furthermore, targeting the middle of the NRV will allow an increase in the overall amount of even-aged stands created by natural stand replacing disturbance without the risk of greatly exceeding the NRV.

Table 1. Amount (%) of an area using an FEM approach that could be under even-aged forest management based on fire disturbance regime and economic rotation age.

	Average time since fire (years)						
Rotation age	**50**	**75**	**100**	**125**	**150**	**200**	**300**
(years)	Even-aged management areas (%)						
50	63	49	39	33	28	22	15
60	70	55	45	38	33	26	18
70	75	61	50	43	37	30	21
80	80	66	55	47	41	33	23
90	83	70	59	51	45	36	26
100	86	74	63	55	49	39	28
110	89	77	67	59	52	42	31
120	91	80	70	62	55	45	33
130	93	82	73	65	58	48	35
140	94	85	75	67	61	50	37
150	95	86	78	70	63	53	39

One way to assess the proportion of the landbase affected by **intermediate disturbances** is to use a temporal series of aerial photographs and/or forest maps to look at pre- and post-disturbance landscapes. In this case study, 22% of the area was affected by intermediate disturbances (such as severe and moderate insect outbreaks or windthrow) which varied between 10 and 30% over time and depending on site type (Table 2). The remaining forest area (i.e., proportion not affected by fire or intermediate disturbances) was considered to undergo **gap disturbances** and represented 37% of the area for this case study (Table 2).

In order to maintain the species composition of future forests to achieve biodiversity objectives, knowledge about the composition of even-aged stands and the associated succession trajectories can be used. For more information regarding this issue refer to Harvey and Bergeron (1997).

Table 2. Amount of the case study area affected by stand-replacing, intermediate and gap disturbances based on historic disturbance patterns.

	Stand-replacing fires	Intermediate disturbances	Gap disturbances
Mean % area affected (range)	41% (25-60)	22% (10-30)	37% (10-60)

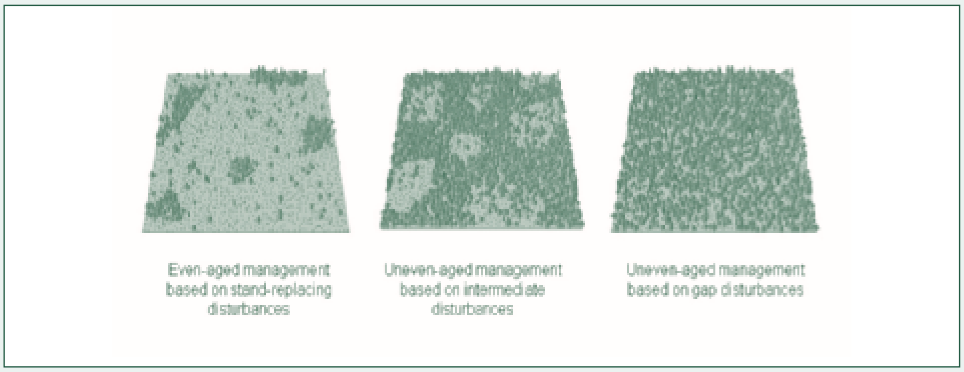

Figure 3. Illustration of forest landscapes resulting from forest management practices based on the natural disturbance regime.

5.2 Management systems based on a fire regime

Fire is the main disturbance agent affecting large areas in boreal forests. Many characteristics of fire regimes can be used to create even-aged management strategies

Fire is the main disturbance agent affecting large forest areas in boreal ecosystems. Several characteristics of the fire regime can be used to guide the creation of even-aged management strategies. The amount of the land base to be managed under an even-aged system can be identified based on historic disturbance patterns. Other characteristics of the fire disturbance regime must also be identified in order to maintain the spatial and severity attributes in forest patterns and structure resulting from the natural fire regime. These attributes will help to define tactical (e.g., harvest pattern, residual forest) and operational objectives (silvicultural techniques) within even-aged systems.

Management strategies based solely on even-aged systems have been widely applied since modern forestry began. Comparisons between conventional even-aged or clearcut systems and wildfire have shown that impacts of current even-aged systems differ from those induced by severe natural disturbances (see McCrae *et al.* 2001 for a review). Regional level comparisons can be used to assist with the identification of diverging attributes in forest patterns and structure and set targets to attain more natural desired conditions in managed forests. Table 3 illustrates this process by presenting characteristics of the fire disturbance regime, analogous characteristics following current even-aged management and recommendations to mitigate differences within the management unit.

