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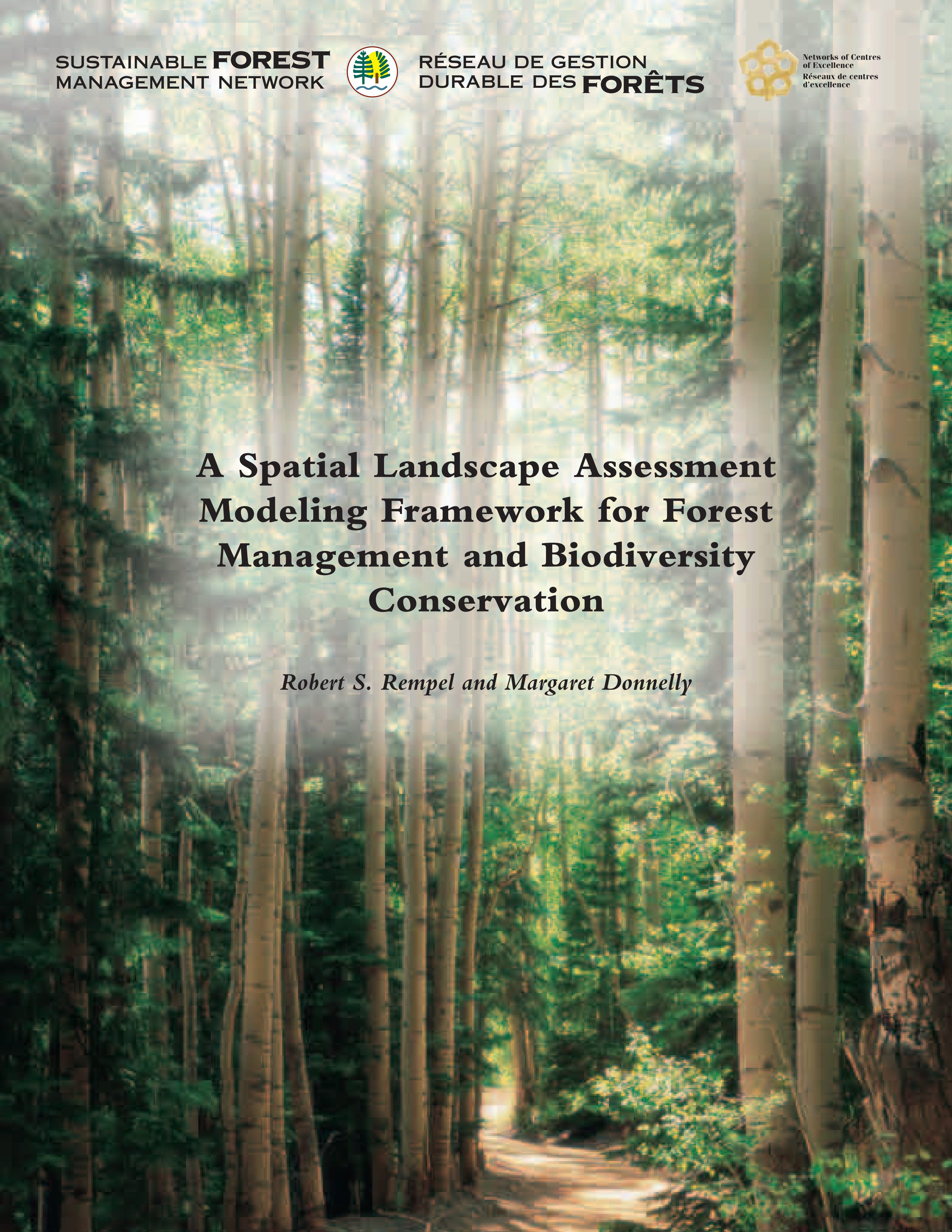

# A Spatial Landscape Assessment Modeling Framework for Forest Management and Biodiversity Conservation

*Robert S. Rempel and Margaret Donnelly*

## 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

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- Forest Engineering Research Institute of Canada
- Lake Abitibi Model Forest
- Manitoba Model Forest
- National Aboriginal Forestry Association

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

# A Spatial Landscape Assessment Modeling Framework for Forest Management and Biodiversity Conservation


By

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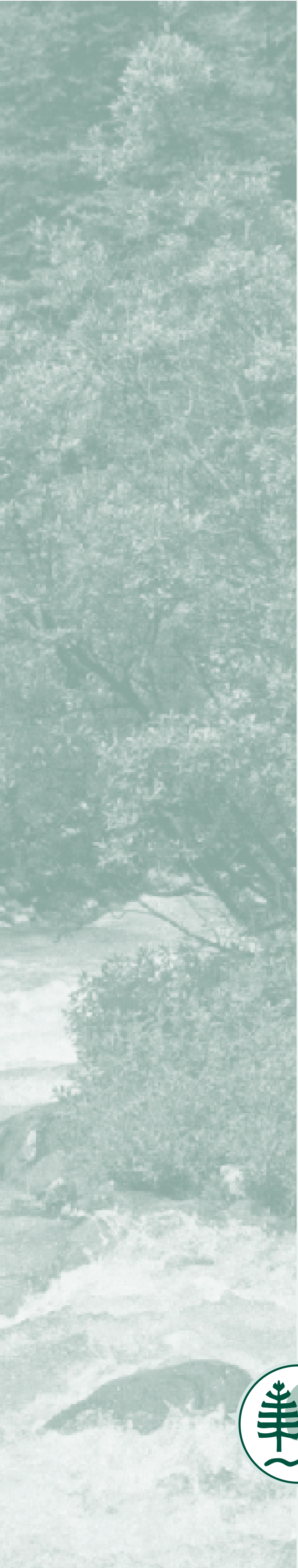



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Sustainable Forest Management Network

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# Executive Summary

Science-based management is becoming increasingly important as an approach to conducting sustainable forest management in the face of uncertain knowledge. However, science-based resource management means more than basing management actions on selected peer-reviewed research results. It means incorporating the scientific method throughout the management cycle, including the development, application, and assessment of policies and management options. When this scientific approach to resource management is coupled with a feedback loop to decision makers, managers have enhanced ability to adapt to new reliable knowledge and refined objectives (adaptive management).

This synthesis document provides an overview of the development and application of a spatial landscape assessment modeling (SLAM) framework for biodiversity assessment, predictive modeling and effectiveness monitoring, within an adaptive management context. We illustrate 7 key steps in the development of a spatial landscape assessment modeling framework:

(i) translate forest disturbance regime into habitat space,

(ii) select focal species,

(iii) forecast future landscape and habitat element conditions,

(iv) simulate or analyze natural disturbance processes,

(v) apply the habitat models to rank management and policy options,

(vi) treat "policy as hypothesis" while monitoring effectiveness, and

(vii) modify management and policy options based on results.

We present several case studies demonstrating SLAM applications in the development of a forest management plan and forest policy. We found that to be successful, forest management strategies and practices must not focus on the needs of a small set of featured species, but rather be designed to maintain a range of forest cover, structure and patterns on the landscape to meet the needs of all species. Biodiversity conservation strategies that create landscape patterns closely resembling those created by natural disturbances are most successful at providing a range of habitat conditions and maintaining forest variability.

From the perspective of adaptive management, a clearly defined, and agreed upon link between effectiveness monitoring results and policy decisions should be made at the beginning of the planning process. This will help ensure that relevant data is considered for policy revisions and plan updates. In forest management planning, strategic direction and assumptions within the plan must be re-visited following plan implementation and effectiveness monitoring to ensure objectives are being met. Standard operating or best management practices should be revised as needed following monitoring to ensure strategies are effectively delivered on the ground.

# 1.0 Introduction

Ecosystem-based management and the conservation of biodiversity are key elements of sustainable forest management (SFM) and primary objectives of government policies and guidelines related to forest planning and operational practices. Sustainable forest management approaches require consideration of a suite of forest-based values and services from an ecological, social and economic perspective. Success in maintaining these values in current and future forests must be measured and reported on a periodic basis. In addition to the challenge of developing forest planning and operational approaches to ensure biodiversity conservation, forest managers are challenged by the complexity of measuring and quantifying biodiversity.

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Enhanced forest vegetation inventories and remotely sensed data, including ecological classifications for terrestrial and aquatic landscape components, are now widely available. These data provide a greater level of detail and permit analysis of habitat attributes in addition to the timber related attributes that have historically been available. This has led to the development of new tools and analytical techniques for forest planning and prediction of future forest condition.

In spite of these recent advances, knowledge gaps remain in our understanding of forest systems, especially regarding ecosystem-level processes and function, and relationships among forest ecosystem attributes in time and space. Increasingly, a science-based approach is needed to fill these gaps and provide insight into these and other non-timber aspects of forest systems.

Canada has the largest area of third-party independently certified forests in the world and contains 40% of the world's certified forest area demonstrating a firm commitment to sustainable forest management in Canada (Forest Products Association of Canada 2010). Continuous improvement is the underlying foundation of most forest certification systems including a cycle of Plan, Do, Check and Act (Canadian Standards Association 2003) Within this cycle, the step related to 'Check' involves monitoring, while the 'Act' refers to revising or adjusting practices based on feedback from the 'Check' stage. Similarly, an adaptive management approach (Figure 1) is based upon a series of steps related to developing hypotheses, the testing of the hypotheses (including predictions of outcomes or forecasts of responses), and monitoring following implementation to validate hypotheses or develop alternate models. Monitoring within both of these approaches should include two key types of monitoring:

***An adaptive management approach is based upon a series of steps related to developing and testing hypotheses, and monitoring outcomes to validate hypotheses or develop alternate models.***

1) ***Compliance monitoring*** – did we do what we said we would do? That is, have provincial guidelines and requirements been met, and has the plan been implemented on the ground according to harvest and renewal prescriptions?

2) ***Effects and effectiveness monitoring*** – what are the effects of our strategies and actions, intended and perhaps unintended, and how effective have our strategies been at achieving the objectives they were designed to address?

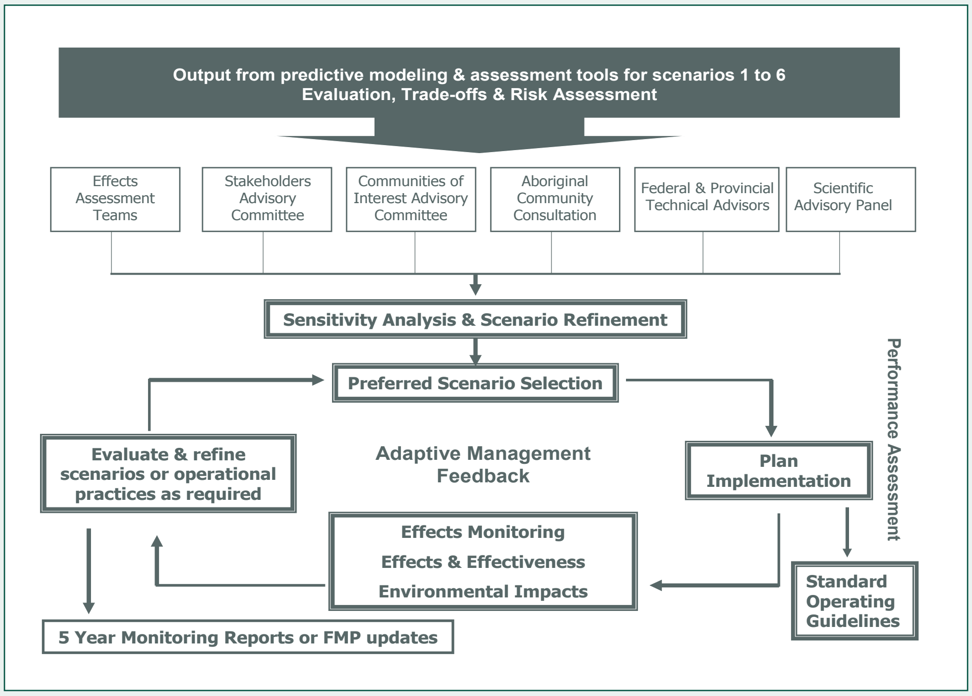


**Figure 1.** Adaptive management cycle from LP Canada Swan River Division 20 Year Sustainable Forest Management Plan, 2006-2026. An effects and effectiveness monitoring program was developed as part of the SFM framework to ensure the preferred management scenario and standard operating guidelines achieved the objectives they were designed to address.

Increasingly we turn to a science-based approach to find the answers, or use the phrase “adaptive management” to deliver these ideas or gain approval of government and/or the public. But what exactly is meant by a science-based or adaptive management approach? We will demonstrate these concepts for forest planning and policy development through the application of a scientific adaptive management framework for the conservation of biodiversity.

This synthesis document will provide an overview of the development and application of a spatial landscape assessment modeling framework (SLAM) for biodiversity assessment, predictive modeling, and effectiveness monitoring, within an adaptive management context. Potential management and policy applications will also be presented through the use of several case studies demonstrating SLAM applications in the development of a forest management plan and forest policy. It will serve as a valuable reference document for forest managers who are developing biodiversity conservation planning and operational practices and considering effectiveness monitoring programs.

## 2.0 Science-Based Management

Science-based resource management has come to mean the application of knowledge gained through scientific studies, but scientific management is as much about assessing the validity of what we think we know, as it is about applying what we think we know. All knowledge, even knowledge gained through scientific research, has inherent uncertainty. Whether it be 95% confidence limits associated with a mean, Type I error associated with hypothesis testing, or probability of habitat occupancy estimated from habitat models, the strength of the scientific method is the ability to estimate the level of uncertainty associated with knowledge. Our understanding of cause and effect relationships is greatly aided through controlled experimentation, but much of our knowledge of natural systems comes from correlation type studies that cannot be controlled. Knowledge generated from such studies must be treated with some level of scepticism. Resource management policies and protocols are designed to achieve a specific objective, but because the knowledge used in the development of policies has inherent uncertainty, those policies are essentially hypotheses.

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***All knowledge, even knowledge gained through scientific research, has inherent uncertainty.***

Some elements of knowledge are critical in that mistakes in understanding can be very costly to species viability, ecological integrity, the environment and/or the industry. Other elements of knowledge involve issues of strong public and political concern where uncertainty may lead to unacceptable risks (Stankey *et al.* 1993). Where managers have identified such critical uncertainties, the effectiveness of the policy to meet their stated objective should be evaluated using a structured and scientific sampling design to monitor management outcomes.

It is worth remembering that science is an approach to learning and the quest for reliable knowledge based on careful observation conducted in a manner to illuminate cause and effect. Rodger Bacon, in the 1300's, championed the move towards structured observation under controlled conditions versus the traditional approach of learning via unstructured and anecdotal natural history observations. Bacon realized that data collected in a manner that isolates potential causal factors from other extraneous sources of variation would lead to much faster and stronger conclusions of cause and effect. Today, scientific experimentation permeates our society, ranging from auto-mechanics using mini-experiments to isolate the cause of a mechanical failure, to ecologists trying to understand and predict the role of phosphates in causing algal blooms in a lake. In every case, the application of science begins with a hypothesis to explain an observation, which advances to a sample design to isolate the issue of interest, careful collection of data, and an assessment of how well the initial hypothesis (or hypotheses) stands up to the newly collected data.

***Science is an approach to learning and the quest for reliable knowledge based on careful observation, conducted in a manner to illuminate cause and effect.***

So can science-based management be simply defined as a careful review of the latest research papers and reports, and incorporation of those findings into management procedures? Absolutely not! Is resource management "scientific" if managers simply fund a set of research activities, with the possibility of incorporating the results into management procedures? Absolutely not! These

*Scientific management is defined by the notion of treating policy as a testable hypothesis.*

activities certainly contribute to the set of activities used in science-based management, but on their own they fall short. Just as "scientific research" utilizes the scientific method to investigate uncertainties, we can say that **scientific resource management occurs when the management system incorporates a structured and careful approach to monitoring management outcomes with the goal of understanding the effectiveness of management actions to achieve desired goals and objectives** (Romesburg 1981, Sinclair 1991, Stankey *et al.* 2006). In other words, scientific management is defined by the notion of treating policy as a testable hypothesis.

# 3.0 Adaptive Management and a Decision Analysis and Management Framework

Adaptive management is a social and institutional engineering concept that conceptualizes how to integrate scientific research and monitoring with resource management (Lee 1993). The term "adaptive management" is familiar to many academics, and more recently some resource managers, but is often confused with "reactive management". In reactive management there are few or ineffective attempts to isolate causal effects from background extraneous effects when examining policy effectiveness. The idea of adaptive management is necessary because in most institutions:

1) The structure to rigorously evaluate policy and management options does not exist, and/or,

2) Science and management often exist as separate silos with no formalized mechanism for communication between those doing research and monitoring and those making policy and management decisions.

*Adaptive management is scientific management, but with the ultimate goal of knocking down the barriers and silos of management versus science.*

As a consequence, the path to learning is tortuous and ineffective, and the ability to adapt policies and guidelines to new knowledge is slow. Adaptive management guides institutional change with the ultimate goal of knocking down the institutional barriers and silos of management versus science. When these barriers have been removed, the philosophy of the scientific method of learning permeates the institution, and every manager and policy analyst thinks as a scientist, and every biologist and forester thinks like a manager or policy maker. The two groups are inextricably connected. When a planning system integrates the philosophy of the scientific method with principles of adaptive management, we use the term "scientific adaptive management".

Nudds *et al.* (2003) described a Decision Analysis and Adaptive Management (DAAM) process for policy development that is outlined in the following 11 steps. This approach was used recently by the Ontario Ministry of Natural Resources (OMNR) in the development process for the Forest Management Guide for Great Lakes-St. Lawrence Landscapes (Ontario Ministry of Natural Resources 2010), with some minor modifications:

1) *Involve as many parties as possible.*

2) *Specify management objectives and options.*

3) *Identify the main uncertainties as hypotheses and examine evidence for alternative hypotheses.*

4) *Evaluate and rank competing hypotheses by likelihood in light of uncertainty.*

5) *Develop models to forecast outcomes, given different hypotheses.*

6) *Evaluate alternative management options.*

7) *Select management options.*

8) *Identify the highest uncertainties.*

9) *Design and implement a hypothesis-based monitoring program to evaluate effectiveness of policy options according to sound principles of experimental design and with focus on values associated with the highest uncertainty.*

10) *Monitor key responses.*

11) *Update ranking of alternative hypotheses by likelihood to achieve desired outcomes given monitoring results.*

Consider the adaptive planning loop illustrated in Figure 1. A scientific approach to the management of biodiversity might begin by assembling stakeholders, First Nations representatives, government representatives, researchers, managers, policy makers, etc. to outline the issues or values involving landscape pattern and wildlife habitat, and eventually settle upon strategic direction and management objectives. Planning teams might then conduct a review of current and past research to identify main uncertainties concerning the effects of landscape pattern on wildlife, and to document competing hypotheses and knowledge gaps. For example, one hypothesis may state that smaller dispersed clear-cuts, together with riparian buffer strips will better maintain natural patterns of the forest bird community, while an alternative hypothesis may state that larger clear-cuts that emulate patterns created by wildfire will better maintain natural communities of forest birds.