For example, in a management unit of 600,000 ha where mean time since fire is 150 years, 0.67% of the area will burn on average each year (Table 3). To create regenerating areas at the same rate as fire, even-aged harvesting activities would be applied to 3,075 hectares per year if fire no longer occurs. Under the current management regime, which aims to harvest approximately 1% of the area annually, the proportion of old-growth forest remaining will be far lower than what would be naturally observed in eastern North American boreal forests over the last eight thousand years (Cyr *et al.* 2009). Taking into account that fire still occurs even though fire suppression programs are active, regenerating areas created by both harvesting and natural disturbances will be even greater than natural levels further reducing the amount of old forest habitat available. Therefore, to reduce differences in age class distribution between managed and natural disturbance regimes, the yearly harvest areas of even-aged managed forests must be reduced. To compensate for this reduction and the concomitant impact on timber supply, uneven-aged systems can be implemented to access fibre while maintaining forest structure (presented in section 5.3).

In regions where fire frequency is lower than the current harvest rate, even-aged management must be reduced – however the use of uneven-aged management can help mitigate this

5.2.1 Size and distance between even-aged regenerating areas

Within a management unit, size and spatial distribution of post-fire regenerating areas can provide guidance to the spatial pattern of areas to be harvested. For example, simulations by Belleau *et al.* (2007) suggested that mean fire size, for a given fire cycle, influences the spacing of regenerating areas. A fire regime dominated by large fires will tend to produce more dispersed regenerating areas than a fire regime where small fires prevail. A fire regime dominated by large fires will therefore create large tracts of regenerating, mature and old-growth forests at the landscape level. Hence, spatial patterns resulting from natural disturbance strongly influence old-growth habitat fragmentation and connectivity which are important features in the conservation of forest-dwelling species.

A harvest plan that provides a range in disturbance sizes (harvest areas) and uses a landscape design that promotes connectivity through the retention of residual forest areas and structure will more closely resemble a forest derived from natural disturbance. This differs from a forest management regime in which harvested areas are of similar size and equidistant from each other.

Table 3. Natural variability of the fire regime and current even-aged management condition in a hypothetical boreal forest ecosystem and recommended approaches to minimize differences between natural and managed conditions.

Forest Attribute	Natural variability under fire	Current state under even-aged management	Silvicultural approaches
Amount of area disturbed annually	0.67% (0.31-0.75)	1.25%	Reduce the annual area being harvested with clearcut systems
Spatial distribution			
Patch Size (range)	30-30,000 ha	400-40,000 ha	Reduce maximum size of contiguous clearcut area
Spacing	10-60 km	1-10 km	Increase distance between contiguous clearcut area
Severity			
Residual forest			
Amount	5-35%	10-45%	Amount should be maintained
Shape	Oblong, large, irregular	linear	Create residual forest with more irregular shapes
Mean size	0-5 ha (0.1-100)	1-10 ha (0.1-50)	Mean size should be maintained, maximum size should be increased
Soil	High level of soil disturbance	Low level of soil disturbance	Adopt silvicultural practices that reduces the organic layer in stands susceptible to paludification

Within the hypothetical case study, the fire regime is characterized by a great variability in size of regenerating areas[4]. The range of fire affected areas varies from 30 to 30,000 hectares and spacing between regenerating areas created varies between 10 and 60 kilometres. Perron *et al.* (2009) found similar results following a comparison of fire and even-aged management in black spruce forests of central Québec such that the largest harvest disturbance area (total amount of area from all harvest patches) was larger than the largest regenerating area created by fire. Similarly, distances between harvest disturbance areas were smaller than those between regenerating areas after fire.

To reduce differences between managed landscapes and those derived from ND, regenerating areas created by clearcut harvesting should be variable in size. Large regenerating areas should be dispersed across the landscape

Other parameters that can vary between clearcut areas and fire landscapes are the shape of the disturbance patches and the sharpness of the edge between the forest matrix and the disturbed area. The resulting forest patterns and structure are very different from those derived from natural disturbance. Forest fire often results in an oblong shape, which can reduce the distance between the burn area and the unburned matrix (Johnson *et al.* 2003). Boundaries between disturbed and non-disturbed forests are usually more irregular following fires than after clearcut harvesting, showing greater structural complexity (Harper *et al.* 2004).

[4] Regenerating areas consist of an amalgamation of either fires or harvest blocks during a period of 20-30 years.

Following the comparisons presented in Table 3, the recommendations for tactical planning would be to:

1) reduce the size of the largest harvest disturbance areas created by clearcut harvesting, and

2) increase the distance between large harvest disturbance areas.

When large harvest disturbance areas are planned, they should be distributed across the management unit to more closely resemble larger forest disturbances that result following fire which eventually grow into large tracts of mature and old-growth forest. These tracts of continuous forest cover may play an important role in the conservation of forest-dwelling species associated with mature and old-growth forests at the landscape level.