***A scientific approach to the management of biodiversity begins by identifying the issues involving landscape pattern and habitat to determine strategic direction and management objectives.***

***"Virtual experiments", using spatial habitat models, are used to assess the performance of alternate spatial arrangements of the forest in terms of meeting the strategic goals.***

Past research, or perhaps results from newly funded research projects would then be used to evaluate the relative likelihood of competing hypotheses. Given the remaining critical uncertainties, alternative management options may be proposed to achieve both the economic and ecological objectives of the plan. This might include a set of harvest schedule options to create landscape patterns that resemble the expected range of natural variation. "Virtual experiments", using spatial habitat models, would then be used to assess the performance of alternate spatial arrangements of the forest in terms of meeting the strategic goals. This information, together with concerns expressed by stakeholders, industry, governments, etc. would then be used to select the final policy or management options.

Following implementation of the plan, an effectiveness monitoring program would be initiated to evaluate the effectiveness of the new guidelines, with data collected both in areas where competing guidelines have been applied and in areas that represent appropriate reference conditions. This approach would assess whether the guidelines are indeed contributing (in a causal manner), to the management objectives, and if the biodiversity response is the same or different from the reference condition. Appropriate reference conditions will depend on the hypothesis. If guidelines are developed under the "natural disturbance hypothesis", then areas that are developed under a natural disturbance regime represent the reference condition. If the hypothesis is that revised Guideline B is better than the old or alternative Guideline A, then data would be collected where both guidelines have been implemented.

***The decision analysis and adaptive management process outlined seeks to achieve a seamless integration of policy, research, monitoring, and management and provides a powerful tool for learning.***

The decision analysis and adaptive management process outlined here seeks to achieve a seamless integration of policy, research, monitoring, and management and provides a powerful tool for learning. One of the strongest legacies of the SFM Network may be the encouragement of scientific adaptive management and policy development in Canada based on an integrated, multidisciplinary approach to developing new knowledge. From this perspective, projects funded under the SFMN represent just the beginning of a new path towards a better understanding of how to achieve and evaluate the success of sustainable forest management.

# 4.0 Scientific Forest Management and Biodiversity Conservation Planning

In forest management and conservation planning, we often make decisions where results may only be manifested decades down the road. For example, it may take decades to directly test whether prescriptions for the conservation of biodiversity associated with older forests were successful. We need a scientific approach to develop conservation and management policies that reduces the uncertainty about their effects and effectiveness. It is in this context that scientific modeling plays an important role, essentially providing a policy filter to reject policy and management options that clearly demonstrate high risk and potentially poor performance in achieving policy and management objectives.

Coupled with this approach is the need to develop and implement field-level monitoring programs to test the effectiveness of selected options in meeting their objectives, and to monitor for unexpected and deleterious effects. Effectiveness monitoring programs essentially provide the social license to move forward in the face of uncertainty. Society is much more willing to accept a policy option based on scientific modeling if a safety feature of effects and effectiveness monitoring is also attached to its implementation.

***Effectiveness monitoring programs essentially provide the social license to move forward in the face of uncertainty.***

The effect of spatial forest pattern on wildlife habitat, and in particular, the amount, composition, and configuration of young and old forest, is of concern to forest managers because of its potential effect on biodiversity. In the boreal forest, conserving biodiversity requires the maintenance of habitat for species that utilize a range of habitat types. Each species has specific habitat requirements that include preferences for mature vs. young forest, hardwood vs. softwood forest, and various levels of mixing and interspersion of these forest types. Creating the right balance is difficult, and is one of the primary reasons that the natural disturbance (ND) paradigm has grown in popularity. A principal tenet of the ND paradigm is that biodiversity can be conserved by harvesting in a manner that creates forest patterns that resemble those created by natural disturbance processes and maintains variability in forest structure (Hunter 1993, Bunnell 1995).

Previous research has shown that some songbird species are resilient to changes in age-class landcover-type pattern, but only to a degree (Wedeles and Donnelly 2004, Parker *et al.* 2005, Schieck and Song 2006). The question of songbird resilience to forest management practices that decrease the amount of mature forest cover and change its configuration should be viewed from the perspective of the overall community response rather than the response of a few individual species. The pressing issue is how to create and assess the complex mixture of forest conditions that is most likely to maintain the collective forest songbird community. A principal argument against the natural disturbance approach is that we can never completely emulate natural disturbance and therefore the approach is not worthwhile. However, from many perspectives the ND approach is a workable hypothesis for biodiversity conservation; therefore we should assign target levels and define the acceptable range of variability for key forest conditions using ND management principles as guidance.

***Songbird resilience to changes in forest cover should be based on the overall community response rather than that of a few individual species.***

# 5.0 Conservation of Ecological Integrity as a Biodiversity Planning Strategy

In general, the goal of forest ecosystem management is to ensure the conservation of ecological services from the forest. Ecosystem services include **provisioning services** that provide essential raw materials such as food, water, timber; **regulating services** such as those that maintain water quality and prevent pest explosions and floods; **cultural services** such as those that provide recreational, aesthetic, and spiritual benefits; and, **supporting services** that are essential for the ecosystem to function such as soil formation, photosynthesis, and nutrient cycling (Ontario Biodiversity Council 2010).

***The conservation of ecological integrity is key to maintaining ecosystem services.***

Conservation of ecological integrity is essential for maintaining these ecosystem services (Gauthier *et al.* 2009). Ecological integrity refers to the wholeness of the system in the context of natural or pristine systems. Two useful definitions of ecological integrity are:

> *"A condition in which biotic and abiotic components of ecosystems, and the composition and abundance of native species and biological communities, are characteristic of their natural regions, and rates of change and ecosystem processes are unimpeded" (Provincial Parks and Conservation Reserves Act 2006).*

> *"The capacity to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region" (Noon* et al. *1999; Karr 1996).*

There is a strong link between ecological integrity, emulation of natural disturbance, and conservation of wildlife communities. If we are reasonably successful implementing forest ecosystem management, and preserving ecological integrity in the process, then we would expect to maintain quality habitat conditions and sustain wildlife communities having a "species composition, diversity, and functional organization comparable to that of natural habitats of the region". Planning for sustained ecosystem services, ecological integrity, and conservation of biodiversity are all linked to the concept of sustaining natural communities of wildlife. From a wildlife perspective, forest ecosystem management requires a shift from featured species management to wildlife community conservation.

***Essentially we use the range of wildlife habitat requirements for all species that occur within the management area to define the range of variability required to conserve biodiversity.***

Planning to sustain habitat quality for a suite of species within a target community is a tangible and achievable objective, and provides a meaningful tool for forest ecosystem planning. The approach is based on understanding the relationship between ecosystem processes (such as natural disturbance), and the habitat needs of the community. But rather than deciding *a priori* what constitutes a sufficient range in forest condition and habitat variability, we let the animals that inhabit the area define this for us. Essentially, we use the range of wildlife habitat requirements for all species that occur within the management area to define the range of variability required to conserve biodiversity. In the process, we create a "bioassay" to guide the development and evaluation of conservation and forest management planning options. The goal is to maintain a sufficient range of forest conditions to meet our biodiversity objectives while continuing to manage the forest to meet our economic and cultural objectives.

## 6.0 The Forest Bird Community as an Indicator Framework for Evaluating Conservation Planning Effectiveness

The forest bird community is well suited to function as an indicator of the effectiveness of biodiversity conservation planning options. Habitat requirements of species within the community vary widely, and reflect the variation that arises from natural disturbance processes. Some species select hardwood forest while others select conifer; some select young forest while others prefer older; and some require an intact, homogenous matrix of forest, while others do best in a more fragmented forest. There is also a broad functional diversity, with some songbirds feeding on flying insects, while others glean insects from decaying trees; some feed on invertebrates dependent on soil nutrient and mineral conditions, while others feed on amphibians produced in forest wetlands; and some species create cavities in decaying trees for nesting, with a host of other bird species dependent on these cavities. Most of these birds are not hunted, so we don't confound hunting effects with habitat effects. When male birds sing or make other vocalizations to defend their breeding territory, they reveal what forest conditions they perceive as suitable breeding habitat. In this manner there is a direct link between observed resource selection and fitness of the population.

***The forest bird community is well suited as a biodiversity conservation indicator since habitat requirements vary widely, and reflect the variation that arises from natural disturbance processes.***

If we are effectively emulating natural disturbance, then we should provide habitat for the entire forest bird community, not just a select few species that say, require older conifer forest (Rempel *et al.* 2007). If we are able to maintain a balanced community of forest birds that is representative of the original (natural) species assemblage, then we increase our confidence that we are effectively contributing to the maintenance of ecological integrity and the conservation of biodiversity.

For many reasons it is not possible to use the entire forest bird community to evaluate planning options. A more focused approach, where species are selected based on the range of forest conditions they represent makes a logical and more manageable method of developing an indicator system. The selection of these "focal" species (Hannon and McCallum 2004), development of associated habitat models, and application of these models to evaluate future forest conditions provides an indicator framework for evaluating planning options (Rempel *et al.* 2004, Rempel 2007).

***A more focused approach, where species are selected based on the range of forest conditions they represent makes a logical, more manageable method of developing an indicator system.***

# 7.0 A Spatial Landscape Assessment Modeling Framework for Management Options

Scientific adaptive management provides a logical, defensible, and efficient approach to developing and evaluating resource management policy and management options (Rempel *et al.* 2004). In this section we illustrate the application of scientific adaptive management through the development, application, and evaluation of spatial landscape assessment models. These assessment models were developed through the SFMN funded project "Multiscale Landscape Indicators of Forest Bird Diversity and Community Structure" and through the Ontario Ministry of Natural Resources funded project "Multiple Scale Resource Selection Functions for Scenario Analysis". The models were used as part of a scientific adaptive approach to forest management planning at LP Canada Ltd, Swan Valley Forest Resources Division (LP) and the Ontario Ministry of Natural Resources, Forest Policy Division (LP Canada 2006, Donnelly *et al.* 2009).

***Scientific resource management provides a logical, defensible, and efficient approach to developing and evaluating natural resource policy and management options.***

*A spatial landscape assessment modeling framework enables forest managers to determine more precisely the range of forest characteristics required to meet biodiversity conservation objectives.*

A spatial landscape assessment modeling framework enables forest managers to determine more precisely the range of forest characteristics required to meet biodiversity conservation objectives (at several scales and over a long time period) for use in forest management planning activities (Figure 2). Biodiversity objectives can be developed and potential effects of forest harvest and spatial pattern assessed while evaluating management scenarios with spatial models. Management objectives and operational practices designed to sustain the boreal forest songbird community should also provide adequate habitat conditions for all the other plants and animal species associated with this community.

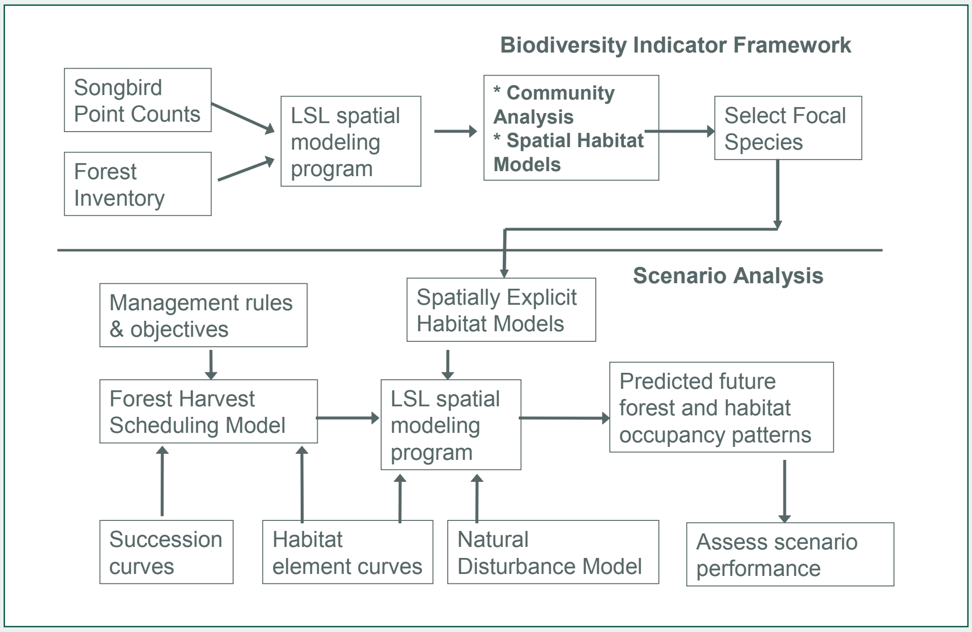


**Figure 2.** Flow chart of information and models used to predict future forest conditions and habitat occupancy for the spatial assessment of landscape management options. LSL is a spatial modeling language used to capture spatial relationships, and to apply the spatial habitat models.

## *Key steps in the development of a spatial landscape assessment modeling framework:*

1) ***Translate forest disturbance regime into habitat space.*** Identify the principal elements of pattern, composition, and structure that forest management affects, and then translate the range and dimensions of forest conditions that arise from a natural disturbance regime into a complementary model of natural habitat conditions.

2) ***Select focal species.*** Select focal species by (i) assessing the range of forest conditions that songbird species within the community are associated, (ii) developing and testing spatially explicit, multiple scale habitat models to predict habitat occupancy and (iii) making a final selection of focal species based on habitat associations and model performance.

3) ***Forecast future landscape and habitat element conditions.*** Forecast future landscape and habitat element conditions by incorporating sets of planning and/or policy options into a spatial harvest scheduler as harvest constraints. The scheduler should also model forest succession and development of habitat elements over time, and produce digital spatial maps as output.

4) ***Simulate or analyze natural disturbance processes.*** Investigate and/or simulate natural disturbance processes to forecast the range of variability in future forest conditions in the absence of management activities. The simulator should model forest succession and development of habitat elements, and produce digital spatial maps as output.

5) ***Apply the habitat models to rank management and policy options.*** Apply the multiple scale habitat models to evaluate and rank the planned management and/or policy option-sets relative to their predicted ability to meet biodiversity conservation objectives (e.g., provide continuous habitat for the full suite of focal species). Evaluate whether the range of variability in forest conditions is shrinking to the point that habitat for some of the focal species is permanently declining.

6) ***Treat "policy as hypothesis" while monitoring effectiveness.*** Treat "policy as hypothesis", and implement an effects and effectiveness monitoring program to test and evaluate the effectiveness of management and policy options for achieving biodiversity conservation objectives. Select an appropriate reference condition. If emulating natural disturbance is central to the choice of conservation options, then also monitor wildlife in forest (of the appropriate age-class) that has arisen from natural disturbance as the reference condition. Identify critical uncertainties, and focus monitoring on these. Monitor for unintended responses (effects) in key areas of social or ecological concern.

7) ***Modify management and policy options based on results.*** Modify, add, or re-affirm management and policy options based on the results of the effects and effectiveness monitoring program. Continue the improvement of habitat and other models used in policy evaluation and forest management planning. Consider expanding the suite of species that are modeled and monitored in the "bio-assay".

These 7 key steps outline a scientific adaptive approach to forest management and policy development. The intent is to illustrate how a science can be used to support development and testing of reliable management and policy options.

## *Step 1. Translate forest disturbance regime into habitat space.*

Natural disturbance in the boreal forest is dominated by wildfire, but also includes insect outbreaks, and blow down. In the case of wildfire, natural disturbance regimes can be characterized by three principal factors: the extent or area that is disturbed (e.g., small versus big disturbances), the intensity of the disturbance (e.g., hot versus cool fires), and the frequency of disturbance (e.g., absent, seldom, infrequent or often). In a similar manner, forest harvest activities also create landscape disturbances with large progressive clear-cuts versus small and dispersed block cuts, `cut-clear' harvesting versus variable retention harvests, and frequent versus infrequent harvest intervals.

***Natural and managed disturbance regimes affect the landscape by changing the degree to which the forest matrix is left intact, the relative composition of hardwood versus softwood, and the general age-structure of the forest.***

Both the natural and managed disturbance regimes affect the landscape by changing the degree to which the forest matrix is left intact (age-class fragmentation), the relative composition of hardwood versus softwood, and the general age-structure of the forest (Figure 3). Through evolutionary adaptation, this range in variability of forest condition is partitioned among the songbird community so that different species are adapted to different sets of conditions. The set of conditions to which a species is adapted to is called "habitat", and the term is species-specific. Without this evolutionary adaptation there would be constant and aggressive competition among species, and ultimately fewer species could occupy the same landscape. A principal objective of conservation planning is to ensure that the variability in forest conditions remains intact so that habitat does not decline for any species.

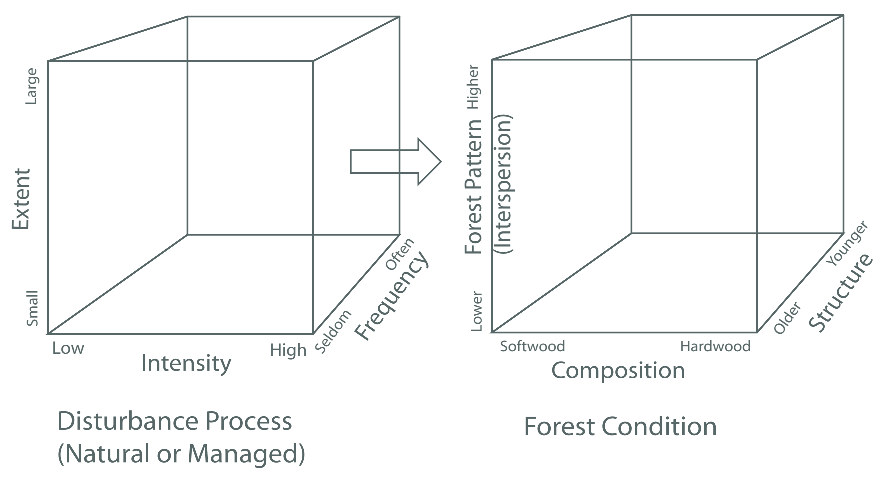


**Figure 3.** Relationship between extent, intensity, and frequency of forest disturbance (natural disturbance variability box) with pattern(forest matrix), composition, and structure of the resulting forest (habitat niche space box).

Attempting to plan and implement forest activities that emulate natural disturbance patterns is a good start to achieving this objective however studies have shown that it is not possible to fully emulate the statistical range of natural disturbance through harvest activities, nor would we want to (Armstrong *et al.* 2003). How then do we ensure that the limits we impose on emulating natural disturbance are not too restrictive? One solution is to let the animals themselves determine if we have maintained a sufficient range of variability.

Consider the conceptual forest habitat model illustrated in Figure 3 and the focal species-habitat model in Figure 4. The habitat niche space model depicts a `habitat box' representing the range of forest types and ages resulting from disturbance. If we can identify species associated with the "corners of the habitat box", and then model their habitat requirements, we can at least begin to understand the minimum range of variability that is required. In addition, we have a mechanism to begin testing the "natural disturbance hypothesis" of conservation planning.