5.2.2 Legacies within regenerating areas

Fire is generally recognized as the most severe disturbance occurring in boreal forests as it frequently exposes mineral soil and kills the majority of trees over large areas. However, variability in fire severity is observed between and within fire events. Some of the factors responsible for these variations may include weather, availability of fuel, forest cover composition and topography. The resulting residual forest areas (embedded in a matrix of burned areas) play an important role as refuges for forest-dwelling species and tree species not adapted to fire which will be able to re-invade disturbed areas when appropriate conditions return.

Residual forests within burned areas are refuges for forest-dwelling wildlife and tree species not adapted to fire

Within a single fire event, fire severity can vary greatly at both the soil and canopy levels. Generally, patches of forest either partially burn or are not affected at all, and living trees may be dispersed throughout the burned area (Van Wagner 1983; Kafka *et al.* 2001; Schmiegelow *et al.* 2006). Two types of residual forest are generally identified: peninsular forest, which is comprised of residuals near the border of the fire that are still linked with the unburned matrix, and inner residual forest (individual trees or patches), that are dispersed within the burned area (Gluck and Rempel 1996; Andison 2001). Information about residual forests (patches) within burned areas can help forest managers prescribe retention levels within clearcut harvest areas (often referred to as variable retention harvesting) (Sougavinski and Doyon 2002, 2005; Serrouya and D'Eon 2005; D'Eon 2006b). The quantity, quality and configuration of residual forests are parameters that need to be considered in the development of silvicultural operations including modified harvest systems (Serrouya and D'Eon 2005).

Amount, configuration, composition and structural attributes are important features when planning residual forests

The residual forests resulting from fires in the case study area are similar in terms of proportion and mean size of residual forests in cutover areas. However, there are differences in the configuration of these forest remnants. Residual forests in burned areas had various shapes while residuals left by management operations tend to be more linear due to adjacency rules and riparian zone requirements. Linear forests can be more susceptible to edge effects, which may have an impact on seed tree availability and biodiversity. Along with the amount and configuration, composition and structural attributes of residual forests (such as large living and dead trees) are also important features to consider when planning for residuals during forest management operations.

Careful logging can reduce productivity in peated areas

Techniques that severely disturb soil can maintain or enhance stand productivity in heavily peated areas

The impact of fire on soils can have a great importance in regions where paludification[5] occurs or where stands are susceptible to invasion by ericaceous species. By consuming the organic matter layer, fire contributes to the maintenance or the recovery of stand productivity. The problem of paludification is well described by Bergeron *et al.* (2007) for the clay belt region in northwestern Québec, where productivity losses through succession are observed. Silvicultural techniques such as careful logging around advance growth (CLAAG/CPRS) help conserve soils because they do not greatly disturb the organic matter layer. However, applying these techniques to susceptible stands may actually contribute to a reduction in stand productivity through increased paludification. Alternative techniques that recreate fire effects (i.e., prescribed burning and scarification) may be more likely to reproduce the effects of fire (i.e., inhibit build up of organic materials and expose mineral soil for seeding in from well planned residual areas (Green *et al.* 2000)) and are therefore better practices to maintain or enhance stand productivity.

5.3 Management based on intermediate and gap disturbance regimes

Insect outbreaks and wind in eastern boreal forests can affect large areas although rarely affect soil or cause total mortality across landscapes

These conditions can be re-created using primarily uneven-aged practices

Fire has long been considered the main disturbance agent in boreal forest ecosystems. However, disturbances such as insect outbreaks and windthrow have recently received more attention because of their important role in forest ecosystem dynamics, especially in regions characterised by long fire cycles (e.g., Maritimes region, eastern Québec). Insect outbreaks and windthrow can affect large areas but rarely cause total mortality at landscape scales and do not severely affect soil and established regeneration. To re-create prevailing conditions under such disturbance regimes, management systems that comprise a high proportion of uneven-aged practices (partial harvests) should be developed and implemented.

Intermediate and gap disturbances involve several disturbance agents. Therefore, characterizing the effects of each agent can be a difficult task because of the possible interactions between them. To overcome this problem, Kneeshaw *et al.* (2009) suggested a characterization of intermediate and gap disturbances based on size of areas affected. **Intermediate disturbances** were defined as events covering areas greater than 1 ha and **gap disturbances** as those affecting areas less than 1 ha. Once the distinction between intermediate and gap disturbances has been made, spatial and severity attributes can be assigned according to disturbance agents. Spatial distribution and retention levels observed in naturally disturbed stands can help managers decide which silvicultural practices should be used to achieve those objectives.