***The habitat niche space model depicts a `habitat box' representing the range of forest types and ages resulting from disturbance.***

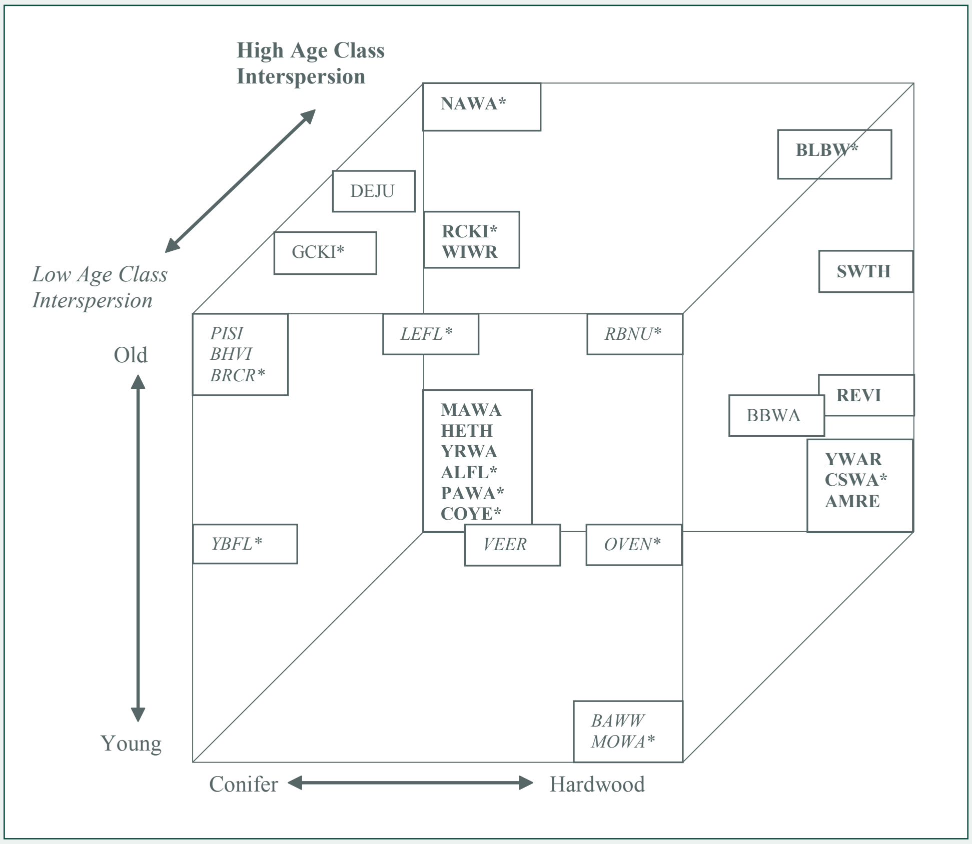


**Figure 4.** Habitat niche space model (habitat box) with focal species selected to represent specific habitat conditions within the forest matrix. The asterisk * represents species selected as evaluative indicators for the OMNR landscape guide development project. Species codes are explained in Table 1.

**Table 1.** List of the 13 focal species selected for the OMNR Landscape Guide project by common name, American Ornithological Union (AOU) Code name and latin name.

| Common name | Code | Latin name |
|---|---|---|
| Alder Flycatcher† | ALFL | *Empidonax alnorum* |
| Black-and-white Warbler | BAWW | *Mniotilta varia* |
| Bay-breasted Warbler | BBWA | *Dendroica castanea* |
| Blackburnian Warbler | BLBW | *Dendroica fusca* |
| Brown Creeper | BRCR | *Certhia americana* |
| Common Yellowthroat | COYE | *Geothlypis trichas* |
| Chestnut-sided Warbler | CSWA | *Dendroica pensylvanica* |
| Least Flycatcher | LEFL | *Empidonax minimus* |
| Ovenbird | OVEN | *Seiurus aurocapilla* |
| Red-breasted Nuthatch | RBNU | *Sitta canadensis* |
| Red-eyed Vireo | REVI | *Vireo olivaceus* |
| Winter Wren | WIWR | *Troglodytes troglodytes* |
| White-throated Sparrow | WTSP | *Zonotrichia albicollis* |

***The underlying hypothesis is that if the measurable parameters of pattern, composition, and structure are similar between forests arising from natural disturbance versus managed forests then the associated ecological processes are similar between managed and naturally disturbed forests.***

The underlying hypothesis is that if the measurable parameters of pattern, composition, and structure are similar between forests arising from natural disturbance versus managed forests then the associated ecological processes are similar between managed and naturally disturbed forests. The testable prediction is that if certain forest characteristics in the managed forest diverge from the natural range of variation (i.e., the box shrinks), then species associated with those characteristics will decline in abundance or probability of occurrence.

### *Step 2. Select focal species.*

The selection of focal species involves 3 stages: (i) explore habitat relationships, (ii) develop and test habitat models, and (iii) select suitable focal species based on appropriate criteria (Rempel 2007). Species selected as focal species should meet the following conditions:

1) Be responsive to the forest management options that are on the planning table,

2) Include species responsive to a combination of local and landscape level patterns,

3) Represent the full range of diversity of habitat conditions found in the management unit,

4) Occur with sufficient frequency so that they can be easily monitored (although a few rare species might also be included),

5) Occur in the core of their distributional range, not the edges,

6) Have strong and rather specific habitat relationships (although a few "generalists" might also be included), and

7) Have associated habitat models that have been tested and demonstrated to be relatively robust over space and time.

The identification of potential focal species requires a combination of community analysis methods and statistical modeling techniques (Rempel *et al.* 2007). We used the community analysis techniques called CCA (Canonical correspondence analysis) (ter Braak and Smilauer 2002) to map the range of variability among the songbird community in the Duck Mountain Provincial Forest of Manitoba, and in the boreal forest of Ontario (Figure 5).

***The identification of potential focal species requires a combination of community analysis methods and statistical modeling techniques.***

The lines with arrow heads in Figure 5 represent the forest variables that best explain why groups of species occur together. The names of songbird species are in small letters. For example, oven refers to Ovenbird. Those species that are close together in the ordination tend to occur together in the forest. The explanatory variables include a combination of local and landscape level characteristics: tree height at the stand level (HEIGHT), Canopy Closure (CANOPY), Intactness of the Forest Matrix (INTACT), Age of the Stand (AGE), general age-class at the landscape scale (YOUNG), and relative composition of cover-types (HARDWOOD).

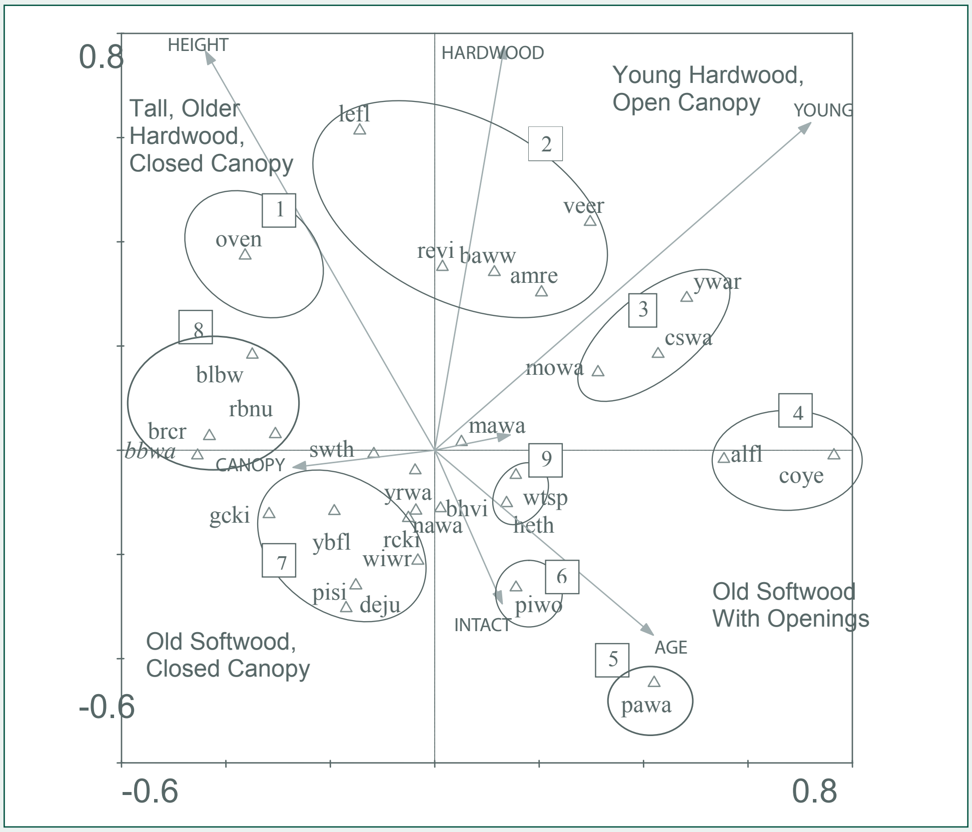


**Figure 5.** CCA Ordination diagram depicting the 9 bird species groupings associated with explanatory variables used to describe habitat relationships.

*Because stand selection depends on local, meso and landscape scale factors, it was important to develop habitat models using spatially explicit, multiple scale modeling techniques.*

The community ordination in Figure 5 allows us to characterize the diversity of habitat requirements among the songbird community, to identify those species that have the strongest relationship with habitat factors (i.e., furthest away from the centre of the diagram), and group common sets of relationships (e.g., species associated with Old Softwood with Closed Canopy). If focal species are selected from the 9 groups identified in Figure 5, we can be relatively confident that collectively, this group of focal species represents a broad diversity of habitat conditions in the forest.