Table 4 presents an example of forest characteristics associated with intermediate or gap disturbances based on different levels of disturbance intensity. The table is based on the results presented in Kneeshaw *et al.* (2009) for the Gaspésie region in eastern Québec. Intermediate disturbance agents in the study area (spruce budworm and windthrow) affected 22% of the landbase. Areas affected were then classified either as light or severe according to the degree of canopy openness. Based on this classification, light intermediate disturbance affected 12% of the territory which suggests that this proportion of the land base should be managed

[5] Paludification refers to the accumulation of organic matter over time.

with techniques that remove between 50 and 75% of the forest cover (partial harvesting). The remaining 10% of the forest is affected by severe intermediate disturbance and should be managed with low retention even-aged techniques (variable retention harvest). An important portion of the landbase (37%) consists of old-growth forests undergoing gap dynamics. A large area should therefore be managed using small openings (<1 ha) (selective harvest).

Spatial distribution and retention levels observed in naturally disturbed stands can guide managers on the choice of silvicultural practices

The area affected annually by intermediate and gap disturbances (41%) can help to determine the proportion of the management unit to be managed annually using partial or selection harvests that are designed to maintain the size and structural characteristics of the targeted disturbance (wind, insects). The area affected annually was only determined for windthrow because spruce budworm outbreaks occur periodically (every 30-40 years). Areas affected by severe and light windthrow occupied 0.16 and 1.29%, respectively. Gap disturbances, for their part, affected between 0.7 and 2.7% of the landscape annually. These results indicate that a large part of the area can be managed under uneven-aged systems every year to compensate for the reductions of even-aged management areas.

Table 4. Attributes of intermediate and gap disturbances in a hypothetical boreal forest ecosystem and suggested management practices.

Forest Attribute	**Intermediate disturbances** (spruce budworm, windthrow)		**Gap disturbances** (spruce budworm, windthrow, senescence)
	Severe (>75% open canopy)	*Light (50-74% open canopy)*	*Gaps (< 1 ha open)*
Proportion of landbase	10% (6-14%)	12% (5-15%)	37% (18-64%)
Area affected annually (%)	0.16%*	1.29%*	0.7 – 2.7%
Spatial distribution			
Size	0.5-60 ha	0.5-100 ha	28 m^2 (3-700 m^2)
Severity			
% stand affected	>75%	50-74%	55% (15-60%)
Mean dead tree density	100/ha	50/ha	
Specificity**	balsam fir (spruce budworm, windthrow), thin soil and steep slope (windthrow)		
Silvicultural techniques suggested	CLAAG+ variable retention	partial cutting	selection cutting partial cutting

* Data for intermediate disturbances only includes areas affected by windthrow because spruce budworm outbreaks occur periodically, affecting large areas during a short time period.

** Specificity refers to the selective nature of a disturbance agent toward one or several types of habitat (or towards a species).

5.3.1 Planning the size of harvest areas based on intermediate and gap disturbance events

The range of sizes of openings created by intermediate and small disturbances can provide guidance on partial harvest design

Considering the spatial configuration attributes of spruce budworm outbreak (SBW) and windthrow is more difficult than in the case of fires. These agents create a complex and widespread network of affected areas of differing intensity which occasionally can affect very large areas. However, like fire, gaps and patches created by those agents span a wide range of sizes. Results presented in Table 4 show that light and severe intermediate disturbances ranged between 0.5 and 100 ha in size following windthrow events and between 0.5 and 60 ha following SBW outbreaks. Gap disturbances, for their part, affected areas of 3 to 700 m^2. These ranges in disturbance size can help forest managers set benchmarks for partial harvest design (a range of harvest area sizes).

5.3.2 Determining retention characteristics within uneven-aged harvest areas

A large variety of severity levels (in terms of mortality) can be found among areas affected by "smaller scale" disturbance agents. For example, a severe insect outbreak can kill all host trees over hundreds of hectares but a lighter outbreak may cause partial mortality over smaller areas. The resulting forest matrix often consists of mortality zones and islands of intact forests (D'Aoust *et al.* 2004).

The range of severity (mortality) and selectivity observed for a given disturbance agent can guide the level of retention and the characteristics of residuals to retain

Factors responsible for the variability in severity effects can be numerous. In the case of SBW, the severity of the outbreak depends on forest composition and forest age since mature balsam fir stands are more vulnerable to this insect (MacLean 1980). In the case of windthrow, specific species (such as balsam fir) are more vulnerable to wind fall (Ruel 2000). Slope and soil thickness can also play a role in the vulnerability of stands to this agent. Specificity, which describes the selective aspect of an agent towards a specific type of habitat, is an important characteristic to consider. It can help forest managers reduce the vulnerability of stands by locating interventions in appropriate stands. For example, mature balsam fir stands could be preferentially harvested, leaving non-host species as residuals, with the intention of re-creating post-severe outbreak conditions. The retention levels can vary as a function of the severity that is to be re-created. Other attributes of residual forests (such as composition, configuration, and retention of dead trees) also need to be documented because they can play an important role in providing wildlife habitats.