The next stage is to develop and test models of habitat association. The modeling approach used here included development of multiple-scale resource selection functions based on Bayesian logistic regression (Genkin *et al.* 2005). Bayesian regression allowed us to guide model development based on known life-history requirements of the species. Resource selection function (RSF) models (Johnson *et al.* 2004, Manly *et al.* 2002) relate the probability of habitat occupancy to forest structure variables. Because selection of a stand may depend not only on conditions within the stand, but also on local, meso and landscape scale factors, it was important to develop habitat models using spatially explicit, multiple scale modeling techniques.

The explanatory variables used in the RSF modeling are the same ones used for the community analysis, and were derived from the same forest inventory datasets used in the forest management plan. This permitted a direct link between models of habitat relationships developed by researchers, and the predicted future forest conditions developed by forest resource planners.

Interpretation of the ordination figure results reveals at least 9 natural groupings of species that collectively define a broad range of environmental conditions on the landscape:

1) *Older, tall, closed canopy hardwood, with little interspersion of young and old forest:* Ovenbird

2) *Immature to younger hardwood, with relatively open conditions:* Red-eyed Vireo, Black-and-white Warbler, American Redstart, and Veery

3) *Younger hardwood, open canopy, interspersion of young and old forest:* Yellow Warbler, Chestnut-sided Warbler, Mourning Warbler, Least Flycatcher

4) *Young mixedwood, open canopy, interspersion of young and old forest, often wet:* Alder Flycatcher, Common Yellowthroat

5) *Old, open, conifer bogs:* Palm Warbler

6) *Older, open, softwood stands in a mature forest matrix:* Pileated Woodpecker

7) *Older, closed, softwood forest, in a mature forest matrix:* Winter Wren, Dark-eyed Junco, Pine Siskin, Yellow-bellied Flycatcher, Golden-crowned Kinglet

8) *Older, closed, mixedwood (hardwood and softwood dominated types), with little interspersion of young and old forest:* Bay-breasted Warbler, Brown Creeper, Red-breasted Nuthatch, Blackburnian Warbler

9) *Open mixedwood, high edge density:* White-throated Sparrow, Hermit Thrush

10) *Species without strong patterns of discrimination for the measured variables:* Magnolia Warbler, Swainson's Thrush, Yellow-rumped Warbler, Blue-headed Vireo, Nashville Warbler, Ruby-crowned Kinglet

This grouping of species provides relevant information for making an informed and unbiased selection of focal species for modeling and monitoring environmental effects of forest management. If species are selected from only one quadrant of the ordination figure, then management assessment would be biased towards a restricted set of environmental conditions and species response. For the Ontario Landscape Guide project, the selection of focal species was based on the 7 factors listed above and resulted in the selection of 13 species whose habitat needs collectively define a broad array of forest conditions.

### *Step 3. Forecast future landscape and habitat element conditions.*

The 3rd step was to forecast future forest conditions by using PATCHWORKS as the modeling framework for simulating forest harvest scheduling and stand development (Spatial Planning Systems 2008). The program was used to create land cover maps depicting predicted future forest conditions through time (up to 200 years into the future) based on alternative forest management plan and/or policy scenarios. Habitat element curves were developed to forecast development of habitat attributes over time. Habitat elements and their application in forest management planning were first used in Canada by Weyerhaeuser Coastal BC operations (then MacMillan-Bloedel) to develop a strategy for the conservation of biodiversity, within an adaptive management framework, and to test the implementation of variable retention harvest systems (Bunnell *et al.* 2003).

Important habitat elements driving stand selection for many songbirds include tree height, canopy closure, percent hardwood component and snag density. PATCHWORKS is one of the few spatial harvest and projection models that can incorporate such stand structure models. The framework also allows for the specification of stand succession and habitat element sub-models, which is important for evaluating the relatively long-term effects of forest structure on biodiversity. The development and validation process for the Habitat Element Curves are further described in a report evaluating alternative methods for modeling the development of habitat elements (Rempel *et al.* 2009).

***Important habitat elements driving stand selection for many songbirds include tree height, canopy closure, percent hardwood component and snag density.***

*Spatial landscape assessment models allow us to assess landscape composition and spatial pattern in terms of meeting policy or management objectives.*

For spatial landscape assessment of biodiversity, the key outputs are the modified FLI (Forest Lands Inventory) map forecasts, which have been updated with projected harvests and silvicultural treatments, stand succession, and stand attributes based on the various management scenarios to be evaluated. This new spatial map is then imported back into the LSL (Landscape Scripting Language) spatial modeling program (Kushneriuk and Rempel 2010) where the spatially explicit resource selection function models are applied to the PATCHWORKS digital map. The models allow us to assess landscape composition and spatial pattern in terms of meeting policy or management objectives, so we termed the habitat models "spatial landscape assessment models" (SLAM) in Rempel *et al.* (2006). An example of the spatial output from forecast models for the LP plan reveals predicted changes in habitat occupancy for Chestnut-sided Warbler (Figure 6).

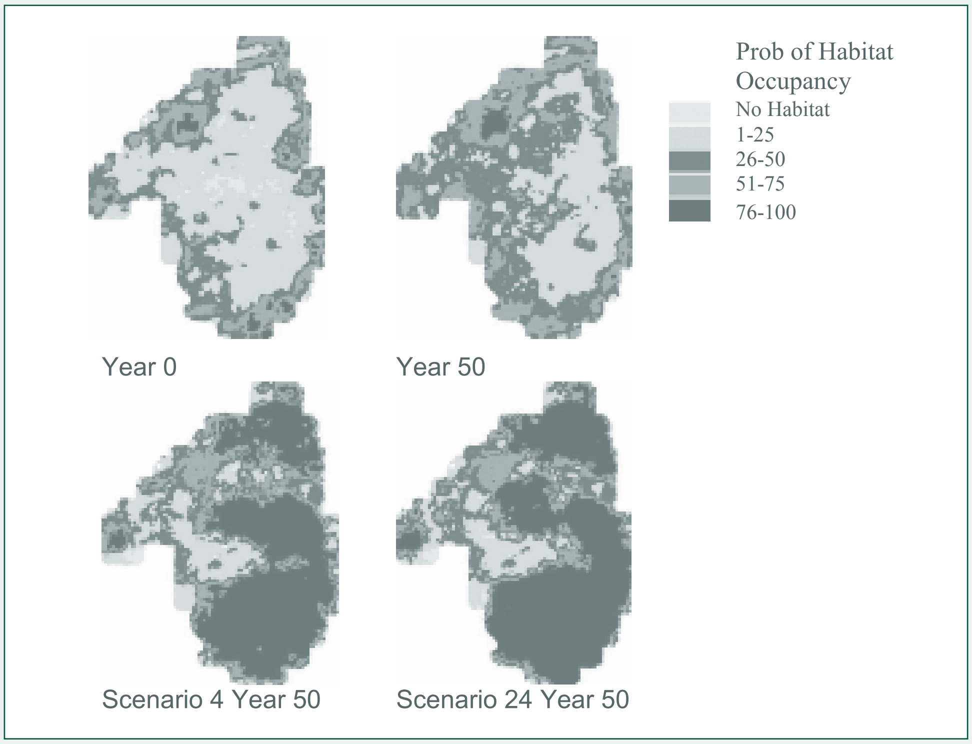


**Figure 6.** Projected patterns of habitat occupancy (probability surfaces) for the Duck Mountain Provincial Forest, Manitoba for Chestnut-Sided Warbler (CSWA) for the current forest condition (year 0), and projected forest conditions under current guidelines (year 50) and two different management scenarios (scenario 4, 24). Darker tones indicate a higher level of the measured variable.

## *Step 4. Simulate or analyze natural disturbance processes.*

Where maintaining environmental and wildlife conditions within the range of variation that occurs naturally is a conservation objective, it is necessary to estimate the expected range of natural variation. Unfortunately, there is little or no data that allows us to estimate long-term trends in natural variation. Current or recent-past conditions are just one of a multitude of conditions that would be expected to occur over time. One approach to understanding the expected range of conditions is to develop process models based on our current understanding of how natural disturbance and forest succession occurs, and then to simulate forest disturbance and succession over time to estimate the statistical distribution of forest conditions. If a limited range of such outcomes is summarized (e.g., the 25th to 75th percentile), then a simulated range of natural variation (SRNV) can be characterized for each ecoregion.

*One approach to understanding the expected range of conditions is to develop process models and then simulate forest disturbance and succession over time.*

For the Ontario Landscape Guide development process, BFOLDS was used to simulate fire cycles (Perera *et al.* 2004). Simulations were initiated with current forest conditions, but then allowed to run for 150 years to reduce or eliminate the current signature of forest management on the landscape. For this study 80 simulations of medium intensity fires were completed for ecoregion 3W, which surrounds Lake Nipigon in northern Ontario. A "spatial signature" was then characterized for low, medium, and high intensity disturbance regimes. These spatial signatures are histograms based on the analysis of edge and landcover composition, and were conducted for a variety of analysis unit sizes, ranging from 50 to 5000 ha. Landscapes arising from the simulated high intensity fire (HFI) disturbance regime displayed a landscape pattern that was quantitatively different from the current landscape (Figure 7). The histogram pattern for the current forest was bell-shaped, indicating that within most of the 500 ha hexagons, about 30-60 % of the hexagon was disturbed by fire or forest harvest. In contrast, the pattern for the simulated fire map was more U-shaped, indicating that forest within a hexagon was either primarily mature undisturbed or fully disturbed by fire.

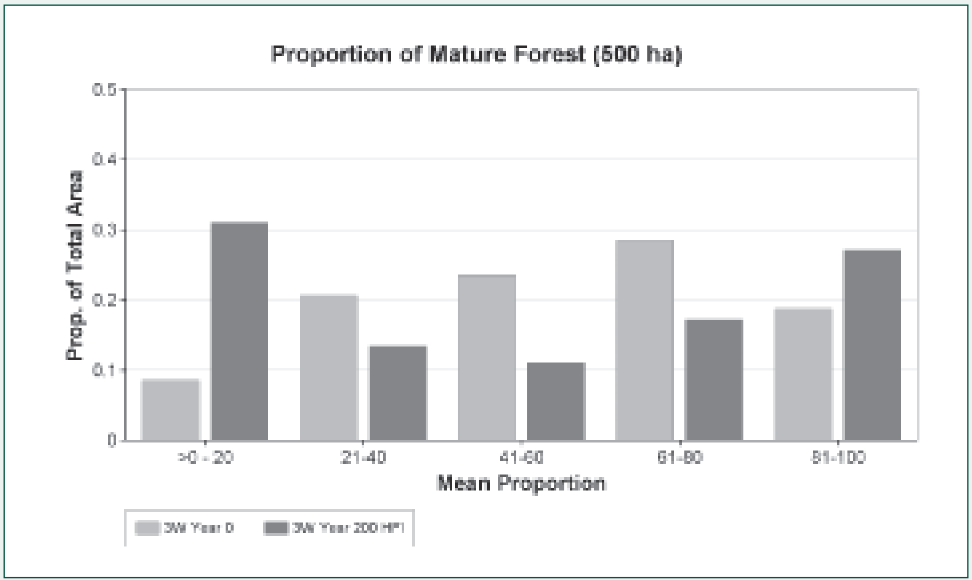


**Figure 7.** Comparison of landscape texture between current forest condition (Year 0) and a simulated high fire intensity (HFI) disturbance regime. The histogram shows the frequency of analysis units (500 ha hexagon cells) that have low to high levels of disturbance within the cell. If the landscape is uniformly disturbed, the pattern will be bell-shaped, but if the landscape has large patches of disturbance separated by mature undisturbed forest, the pattern will be U-shaped.

## *Step 5. Apply the habitat models to evaluate and rank the planned management and/or policy scenarios.*

***A critical step is the ranking and evaluation of the planned management scenarios and/or policy option-sets relative to their predicted ability to meet biodiversity conservation objectives.***

A critical next step is ranking and evaluating the planned management scenarios and/or policy option-sets relative to their predicted ability to meet biodiversity conservation objectives. For example, we might want to assess if a management scenario will provide continuous habitat for the full suite of focal songbird species. The habitat models are applied to the digital maps created by the harvest scheduling program using the planning tool OLT (Ontario Landscape Tool) (Elkie *et al.* 2009). For each prescriptive indicator (e.g., total area within each landscape class), the target SRNV, the initial forest condition for the ecoregion, and the predicted condition within the forest management unit is presented graphically (Figure 8). In this illustrative example, the level of both pre-sapling and immature conifer is lower than the desired SRNV. Likewise, for each evaluative indicator (e.g., focal species) the amount of habitat (in this case, proportion of area occupied) resulting from the proposed management scenario is presented graphically, as are the current condition and SRNV (Figure 9).

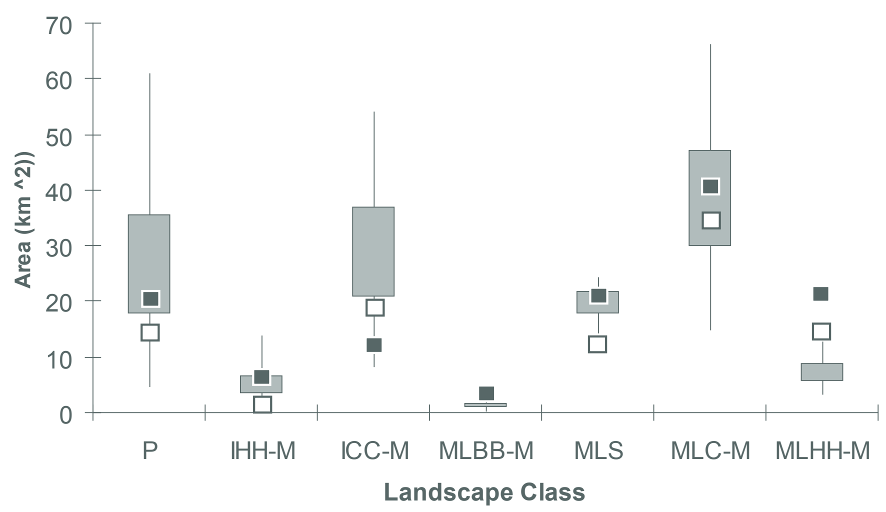


**Figure 8.** Simulated range of natural variation (SRNV) for landscape classes within Nipigon-Armstrong Forest Management Plan (FMP) based on 80 natural disturbance simulations. Line indicates upper and lower range, box is upper (75th) and lower (25th) quartiles, filled-square is current forest condition, and open-square is the expected condition based on proposed Forest Management Plan (FMP) scenario. P = Presapling, I = Immature, L = Late, C= Conifer, H = Hardwood, -M = Mixedwood, B = Balsam Fir, S=Spruce. For example, Immature Conifer and Conifer Mixedwood (ICC-M) has current forest lower than target value, but proposed scenario brings value closer to management target (SRNV).


**Figure 9.** Modeled probability of habitat occupancy (= proportion of area occupied) for 7 of the 13 focal species of songbirds (evaluative indicators) in the Nipigon-Armstrong Forest Management Unit (FMU). Annotations as in Figure 8 and species codes as in Table 1.

From such reports planners can assess expectations from alternative management scenarios, including the relative success in emulating the natural range of variability for forest conditions and maintaining populations of key wildlife species. Ultimately, the goal is to keep the habitat box from shrinking, and to avoid loss of species or important forest ecosystems.

***For each evaluative indicator (e.g., focal species) the amount of habitat resulting from the proposed management scenario is presented graphically.***

For development of the Landscape Guides in Ontario developers ran spatially-explicit, multiple scale habitat models using predicted future forest conditions arising from 3 different management option-sets (scenarios) generated by the PATCHWORKS harvest scheduling model. As described above, they also ran a natural disturbance simulator to estimate the SRNV for habitat condition and species occupancy.

Conservation analysis of these scenario simulations is shown in Table 2. Management options that kept the predicted environmental or species response within the SRNV was the ultimate goal, so decreasing habitat relative to SRNV under a scenario scores a -1, maintaining habitat scores a +1, and increasing habitat scores a -0.5. Increasing habitat for edge dependent species may mean a decrease for edge-avoiding species, and vice versa. Scores were also weighted by model performance (ROC) so that results from better performing habitat models weighted heavily in the analysis. The lower the score (sum) the poorer the performance of the scenario for conserving all the species.

**Table 2.** Assessment of scenario performance in conserving biodiversity.

| Species | Scenario | | | | ROC |
|---|---|---|---|---|---|
| | CURRENT | NOSPATIAL | ALLGUIDES | NATURAL | |
| Alder Flycatcher | 1 | 1 | -0.5 | 1 | 0.77 |
| Black-and-white Warbler | -1 | -0.5 | 1 | -0.5 | 0.68 |
| Bay-breasted Warbler | -1 | -1 | -1 | -1 | 0.73 |
| Blackburnian Warbler | -0.5 | 1 | -0.5 | 1 | 0.67 |
| Brown Creeper | -0.5 | -1 | -1 | -1 | 0.73 |
| Common Yellow-throat | -1 | -1 | -1 | -1 | 0.83 |
| Chestnut-sided Warbler | -0.5 | 1 | -0.5 | 1 | 0.76 |
| Least Flycatcher | 1 | 1 | 1 | 1 | 0.69 |
| Ovenbird | 1 | -1 | -1 | -1 | 0.80 |
| Red-breasted Nuthatch | 1 | -1 | -1 | -1 | 0.71 |
| Red-eyed Vireo | -0.5 | -0.5 | -0.5 | -0.5 | 0.80 |
| Winter Wren | 1 | 1 | 1 | 1 | 0.81 |
| White-throated Sparrow | 1 | 1 | -0.5 | 1 | 0.75 |
| Sum | 1 | 0 | -4.5 | 0 | |
| Weighted Sum§ | 0.8 | -0.09 | -3.49 | -0.09 | |

§ Decreasing habitat relative to SRNV under a scenario scores a -1, maintaining habitat scores a +1, and increasing habitat scores a -0.5. Score was also weighted by model performance (ROC) so that results from better performing habitat models weighted heavily in the analysis. The lower the score (sum) the poorer the performance of the scenario for conserving all the species (from Rempel *et al.* 2007).

Not too surprisingly, the guidelines that include strict spatial requirements performed the poorest relative to the SRNV. Deviation from SRNV was caused by the dispersed block cut pattern used in the moose guidelines (OMNR 1988b) and linear reserves used in the aquatic guidelines (OMNR 1988a) (SPATIAL). Conservation performance improved for the scenarios where either no strict spatial rules were in place (NOSPATIAL), causing the harvest scheduler to follow the age-class structure created by past disturbances, or where only simple spatial rules were in place (NATURAL).

### *Step 6. Treat "policy as hypothesis", and implement an effects and effectiveness monitoring program.*

***The critical assumptions should be cast as hypotheses, and evaluated as scientific hypotheses through a monitoring program.***

Although the selection of the preferred management scenario or policy option is now based on a rigorous evaluation of alternatives, its success and effectiveness is still hypothetical. Some assumptions and expectations are more critical than others. The critical assumptions should be cast as hypotheses, and evaluated as scientific hypotheses through a monitoring program. For example, one might assume that the management attempts to emulate natural forest patterns will maintain a community assemblage of songbirds similar to those typically found in forests arising from natural disturbance. The key difference between "monitoring" and "research" is that monitoring evaluates "outcomes" of existing policies, whereas research provides "inputs" for developing new policies. Scientific rigour applies equally to both.