5.3.3 Selection of appropriate silviculture activities

Developing silvicultural systems closer to natural conditions requires the use of a variety of techniques

Aside from even-aged management, there are several uneven-aged silvicultural practices that would be appropriate for use in Canada's boreal forest. However, these techniques have not been widely used for economic and productivity reasons. With the implementation of FEM, an increase in the use of a variety of harvesting techniques will help managers to develop silvicultural systems that are more similar to natural disturbances in terms of their impact on forest ecosystems.

In Table 4, harvest treatments are prescribed for each group of disturbances. In the case of severe intermediate disturbance, small areas of CLAAG could be used to re-create the largest openings that are created by severe SBW outbreak. It would likewise have a low impact on forest regeneration. However, in conventional CLAAG practices, very few large trees (living or dead) are left within cutblocks. It is recommended that variable retention harvest be combined with CLAAG to enhance biodiversity effects. VR levels could be developed based on forest composition and age of the original stand, with an emphasis on providing a variety of species for retention and a range of sizes where feasible (depending on the original stand attributes).

In the case of light intermediate disturbances, partial cut systems (e.g., irregular shelterwood, harvest with advanced regeneration protection [HARP]) using variable levels of retention similar to those induced by natural disturbances could be used to re-create conditions similar to the natural ones. Similarly, gap dynamics can be re-created with partial cut systems, selection cuts or multiple pass systems.

It is important to note that the choice of silvicultural techniques used to create a management system based on intermediate and gap disturbances will depend on management objectives determined from the natural disturbance regime. There is no single prescription for the development of such harvesting systems. Examples provided here are strategic and will need further development with regards to tactical and operational planning details. The key to creating appropriate silvicultural systems is the creativity of the foresters and not adherence to a predefined set of rigid rules.

The key to creating appropriate silvicultural systems is the creativity of the foresters and not adherence to a predefined set of rigid rules

5.4 Reconciling tactical and operational plans with social and economical considerations

Forest ecosystem management targets establish the options for resource development on which we rely to keep managed ecosystems within their limits of natural variability (i.e., to maintain ecosystem integrity). Once targets have been determined based on relevant ecological knowledge, they can be modified when integrating them into a forest working plan where all the stakeholders are involved in trade-off and decision-making processes. Economic (e.g., mining, hunting, forestry, tourism, etc.) and social issues (e.g., trapping and hunting territories, ancestral activity, etc.) can be addressed in a dialogue process where management options are discussed.

An FEM strategy must be founded on natural forest dynamics. While it is possible to review ecological targets such as amount of area under even-aged management at this scale, this implies accepting a risk concerning the long term sustainability of the forest ecosystem. There is much more flexibility in altering management options at the tactical and operational levels. In this respect, modelling tools can help to assess the divergence between the impact of management scenarios encompassing a range of ecological, social and economic values on forest attributes and the variability generated by natural disturbance regimes in order to identify the biodiversity values at risk (Doyon *et al.* 2008).

An FEM strategy must be founded on natural forest dynamics; modulating management options must therefore be done at the tactical and operational levels

Box 3. Developing a scenario planning process and implementing operational practices for a 20-yr Sustainable Forest Management Plan for LP Canada – Swan River

Context:

Louisiana Pacific (LP) Canada Ltd, Swan Valley Forest Resources Division is responsible under Forest Management License Agreement #3 for forest management and renewal activities on crown lands within the Duck Mountain Provincial Forest in west-central Manitoba. LP developed a strategic planning and communication process to develop their 20-yr Sustainable Forest Management Plan (2006-2026) that incorporated the natural disturbance model and associated principles. A sustainability analysis for a wide range of forest values was conducted using spatial planning models and landscape assessment tools.

Objectives and goals of the planning process:

The primary objective of the scenario planning exercise was to develop and test alternative management scenarios, strategies and implementation options to achieve a suite of SFM objectives. The main goal was to maintain a healthy, functioning forest ecosystem where the conservation of biological diversity was an important aspect of the SFM framework.

Specific objectives of the planning process were to:

- Develop a series of forest management scenarios for the Duck Mountain Provincial Forest including a natural disturbance management scenario; and
- Evaluate the effectiveness of the management scenarios to conserve biodiversity in the future forest in terms of the:
  - a) Maintenance of forest composition (species and age class),
  - b) Maintenance of landscape pattern (patch size and distribution), and
  - c) Maintenance of landscape structure (remnant habitats and residual forest).

Steps for the development of the plan:

The scenario planning exercise was based on an iterative process of analysis, consultation and evaluation of alternative management strategies and the ability of the various scenarios to meet goals and values associated with desired future forest conditions. Three rounds of analyses were conducted, each followed with public consultation meetings and committee reviews. A series of modeling and forecasting tools were used during each round to evaluate the potential of each scenario to meet biodiversity objectives using a suite of indicators (spatial and temporal).

Box 3. Continued

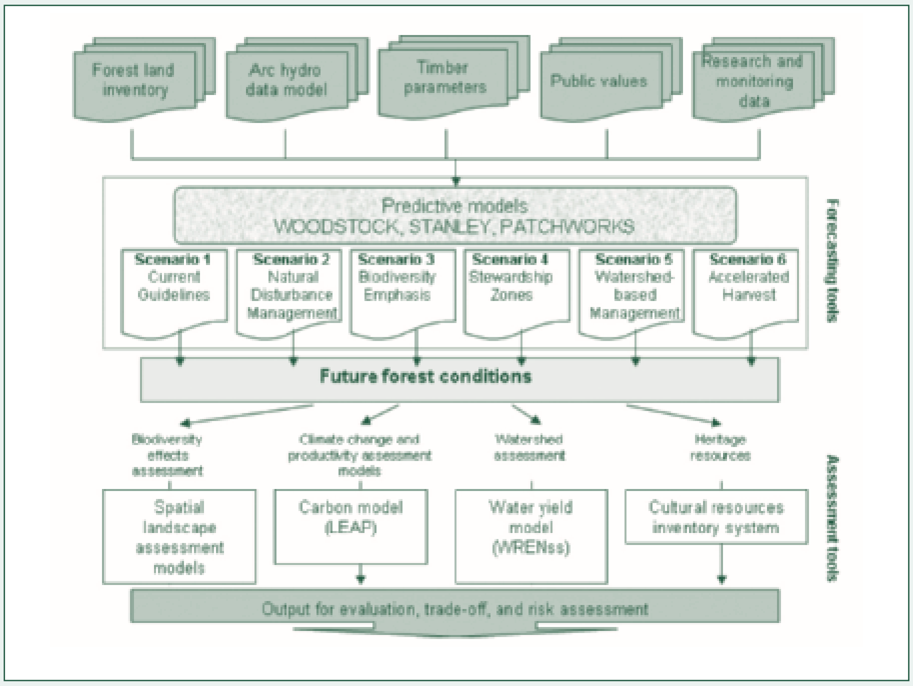

Figure 4. Overview of LP's scenario planning framework (from Donnelly *et al.* 2009).

Reliable information about natural dynamics for the Duck Mountain Forest was used during the scenario planning exercise to build robust models that forecast future forest landscapes and assisted the decision-making process. These included stand dynamic and successional models for Duck Mountain ecosystems (Hamel and Kenkel 2001; Kenkel *et al.* 2003) and spatially explicit, multiple scale songbird habitat models to evaluate scenario results in terms of biodiversity objectives (Rempel *et al.* 2006).

This iterative planning process enabled the refinement of management scenarios through a participatory process with local stakeholders, governments, scientists and experts, non-governmental organizations and the general public. Two scenarios were compared in the final round of analysis: the Manitoba Base Case Scenario – which represents current LP standard operating guidelines and provincial regulations; and the Preferred Scenario – which contains natural disturbance-based principles within a ecosystem based management framework. This scenario was the result of combining several of the scenarios initially developed into a more feasible scenario in terms of the current regulatory framework and the ability to achieve the biodiversity objectives. The Preferred Scenario also incorporated many of the public values and concerns expressed during consultations.

The Preferred Scenario provides the basis for the development of LP's 20-yr Sustainable Forest Management Plan for Forest Management License #3. Natural disturbance-based management features in the Plan included old forest area targets, variable retention, understory protection strategies and a larger harvest size distribution range.

Box 3. Continued

Future needs and assessments

An important aspect of LP's 20 yr FMP is the inclusion of adaptive management as part of their approach to SFM. The plan includes a program to monitor the effects and effectiveness of the forecasts, predictions and assumptions it was based on during and following implementation. Over the next five to 10 years LP will conduct research and monitoring to assess the suite of biodiversity indicators selected in the plan and report to government and the public on their progress towards SFM (see Tetres Consulting, 2003) and the implementation of an ecosystems approach.