***The monitoring results directly evaluate whether the policies and management direction are achieving the desired goals and the occurrence of undesirable or unanticipated effects.***

The effectiveness monitoring program should be designed to unambiguously evaluate whether the policies and management direction are achieving the desired goals and if there are any undesirable or unanticipated effects. Selection of appropriate reference conditions, sample design, frequency of sampling, and analytical methods should all be focused on providing a sufficient design to evaluate the critical hypotheses. In some cases, management direction is based in part on process models (e.g., fire simulation and stand growth models) or statistical models (e.g., resource selection functions). These models themselves are hypotheses, and effectiveness monitoring should include an evaluation of model accuracy (Kimmins *et al.* 2005, Kimmins *et al.* 2007).

An important stage of the process is to identify the critical uncertainties and associated management hypotheses based on underlying policies and goals. For example, consider the following contrasting management hypotheses:

a) Emulating natural disturbance will result in the conservation of biodiversity,

b) Implementation of the plan will result in no significant decline in the abundance of critical species relative to the start date of the plan, and

c) Following the direction given in Guideline B will maintain water yield within the expected range of natural variability better than following Guideline A.

Clearly translating policy into unambiguous hypotheses is a critical step in scientific adaptive management. It is also useful to think early on in the policy development and planning process how the critical hypotheses will be expressed, as this will help clarify selection of management or policy options.

***Clearly translating policy into unambiguous hypotheses is a critical step in scientific adaptive management.***

### *Step 7. Modify, add, or re-affirm management and policy options based on results of the effects and effectiveness monitoring program.*

From the perspective of adaptive management, a clearly defined, and agreed upon link between effectiveness monitoring and policy decision making will help ensure that relevant data is being considered for policy revisions and plan updates (Figure 1). Without this, monitoring results may simply sit on the shelf, and the safe-guards of scientific adaptive management will be effectively disabled.

***Strategic direction and assumptions within forest management plans should be re-visited following plan implementation and an appropriate period of effectiveness monitoring.***

Strategic direction and assumptions within forest management plans should be re-visited following plan implementation and an appropriate period of effectiveness monitoring. Standard operating or best management practices should be revised as needed following monitoring to ensure strategies are effectively delivered on the ground. This is likely best accomplished on a periodic basis, and co-ordinated with planning or reporting cycles (e.g. strategic level plans every 5 years, and 3 years for annual operating plans and operating procedures or certification audits). Effectiveness monitoring outcomes, and evaluation and adjustment of planning and practices should involve any public advisory groups and scientific advisors that were originally consulted during their development for best results.

Of all the steps involved in scientific adaptive management, Step 7 is perhaps the hardest. It means re-opening old discussions, facing renewed criticism, potentially admitting to management failures, sparking new debates, and garnering support for new or revised management options and objectives in the face of a critical audience. Yet it is at this stage of the process that the most important gains and rewards of a scientific approach to management are accrued. A strong conviction and perhaps a formal or legal requirement to carry through with the final step will help ensure the success of a scientific approach to resource management.

## 8. Conclusions

Science-based resource management means more than basing management actions on selected peer-reviewed, scientific research results. Science is a philosophical approach to assessing reliable versus unreliable knowledge. A scientific approach to resource management will incorporate the scientific method throughout the management cycle, including the development, application, and assessment of policies and management options. An essential part of this philosophy is the notion of treating “policy as hypothesis”. The policy (or management option) is intended to achieve a desired result, but until the response to this policy has been predicted and then monitored, we have no reliable evidence that the policy was indeed effective. When this scientific approach to resource management is coupled with a feedback loop to decision makers, managers have enhanced ability to assess the reliability of existing knowledge, adapt to new reliable knowledge and to refine or revise current planning objectives. We call this **scientific adaptive management**.

Ecosystem management shifts the management focus to the entire forest ecosystem, not just a few featured values. In ecosystem management the goal is to ensure the ecosystem functions as it would naturally, and will consequently continue to provide the essential ecosystem services, such as clean water, wood fiber, nutrient cycling and insect pest control that we depend upon. One approach to measuring success is to monitor ecological integrity through indicator systems such as community assemblages. Spatial habitat models can be a valuable tool in defining the relationship between forest condition and habitat requirements, and ultimately selecting a group of focal species for monitoring ecological integrity.

Specifying management targets for key forest conditions (i.e., prescriptive indicators) is critical to meeting plan objectives, but these targets should be expressed in terms of the expected range of natural variability. Recent past conditions are insufficient to characterize the range of natural variability, so we must rely on simulations resulting from process-based models. The simulated range of natural variability is extremely large and asymmetrical, and a reasonable limit is to set the limit between the 25th and 75th percentiles of the simulation results. This is referred to as the simulated range of natural variability (SRNV).

Creating forest patterns and stand structure that resemble natural forest conditions in an attempt to conserve ecological integrity and biodiversity should essentially be treated as a hypothesis. Evaluative indicators should be developed to "test the hypothesis" that the management prescriptions are effective in meeting the conservation planning goals. We illustrated the use of a focal group of songbirds as an evaluative indicator, and the species we selected for the focal group represent extremes of forest conditions within the community-niche space. For example, the focal group includes species with the strongest need for an intact mature forest matrix or the greatest need for edge habitat. Modeling habitat conditions for this focal group provides solid information to help forest managers develop and evaluate plans that will create a sufficient range and diversity of forest conditions to support the songbird community.

Putting the pieces together for a scientific, adaptive approach to resource management requires a solid planning framework. In this report we illustrated a planning framework based around spatial landscape assessment models to support developing, selecting, testing and refining preferred management or policy options. Seven key steps were identified based on concepts of scientific adaptive management, and although each planning situation is different, in a general sense these steps will be common among most planning or policy development situations.

The models used in this planning approach are meant to provide strategic and general insights within a framework of operational realism. The role of spatial habitat and forest simulation models is to inform decision making, and to help place management objectives and decisions in a broader context of ecosystem services, ecological integrity, and biodiversity conservation. Science is silent on which options should ultimately be selected. The final selection of policy options for management guides or the preferred management option for forest management plans depends on a broad analysis of ecological, economic, political and social factors. However, by adopting a scientific approach to management and decision making, the strength of the most powerful approach known to acquire and assess reliable knowledge can be brought down to bear on the problem and to support the decision making process.

## Key Messages

1. Science-based resource management means more than basing management actions on selected peer-reviewed research results. It means incorporating the scientific method throughout the management cycle, including the development, application, and assessment of policies and management options. When this scientific approach to resource management is coupled with a feedback loop to decision makers, managers have enhanced ability to adapt to new reliable knowledge and refined objectives (adaptive management)

2. To be successful, forest management strategies and practices must not be focused on the needs of a small set of featured species, but rather be designed to maintain a range of forest cover, structure and patterns on the landscape to meet the needs of all species. Biodiversity conservation strategies that create landscape patterns closely resembling those created by natural disturbances are most successful at providing a range of habitat conditions and maintaining forest variability.

3. The conservation of biodiversity and ecological integrity was assessed using a community perspective rather than a featured species approach. A group of focal species was selected to represent an assemblage of forest songbirds which required the maintenance of a broad range of habitat conditions.

4. The spatial habitat models for the set of focal species describes target levels and range of variability in forest conditions required as a minimum to support the full complement of boreal forest songbird species.

5. The variables considered in this synthesis should be considered coarse-filter variables, therefore the spatial habitat models simply describe the general framework of forest structure and pattern required by the focal species. The final selection of policy options for management guides or the preferred management option for forest management plans depends on a much broader analysis of factors.

6. From the perspective of adaptive management, a clearly defined, and agreed upon link between effectiveness monitoring results and policy decisions should be made. This will help ensure that relevant data is being considered for policy revisions and plan updates.

7. In forest management planning, strategic direction and assumptions within the Plan must be re-visited following plan implementation and effectiveness monitoring to ensure objectives are being met. Standard operating or best management practices should be revised as needed following monitoring to ensure strategies are effectively delivered on the ground.

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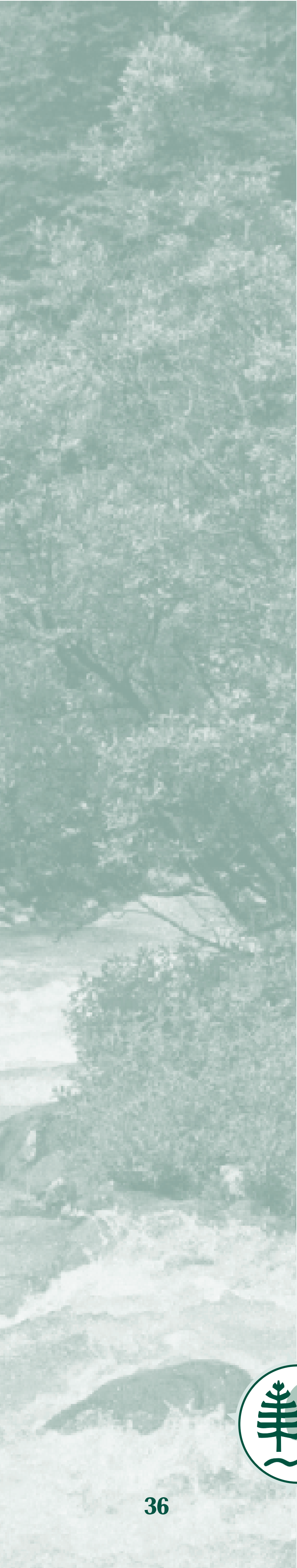


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