5.5 Monitoring

Monitoring must be used to determine if FEM objectives set at the strategic, tactical and operational levels were met

To ensure objectives defined in the context of an FEM framework are reached, monitoring is essential. Monitoring will enable the evaluation of success or failure of FEM implementation. Measuring the success of FEM requires the development of monitoring programs to verify whether targets have been achieved. Monitoring programs should include a review of the ecological targets based on the natural disturbance regime. These programs must also assess the effectiveness of fixed management targets in maintaining living organisms and ecological processes within the managed ecosystem (Rempel *et al.* 2004).

The first step of a monitoring program is to establish indicators based on objectives shown in Sections 5.2 and 5.3. These indicators are then used to evaluate the achievement of FEM strategic, tactical and operational objectives determined prior to system implementation. For example, one indicator could be the amount of area managed using an even-aged management regime. This would determine whether targets related to the amount of area managed with even-aged and uneven-aged practices were attained. For each practice, it is important to verify if objectives concerning severity, spatial distribution, legacies, etc. are met.

Monitoring must also validate the effectiveness of the FEM strategy and operations at preserving ecosystem biodiversity

The second step of a monitoring program is to validate the effectiveness of the FEM strategy and operations at preserving ecosystem biodiversity. One way to accomplish this is to use targeted organisms and measure their response to management practices. Relevant indicator species (those that are sensitive to key forest attributes and processes and respond at different spatial scales) must be selected. Suggested species include woodland caribou, American marten, mature forest birds specialists, lichens and species dependant on dead trees (insects, fungi, mosses and liverworts, etc.) (Drapeau *et al.* 2009).

Within managed even-aged stands, the ability of the spatial configuration of old-growth habitats to maintain and accomplish ecological functions should be evaluated. The capacity to accomplish functions such as organism dispersion, population growth, and reproduction will ensure the maintenance of forest-dwelling species in the managed landscape.

Within managed uneven-aged stands, effectiveness monitoring should include an assessment of the capacity of the structural conditions created by partial cuts (forest cover, living and dead trees) to offer good quality habitat to indicator species. For example, partial cuts frequently disturb larger total areas and require a widespread road network compared to clearcut harvests. The effectiveness of partial cuts could be decreased as a result of a larger area being disturbed (although area is less intensively disturbed) as they could be harmful to species such as woodland caribou that have a large home range and are very sensitive to human presence.

Forest ecosystem management must be implemented within a framework that is adaptive and able to respond to uncertainties since it relies on complex and yet incomplete knowledge. More research is needed to improve our understanding and learn the best way of achieving the desired objectives. It must therefore rely on an adaptive management perspective (an iterative process where monitoring results are evaluated and changes recommended to strategies) (*Figure 5*) embedded within a flexible planning and policy environment. As new knowledge and understanding is developed, management strategies must be adapted to incorporate new findings from the scientific community. Variations that are observed within provinces and even within regions need to be addressed within such flexible frameworks. Forest management frameworks must also be flexible to be able to address environmental changes such as the anticipated impacts of climate change on forest ecosystems.

FEM must be accomplished in a flexible planning and policy framework to integrate new knowledge on forest dynamics and species response and also be able to adapt to uncertainties

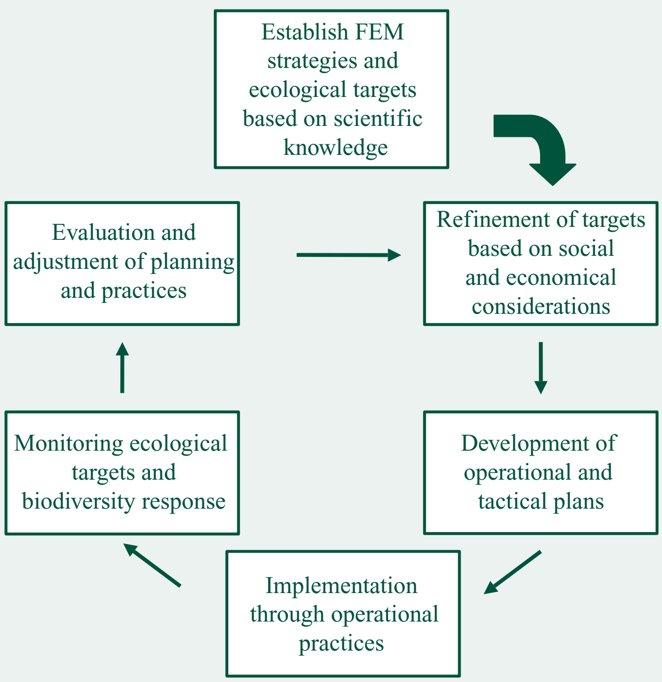

Figure 5. Schematic illustrating the ecological components of an adaptive management strategy in the context of FEM.

6.0 Conclusion

In this synthesis report, we have illustrated why and how FEM can be used to maintain biodiversity and ecological processes in managed forest ecosystems. By maintaining ecological resilience, FEM will permit managed forests to continue playing their historical ecological role and continue furnishing goods and services such as wood production and other things, even in a changing environment.

Boreal forest ecosystem dynamics are complex. Since forest management is done over large tracts of forest, management activities must ensure that complexity is maintained to conserve biodiversity, sustain forest productivity and economic activities over the long term. Implementing FEM is a scientific and practical challenge where both researchers and forest managers must participate and interact with all stakeholders to build management systems that are both ecologically and operationally relevant.

Implementing FEM systems based on natural disturbances requires a major change in the current forest planning process. To achieve forest conditions similar to those prevailing in naturally disturbed forests, managers need to work with forest scientists to obtain knowledge on the natural disturbance history and dynamics for their region. Moreover, managers will have to plan harvest operations over larger spatial and temporal scales. FEM also requires a shift in planning approaches to recognize that the design of leave areas and residual forest is as important as planning harvest volume at both the stand and landscape scales.

Scientific knowledge related to forest dynamics is increasing across the boreal forest. So far, there have been few large-scale and long-term experiments of FEM implementation integrating this knowledge. Going from concept to practice is a complex task that not only requires the relevant ecological information but also the will of forest stakeholders to address the challenge of experimenting with new planning and operational techniques.

Currently there is sufficient scientific knowledge and silvicultural techniques to initiate the implementation of FEM strategies in most parts of the boreal forest. Since large tracts of forests have already been harvested, it is urgent to implement FEM in order to maintain old-growth forest characteristics and reduce the risk to biodiversity and the sustainability of forest resources. Otherwise, it may result in a situation where restoration is the only option available to ensure more natural forest conditions. Although FEM frameworks can be used in a restoration strategy, it is operationally easier and much less costly to implement ecologically-based forest management while intact boreal forest tracts remain.

Future needs

Although we are ready for large-scale implementation of forest ecosystem management, there is a need to ensure that large areas of forest are conserved for reference purposes. To properly evaluate the effectiveness of an FEM approach, it is important to develop a network of protected areas where natural disturbances are left to run their course. These areas serve as ecological reference points for new forest management systems based on natural disturbance and for monitoring the resilience of forest ecosystems over time.

Research is required to address knowledge gaps, especially with respect to insect outbreaks and small-scale disturbances. There is also a need to ensure that disturbance dynamics are better understood at regional scales to provide forest managers with good baseline knowledge for adapting their FEM approaches to regional specificities.

In light of the implementation of new silvicultural practices (for example, variable retention or partial cutting) that involves a better understanding of natural forest dynamics, there is a need to build and refine models that predict the development of forest stands beyond commercial harvesting age and forecast future stand attributes in terms other than those relating solely to timber values. Studying the development of stands undergoing silvicultural treatments to generate or maintain an uneven-aged structure is of equal importance.

One of the shortfalls of FEM implementation is the continued absence of an integrated approach to land-use planning for all resource based activities (energy or mining for example, not just forestry) over large areas. So far, resource managers have failed to integrate multiple resource uses which leads to an inability to determine cumulative effects, operational inefficiencies and lost opportunities. However, a greater participation of multiple government agencies is necessary to integrate multiple resources into land-use planning and create synergetic decisions among users.

Finally, integrating environmental risk into forest management planning is another major change proposed by FEM. Currently, the planning of forest operations, as well as the calculation of sustainable harvest levels, is done without consideration for various environmental risks, including fire, insect outbreaks, and the interaction of these disturbance types with climate change. This could be done using cumulative effects assessment modelling (Yamasaki *et al.* 2008). Cumulative effects assessment methods would also facilitate the inclusion of the impact of other activities within forest areas (such as mining, and oil and gas activities, when present) to the planning process. In doing so, we will be more likely to ensure the efforts to maintain ecological integrity and biodiversity conservation through forest management activities are successful.

Acknowledgements

This synthesis emanates from the work of several researchers and students who were involved in studies conducted as part a Sustainable Forest Management Network project on the use of natural disturbances and natural processes as a template for the sustainable management of boreal forests. We are grateful to the several authors that participated in the writing of the book that was the main output of this project and inspired the writing of this synthesis. Special thanks goes to Sonia Légaré and Margaret Donnelly for their contribution in the writing of the text boxes presenting specific ongoing projects led by Tembec and Louisiana-Pacific, respectively. We must also acknowledge the Centre d'étude de la forêt, the Canadian Forest Service, the Ministère des Ressources naturelles et de la Faune du Québec and several industrial partners that participated in the several studies involved in the research projects. Finally, we also thank several anonymous reviewers for thoughtful comments that helped to improve this synthesis.

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